Geology and Ore Deposits of the Front Range Colorado

By T. S. LOVERING *and* E. N. GODDARD

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ABSTRACT

Introduction.—The Colorado Front Range extends northward from Canon City to Wyoming, where it merges with the Laramie Range. The most rugged mountains of the Front Range are in the central part and lie mostly between altitudes of 12,000 and 14,000 feet. The western mountain flank slopes steeply away from the crest of the range, but the eastern slope is characterized by broad dissected benchlike erosion surfaces that descend in steps to the plains.

Much of the Front Range is served by excellent automobile roads, and the standard-gauge Denver & Salt Lake Railway, "The Moffat Road," passes almost due west from Denver across the range. The many narrow-gauge railroads that formerly served the mining districts have all been abandoned, and trucks are used to move freight between the mining districts and loading points on the standard-gauge railroads.

Physiography.—The most prominent physiographic features of the Front Range are due to the dissection of five moderately smooth erosion surfaces which stand in benchlike relations to one another, namely, the Flattop, at altitudes between 11,550 and 12,500 feet, the Green Ridge between 10,000 and 10,700 feet, the Cheyenne Mountain between 9,200 and 9,600 feet, the Overland Mountain between 8,200 and 9,000 feet, and the Bergen Park between 7,500 and 7,800 feet. Both the Flattop and Green Ridge surfaces are probably pre-Oligocene. Remnants of broad valleys are present about 500 feet below the Overland Mountain surface and constitute the Flagstaff Hill surface. Many rock terraces, most of which are Pleistocene, are found between it and the present stream valleys.

Geology.—The crystalline core of the Front Range is essentially pre-Cambrian granite, schist, and gneiss; it is nearly everywhere bordered by steeply tilted Paleozoic rocks, but along the west side, near Breckenridge, steeply dipping Mesozoic beds rest directly on the pre-Cambrian basement. Locally the truncated edges of Mesozoic and Paleozoic sediments are covered by gently dipping Tertiary beds, which lap onto the pre-Cambrian rocks. In the north the Tertiary is made up chiefly of clastics, and in the south the Tertiary rocks comprise interbedded shale, algal limestone, tuff, and lavas. Middle Tertiary intrusive rocks are associated with the lavas in the southern part of the pre-Cambrian terrane and in the Rocky Mountain National Park. Many stocks and dikes were intruded into the central part of the range during the Laramide revolution but are uncommon elsewhere.

The oldest rocks in the Front Range are the schists and gneisses of the Idaho Springs formation, which are highly metamorphosed sedimentary rocks of early pre-Cambrian age. The thickness is approximately 20,000 feet. The hornblende schist and gneiss of the Swandyke hornblende gneiss overlie the Idaho Springs formation and are probably about 6,000 feet thick. At Coal Creek the Swandyke hornblende gneiss is overlain by a series of quartzites and quartz pebble conglomerates at least 14,000 feet thick. These formations are all cut by an extensive series of granite intrusives, the oldest of which is a quartz monzonite gneiss. It occurs chiefly in small stocks peripheral to granite batholiths or as a lit-par-lit injection of the older schists and gneisses. Gneissic granite, gneissic aplite, and gneissic diorite are found in abundant but small masses within the metamorphic terrain and are believed to be related to nearby granite batholiths of different ages.

The earliest of the batholithic granites is the Boulder Creek granite; it is common in stocks and small batholiths in the central part of the Front Range. Its dark-gray color and faintly banded appearance distinguish it from the pink coarse-grained Pikes Peak granite, which is somewhat younger and forms the extensive batholith of the southern part of the Front Range. The appearance and age relations of the Pikes Peak granite are the same as those of the Sherman granite exposed in the large batholith extending from the northern part of the Front Range well into Wyoming. Small batholiths and stocks of the younger fine-grained to medium-grained light pinkish-gray Silver Plume granite are widely distributed, and locally have been given different names. Lead-uranium ratios indicate that the age of the Pikes Peak granite is approximately 1 billion years and that of the Silver Plume granite approximately 940 million years.

The outward-dipping Paleozoic and Mesozoic sediments, which almost girdle the Front Range, show marked overlaps near the borders of the range, and in this same zone strong unconformities appear between formations that elsewhere seem conformable. The overlaps and accented unconformities reflect the presence of a pre-Tertiary high in the Front Range region.

The quartzite, shale, and dolomite of the Upper Cambrian Sawatch quartzite border the southern part of the Front Range from Breckenridge to the Royal Gorge on the western side and from the vicinity of Colorado Springs northward to Perry Park on the eastern side. Elsewhere the formation is absent. The Ordovician system is nearly coextensive with the Sawatch quartzite, but Ordovician rocks are known in the Canon City embayment where Cambrian beds are probably lacking. The Ordovician formations include the Manitou limestone, the Harding sandstone, and the Freemont limestone. The distribution of the Devonian rocks is almost identical with that of the Ordovician. The Devonian Chaffee formation of the western slope consists of the basal Parting quartzite member and the overlying Dyer dolomite member. The Mississippian beds are almost coextensive with the Devonian and on the western slope are represented by the Leadville limestone, famous as a host rock for replacement ores. On the eastern slope the equivalent Madison (?) limestone borders the southern part of the range.

Pennsylvanian and Permian formations crop out almost continuously on the eastern side of the Front Range from Canon City to the Wyoming line and on the western side from the Royal Gorge to Breckenridge. Beds of Pennsylvanian and Permian age are separated from older and younger formations

by conspicuous erosional unconformities. On both sides of the range the beds of Pennsylvanian and Permian age are dominantly red and gray arkosic sandstone, shale, and conglomerate, with some interbedded limestone. The uppermost beds are bright-red siltstone and micaceous shale. The Permian (?) and Triassic (?) Lykins formation of the eastern slope is separated from the arkosic lower Pennsylvanian Fountain formation by the well-bedded Lyons sandstone. On the western slope the Pennsylvanian beds have been called Weber (?) formation where the lower part of the system is gray shale, grit, and limestone; the overlying beds, predominantly maroon and brick red, are included in the Maroon formation. Recently the term Beldon shale has generally been adopted for the dark shaly beds underlying the Maroon formation. The age of the uppermost Maroon formation is uncertain, but most of the Pennsylvanian beds on the western slope are known to be equivalent to beds of Des Moines age in the central States.

There are no Triassic rocks on the western border of the Front Range, nor are they recognized with certainty on the eastern slope. Jurassic sandstone correlated with the Entrada sandstone and the Sundance formation is present in the areas bordering the northern half of the Front Range on both the eastern and western slopes. The Upper Jurassic Morrison formation is widespread in the Front Range and almost everywhere underlies the Cretaceous Dakota group. In most places, the Morrison formation comprises interbedded sandstone and variegated nonmicaceous shale. The sandstone with minor interbedded shale that overlies the Morrison formation is commonly ascribed to the Dakota group of Lower and Upper Cretaceous age. The Dakota group is overlain by Benton shale, 350 feet thick, and the clay shales of the Benton are overlain by the predominantly limy shale and interbedded limestone of the Niobrara formation. The Pierre shale rests conformably on the Niobrara formation. It is largely clay shale but contains a few interbedded limy sandstones. The Pierre shale is overlain conformably by the Fox Hills sandstone on the eastern slope, but the Fox Hills has not been recognized on the western slope. The marine Fox Hills sandstone is overlain by the brackish-water deposits of the coal-bearing Laramie formation. Coarsely clastic Upper Cretaceous beds overlie the Laramie formation with marked erosional unconformity on the eastern slope and were formerly regarded as Eocene. Near Denver the lower part of the series that lacks volcanic debris is distinguished as the Arapahoe formation, and the overlying tuffaceous beds constitute the Denver formation. The Arapahoe and the lower part of the Denver formation contain Upper Cretaceous fossils and the upper part of the Denver formation contains a Paleocene fauna, but no stratigraphic break has been recognized. Equivalent formations have been found in South Park, Middle Park, and North Park. The Denver formation and its equivalents were formed while the Front Range area was arching itself well above the surrounding regions, but before the severe folding and faulting that marked the climax of the Laramide revolution.

No Eocene beds have been recognized near the Front Range. Oligocene beds are known in the Denver basin, Middle Park, South Park, and near Florissant. In most places the Oligocene beds are light-colored tuffaceous sands and clays, but south of Denver the Oligocene Castle Rock conglomerate is made up of boulders and coarse arkosic sandstone and contains a small amount of finely divided gold, probably derived from the mineral deposits associated with the Laramide revolution of the Front Range to the northwest.

Coarsely clastic beds of Miocene age are known in the northern part of the Front Range on both the eastern and western slopes. Along the eastern border of Middle Park they contain interbedded lavas, derived chiefly from Specimen Mountain, Rocky Mountain National Park. Small areas of preglacial sheet-wash gravel on high interstream areas between Nederland and Idaho Springs may be of Pliocene age, but conclusive evidence is lacking. Early and late glacial deposits can be correlated with well-developed rock terraces locally covered by gravel below the limit of glaciation.

Laramide igneous rocks.—The Laramide extrusive rocks interbedded in the Denver formation and its equivalents are dominantly andesites but also include early basalts and late rhyolite in the Denver basin, and rhyolite in South Park. The rhyolite and welded rhyolite tuff near Castle Rock are pre-Oligocene but are younger than most of the Denver formation and may have been derived from an Eocene volcano at Pikes Peak after the Laramide revolution.

The porphyritic intrusive rocks of the Laramide revolution are almost limited to a narrow belt extending southwestward from Boulder to Breckenridge, within which nearly all the productive Laramide mineral deposits of the Front Range have been found. The belt, therefore, is known both as the "porphyry belt" and the "mineral belt." The northwestern side of the porphyry belt is marked by a line of stocks that range in composition from diorite to quartz monzonite. Dikes and small irregular intrusive bodies are abundant in a strip ranging from 2 to 10 miles in width, just southeast of the line of stocks, but are almost lacking to the northwest; it is in this strip that the mineral deposits are found.

The sequence of intrusion is similar throughout the porphyry belt, but the latest members of the magmatic series are found only in the northeastern part. In the area southwest of Georgetown, where complex lead-silver-zinc ores predominate, only diorite, monzonite, quartz monzonite, sodic quartz monzonite, and closely related rocks are present. Northeast of Silver Plume where pyritic gold ores appear, bostonite, alkalic syenite, and alkalic trachyte porphyry are found. Dikes of biotite latite, biotite monzonite, and latitic intrusion breccia are scattered through the mineral belt from Idaho Springs to Jamestown and seem to be coextensive with areas in which gold-telluride veins are found. The pitchblende ores of Central City are a local variant of the pyritic gold ores; their lead-uranium ratio indicates an age of approximately 60 million years, harmonizing with other evidence of emplacement during the Laramide revolution. The most mafic rocks in the porphyry belt are found at Caribou, just west of the Boulder County tungsten belt, and near Sugarloaf at the eastern edge of the tungsten belt. The rocks of the Caribou stock are among the earliest of the porphyry belt and range in composition from titaniferous magnetite to calcic quartz monzonite, and the rocks near Sugarloaf include limburgite, one of the latest of the igneous rocks of the Laramide revolution.

About 35 miles northwest of the porphyry belt another zone of intrusive rocks of the Laramide revolution extends from Radial Mountain in Middle Park northeastward through the Cameron Pass area to the Manhattan-Home mining district, about 20 miles west of Fort Collins. Most of the rocks range in composition from diorite to quartz monzonite. Some mineralization followed their intrusion, but the deposits thus far discovered have little commercial value.

The age relations and differences in composition of the intrusives in the mineral belt suggest widespread fusion of a deep crystalline substratum and its subsequent slow solidification, with periodic withdrawals of portions of the changing liquid to shallower reservoirs in which magmatic differentiation proceeded through crystal settling, zoning, and filter-pressing. The ore deposits and most of the rocks exposed in the porphyry belt probably were derived from the shallow hearths, but some of the earlier persistent dikes and the mafic volcanic plugs sparsely scattered through the range both north and south of the mineral belt may represent withdrawals from a deep layer.

Post-Eocene igneous rocks.—Post-Eocene andesitic lavas are found in and near the northwestern part of Rocky Mountain National Park and in the southern part of the Front Range west of Cripple Creek. The Cripple Creek volcanic crater is filled with tuffs and phonolitic breccias cut by a variety of alkalic intrusive rocks and by rich gold-telluride veins. Post-Eocene intrusive rocks are confined to the volcanic centers and are almost restricted to volcanic throats. The intrusive at Specimen Mountain west of Estes Park is rhyolite; at Guffey, augite-biotite monzonite; in the Bare Hills west of Cripple Creek, basalt, diorite, and andesite; and at Cripple Creek the intrusives include phonolite, nepheline syenite, monchiquite, and related rocks.

Pre-Cambrian structure.—The foliation in the metamorphic rocks commonly parallels the original bedding of the sediments and the flow structure of the interbedded lavas. The Front Range area is the site of a regional pre-Cambrian anticline that trends almost due north, and thus the schist and gneiss of the Idaho Springs formation largely occupy the central part of the range, the Swandyke hornblende gneiss is abundant along the flanks, and the quartzite at Coal Creek crops out only at the easternmost edge of the mountain. However, extremely complex crenulations, cross folds, and longitudinal folds greatly modify this regional structure. The major folds in the western flank of the anticline are parallel to its axis, but the eastern flank is crumpled into many tight transverse folds plunging east-northeastward. The Pikes Peak and Sherman granite batholiths follow the axis of the regional anticline, and the Boulder Creek batholith is parallel to it. Most of the stocks and batholiths of Silver Plume granite and the earlier quartz monzonite gneiss and granite gneiss are essentially parallel to the foliation of the country rock in which they were emplaced.

Laramide structure.—The pre-Tertiary topography and structure of the Front Range region did much to localize folding and faulting during the Laramide revolution. The site of the present Front Range was a positive area that stood well above the sedimentary basins on either side during most of the Paleozoic and Mesozoic eras, but it was undoubtedly submerged during most of the Upper Cretaceous. Uplift of the Front Range began in middle Pierre time while the Denver basin was still being downwarped, and from that time till well into the Paleocene the central part of the range moved upward at an ever increasing rate. Parts of it rose above the ocean during Fox Hills time, and at the beginning of Denver time large areas were shedding pre-Cambrian debris to the east and west. Intense folding and faulting occurred at the edges of the basins of deposition where the troughs merged with the old positive element about the end of Denver time and outlined the Front Range as it now is.

The western side of the Front Range is marked by a series of great overthrust faults that formed at this time from the southern end of South Park as far north as the Wyoming line. The displacement on the Williams Range thrust fault north of Breckenridge is more than 4½ miles, and the movement on the Never Summer thrust north of Granby is more than 6½ miles. The eastern side of the Front Range was subjected to much less severe deformation but was the locus of many echelon northwesterly folds and persistent steep northwesterly faults. Its structure is dominantly that of a steep monoclinal fold, though locally, as at Colorado Springs and Boulder, some thrusting has taken place.

The period of overthrusting was followed by northeasterly and east-northeasterly faulting on a large scale throughout the mineral belt during and after the intrusion of the porphyritic rocks that dot it. Many of the mineral deposits are localized at the intersection of easterly and northeasterly faults with the earlier persistent northwesterly faults where they cross the mineral belt.

Faults formed after the Laramide revolution are comparatively local and largely confined to Miocene volcanic areas and Tertiary basins close to the mountain front.

Ore deposits.—The ore deposits of the Front Range are classified as pre-Cambrian, Tertiary, and those associated with the Laramide revolution. The ores assigned to the pre-Cambrian include (1) the chalcopyrite-marmatite-pyrrhotite-magnetite ores associated with intrusive hornblende gneiss, best represented by the zinc deposit at Cotopaxi, and the copper ores of Jefferson County west of Golden, (2) the hydrothermal replacement deposits commonly found near the edge of granite batholiths in calcic beds of the Idaho Springs formation, which contain chiefly chalcopyrite and pyrrhotite and locally nickel and cobalt minerals but which, although the most widespread of the pre-Cambrian ores, are nearly everywhere noncommercial, and (3) pegmatites and pegmatitic quartz veins, many of the pegmatites being profitably exploited for feldspar, mica, beryl, and tantalum but the hypothermal gold-chalcopyrite-quartz veins into which the pegmatites grade being mostly noncommercial.

Laramide ore deposits of the mineral belt.—The mineral belt extends northeastward from the Breckenridge district through the Montezuma, Silver Plume, Georgetown, Idaho Springs, Central City, North Gilpin County, Boulder County tungsten, Caribou, Ward, Gold Hill, and Jamestown districts and is an almost continuous belt of mineralized Laramide fissures. Southwest of Georgetown the mineral belt is almost entirely confined to a northeastward-trending zone of metamorphic rocks bordered by batholiths and smaller masses of granite. North of Central City, the mineral belt follows metamorphic rocks along the western and northwestern border of a Boulder Creek granite batholith. The Laramide faulting localized at the edge of the granite masses created fissures approximately parallel to the regional trend of the porphyry belt that were subsequently mineralized from many local sources. The belt is also crossed by many persistent northwestward-trending "breccia reef" faults. These faults are almost barren, but they exercised an important control on the localization of ore in the more open easterly and northeasterly fractures that intersect them. Most of the tungsten, gold, and gold-telluride ore of Boulder County has come from easterly and northeasterly fissures close to their intersection with the persistent early northwesterly faults. A similar control has been observed in several other districts, notably the Central City-Idaho Springs district and the Silver Plume district to the southwest.

Although there were many local centers of mineralization, it is probable that solutions emanating from them at corresponding periods in their magmatic history were similar. The general sequence of mineralization was (1) pyrite, (2) sphalerite, (3) chalcopyrite, (4) galena and chalcopyrite, (5) silver-bearing sulfantimonides, sulfarsenides, and bismuthinides, (6) pyrite and subordinate chalcopyrite, (7) free gold, (8) minor amounts of sphalerite, galena, and silver minerals, (9) gold tellurides, and sparse pyrite, gold, sphalerite, and galena, and (10) ferberite and sparse sulfides. Most of the ores between Breckenridge and Idaho Springs belong in groups 1 to 5 (pl. 7 and fig. 12). To the north most of the output has come from groups 6 to 10. The association of ore types with intrusive rock types of the Laramide revolution is notable as mentioned earlier.

The persistence of individual ore shoots in depth is rarely more than a few hundred feet, and ore shoots at depths of as much as a thousand feet are unusual. However, there is no evidence that the bottom of the zone of mineralization has been reached in any locality, and commonly ore is found from the tops of the highest hills to the bottoms of the valleys; thus the range through which ore was deposited in a district may exceed 2,000 feet, although the deepest individual ore shoot may be less than 500 feet. Some blind ore shoots have been found in nearly every district, but generally the expense of finding them has been too great to encourage exploration.

Both residual enrichment and supergene enrichment are common. Gold is concentrated in the oxidized zone of pyritic gold and complex lead-silver-gold ores, but no enrichment of gold in the gold-telluride veins has been observed. Residual enrichment is most prominent in the tungsten veins and in pyritic gold veins. The oxidized zone ranges from a few feet to a maximum of approximately 100 feet in most parts of the pre-Cambrian terrain, but in the Breckenridge district oxidized ores have been found 300 feet below the surface. The oxidized ores are richer in gold, silver, and lead and poorer in zinc and copper than the primary ores. Immediately below the oxidized zone there is a marked increase in the silver content of the veins due to the presence of native silver or supergene ruby silver, both of which are usually associated with secondary copper sulfides. The extent and richness of the secondary ores are related to the erosion surfaces on which the veins crop out. The enriched zones are shallowest on the Flattop surface and deepest on the Overland Mountain and Bergen Park surfaces.

Almost all the ore found in the Front Range has been localized in breccias resulting from faulting, aggressive intrusion, or explosive volcanism. Replacement deposits are negligible. The localization of ore deposits is primarily the result of the features that controlled the permeability of the hydrothermal conduits. Quartzite and granite tend to break into open breccia, whereas shale and schist make a tight impermeable gouge. Many ore shoots are localized at a change in the course or the dip of a fault fissure where the movement of the walls caused them to move apart and create open spaces. Junctions of intersecting veins or points of divergence of branch veins commonly coincide with a higher degree of brecciation than at other places along faults, and as a consequence ore shoots are common at such places.

Localization of gold in placer deposits is related to the physiographic history of the region, the structure and character of bedrock and gravel, and the location and character of the primary deposits. Placers are not associated with gold-telluride deposits, but nearly every district containing pyritic gold deposits has some placer ground. Glacial drift is almost barren of placers, but a few ground moraines locally contain commercial concentrations. The outwash just below a terminal moraine is usually richer in placer gold than the gravels downstream. As much as 90 percent of the gold in a 50-foot gravel bed may be present in the lower 5 feet of gravel and in the upper 3 feet of weathered bedrock.

Laramide deposits outside the mineral belt.—Numerous small deposits of Laramide age are widely scattered through the Front Range, outside the mineral belt, but only a few have been productive. Some have been found along the early breccia-reef faults. The Dailey or Jones Pass district, about 6 miles west of the main mineral belt, has produced small amounts of low-grade pyritic gold ore, but most of the district's output has beeen molybdenum ore from the Urad mine. The Mayesville, Manhattan, and Home districts, in the northeasterly belt of porphyries about 35 miles northwest of the main mineral belt, have had a very small output of gold ore from the oxidized zone.

Copper deposits of the redbeds type have been found in the Pennsylvanian and Permian outcrops at a number of places in the Front Range. The only district of this group that had an appreciable output is the Red Gulch district, near Cotopaxi, in the southwestern part of the Front Range.

Post-Laramide ore deposits.—In the Guffey district, about 20 miles west of Cripple Creek, a small output of gold and gold-telluride ore has been made from veins cutting Tertiary lavas near a small stock of biotite-augite syenite. However, the only post-Laramide ores that have been commercially important in the Front Range were found in the extremely productive Cripple Creek district, where gold-telluride ores are associated with mid-Tertiary volcanic rocks in the crater of a denuded composite volcano.

SUMMARY OF MINING DISTRICTS

The Breckenridge district is in the Front Range mineral belt on the western side of the range. It is in a northward-trending syncline of Paleozoic and Mesozoic sediments cut by extensive masses of monzonite and quartz monzonite porphyry. The sedimentary rocks include the Maroon formation, the Morrison formation, the Dakota quartzite, the Benton shale, the Niobrara formation, the Pierre shale, and glacial deposits. The syncline is broken on the eastern side by a thrust fault, the Williams Range underthrust, and is crossed by a zone of northeasterly fissures that carry most of the ores of the district. The ores include stockworks, contact metamorphic ores, veins, blanket ores, and placer deposits; most of the output has come from the veins and placers. The district is most noted for the placer gold and the beautiful crystallized gold from Farncomb Hill but has also had a very substantial output of zinc and lead sulfide ores, chiefly from the Wellington mine.

The Montezuma district is about 5 miles northeast of the Breckenridge district. A large stock of porphyritic quartz monzonite lies just north of the town of Montezuma and is nearly surrounded by pre-Cambrian rocks, but at its western end it has intruded and baked Pierre shale, which underlies the upwarped plane of the Williams Range thrust fault. The Idaho Springs formation covers most of the eastern half of the district, and the Swandyke hornblende gneiss is prominent to the southwest and west. Dikes of porphyry are abundant in the mineral belt southeast of the stock. Mineralized fissures nearly all trend northeastward, but several strong northwest faults occur in the area south of the stocks and, though poorly mineralized themselves, some have localized ore in the northeasterly veins that cross them. The ore deposits are mesothermal veins containing gold, silver, galena, sphalerite, sulfarsenides, and sulfantimonides of silver and copper with some bismuth. Within the northern and central part of the stock high-grade silver veins have been found but no large output has come from veins of this type. In the south-central part of the stock sphalerite and galena are common in the intersecting but nonpersistent fractures found in this part of the district. In a southeasterly branch of the mineral belt extending from Glacier Mountain to Hall Valley barite and gray copper ore is common, and locally bismuth is found. East of Montezuma, in the Silver Wave-Pennsylvania vein system, several substantial bodies of chalcopyrite-sphalerite-galena ore have been found that contain gold and silver in commercial quantities.

In the Argentine district, between Montezuma and Silver Plume, ores similar to those near Montezuma have been found in northeasterly veins. The most productive veins are the Pennsylvania, Santiago, and Stevens.

The Silver Plume district is in an area of the Idaho Springs formation that is complexly intruded by small masses of Silver Plume granite and cut by many monzonite, quartz monzonite, and granite porphyry dikes. The mineralized area is localized at the intersections of eastward-trending veins with a northwesterly trunk vein, the Dives-Pelican-Bismarck system. Both sets of veins break across the foliation of the injection gneiss of the Idaho Springs formation but locally follow the contacts of porphyry dikes or granite bodies. The northwesterly vein system is mineralized through a distance of about three-quarters of a mile, and most of the output from the easterly veins has come from the segments within a quarter of a mile of the mineralized part of the Dives-Pelican-Bismarck vein. Individual ore shoots have been localized by changes in wall rock and changes in course or dip of the fissures. Granite and porphyry walls are more favorable than schist, and, as most of the movement along the premineral fissures was horizontal or at a low angle, changes in course were more effective in localizing ore shoots than changes in dip. The district has had a substantial output of silver, lead, and zinc from complex sulfide ores.

The Georgetown district lies just east of the Silver Plume district and has a similar geologic setting, except that most of the veins are in a small irregular northeastward-trending granite stock. The southern part of the district includes several northeastward-trending veins that contain ore near the barren southeasterly continuation of the Dives-Pelican-Bismarck fissure of Silver Plume, the most outstanding being the Colorado Central vein near the southern end of this northwesterly trunk fissure. A similar relation between northeasterly veins and west-northwest trunk fissures exists on Democrat Mountain about a mile north of Georgetown, but the productive mines at Georgetown itself have exploited northeasterly veins containing extensive ore shoots unrelated to intersecting northwesterly fissures so far as known. Much of the ore from the Georgetown district is similar to that of the Silver Plume district, but in addition to the complex sulfide ores some substantial shoots of pyritic gold ore have been found.

The Empire district, about 4 miles north of Georgetown, is in small stocks of Boulder Creek granite just east of a stock of hornblende monzonite porphyry. Silver Plume granite crops out to the south, and many irregular small masses of schist and numerous dikes of porphyry ranging in composition from quartz diorite to bostonite are present in the district. The ore deposits are almost entirely of the pyritic gold type. Most of the ore has come from two breccia zones bordering a body of monzonite about 1,500 feet long, elongated in a north-northeasterly direction. The Silver Mountain ore zone is several hundred feet wide and about 3,500 feet long and lies just southeast of the small monzonite stock. The Comet-Little Johnny group of lodes parallels it to the northwest. Northwesterly cross lodes connect the Comet-Little Johnny and the Silver Mountain ore zone where these northeasterly breccia zones die out. This encircling zone of fractured ground was probably formed by stresses related to the intrusion of the porphyry stock. A very substantial production of pyritic gold ore has been made by the Minnesota mine in recent years from the wide brecciated zones northwest of the stock. Smaller northeasterly pyritic gold veins have been found in several other places in the district.

The Lawson-Dumont district is halfway between Empire and Idaho Springs and has been intermittently productive for many years. The rocks in the western part of the district are chiefly Boulder Creek granite and Silver Plume granite, and those in the eastern half comprise chiefly the Idaho Springs formation and granite gneiss. Monzonite porphyry, quartz monzonite porphyry, and bostonite occur in persistent eastward-trending dikes. Veins in the western part of the district are predominantly northeasterly and contain lead-silver-zinc ores, but the veins in the eastern section strike east and contain pyritic gold ores.

The Alice-Yankee Hill district is about 7 miles west-northwest of Central City and is chiefly noted for the presence of the pyritic stockwork exploited by the Alice mine, athough a number of small lead-zinc veins are also known. The Alice ore body was in a much fissured quartz monzonite stock that carried innumerable seams of low-grade pyritic gold ore at depth. Supergene enrichment made the large irregular mineralized mass workable to depths of as much as 100 feet below the surface.

The Central City-Idaho Springs district has the largest output of any comparable area in the Front Range mineral belt. Central City is in the northern part of the district and is on the axis of a northeasterly anticline, which exposes a core of granite gneiss bordered on both sides by schist of the Idaho Springs formation. Scattered through the district are many small dikes, sills, and irregular masses of pegmatite, Silver Plume granite, and porphyry formed during the Laramide revoution. The rocks formed during the Laramide revolution include monzonite, alaskite, granite, bostonite, alkalic syenite, and biotite-latite porphyries. Idaho Springs lies on the southerly limb of a syncline in the Idaho Springs formation south of the Central City anticline. A strong northeasterly pre-Cambrian shear zone extends along the northwest side of a large body of hornblende gneiss at the eastern edge of the district. The earliest fractures of the Laramide revolution are northwesterly faults of the breccia reef type, which can be traced for miles beyond the limits of the district. The later faults strike from east to northeast and contain nearly all the veins. Most of the ore is in veins that follow faults, but a few ore bodies followed chimneylike zones of brecciation. The productive veins commonly have one or both walls in granite gneiss, pegmatite, or porphyry dikes, but southwest of Idaho Springs several productive veins lie in schist but cut across the foliation. The longest continuously mineralized northeasterly vein, the California-Mammoth, is traceable for about 2 miles. The west-northwesterly Gem vein is more extensive but less continuously mineralized. Many ore shoots have been mined to depths of 1,000 to 1,500 feet. Near the center of the mineralized area is The Patch, a pipe of mineralized breccia known to extend from the surface to a depth of more than 1,600 feet without change in size but with a marked decrease in mineralization. The ores exhibit a striking zonal arrangement. A short distance east of The Patch the veins contain enargite and fluorite. Surrounding this inner zone is a broad area of pyritic gold veins, which is bordered by a girdle of pyritic galena-sphalerite veins, and this outer girdle is locally fringed by a discontinuous zone of lead-silver veins. A notable feature of the district is the presence of a narrow belt nearly 7 miles long that crosses north-northeast from one side of the district to the other and is unique in containing all the gold-telluride ores that have been found. Some pitchblende occurs as a minor constituent of pyritic ores in the western part of the district.

The North Gilpin County district contains many veins of the pyritic gold type, but few have had important production. Several of them are found at the northwestern ends of the early breccia reef faults. Near Apex the unusual copper ore body exploited in the Evergreen mine has aroused much interest among geologists, but its output has been small. Chalcopyrite, bornite, and pyrite are intergrown with wollastonite and other unusual calcic minerals in a monzonite porphyry, and the ore deposit is attributed to magmatic differentiation modified by hydrothermal processes.

The Eldora district, about 3 miles west of Nederland, in the southwestern part of Boulder County, has had a small output of gold-telluride ores from eastward-trending veins that cut across the foliation of the enclosing Idaho Springs formation.

The Caribou-Grand Island district is about 2 miles northwest of Eldora and 20 miles west of Boulder. The outstanding feature of the district is a composite stock composed of early Tertiary gabbro, monzonite, and quartz monzonite porphyries with minor magmatic titaniferous magnetite and related mafic rocks. Most of the titaniferous magnetite bodies are small, but one dikelike mass has a length of 1,500 feet and contains as much as 4½ percent of titanium oxide. The stock is bordered on the east, west, and south by the Idaho Springs formation and on the north by Boulder Creek granite. The schists and gneisses east of the stock are cut by eastward-trending lead-silver-zinc veins, and most of the ore shoots near Caribou were found near the intersections of easterly veins with a strong northeasterly fissure, the No-Name vein. The district is best known for the substantial output of high-grade silver ore made from the Caribou and No-Name veins during the seventies, but in recent years the complex lead-silver-zinc ores of the Boulder County vein 2 miles east of Caribou have been the chief source of the district's output. In 1948 some pitchblende was found in the No-name vein at depth.

The Ward district is about 8 miles due north of Nederland in an area of interfingering schist and Silver Plume granite cut by west-northwest dikes and veins and many irregular bodies of porphyry of Laramide age. Representatives of nearly every type of porphyry known in the mineral belt except limburgite and biotite latite have been found in the Ward district. Near Ward most of the intrusives associated with the Laramide revolution are monzonite or quartz monzonite porphyries, but a few miles southeast, near Sunset and Copper Rock, stocks of alkalic syenite and bostonite are present. The northeastern part of the district near Gold Lake is crossed by the remarkably long gabbro dike called the "Iron dike," which has been traced from the foothills belt northwest to Estes Park. Gold, silver, and lead have been the chief metals obtained from the quartz veins of the district, but minor amounts of copper, zinc, and tungsten also have been mined. The ore shoots have been found in granite and gneiss along Laramide dikes, but some of the dikes are later than the ore. A substantial amount of free-milling gold ore was taken from the oxidized zone of the pyritic gold-silver ores, but much of the primary ore from these veins was too low grade to work.

The Boulder County tungsten district lies a few miles west of Boulder and has been one of the most productive in the United States. It is a narrow belt about 9 miles long and extends east-northeast from the vicinity of Nederland. Most of it is within a batholith of Boulder Creek granite, but the most productive area, which centers around Nederland, is within a zone of interfingering granite gneiss, Boulder Creek granite, pegmatite, gneissic aplite, and schist. The foliation of these rocks trends north-northeast parallel to the western edge of the batholith, which crosses the district about a mile east of Nederland. The igneous rocks of the Laramide revolution include the early diabase Iron dike in the eastern part of the district, hornblende monzonite and hornblende diorite porphyry in the western part of the district, small dikes of biotite monzonite porphyry and biotite latite intrusion breccia in the east-central part, and small dikes of late limburgite. The district is crossed by several early northwesterly fractures of the breccia reef type, which are spaced 2 to 3 miles apart. The breccia reefs are cut by east-northeasterly mineralized fractures that are mostly concentrated in three zones extending through the southern, central, and northern parts of the tungsten belt. The southern belt contains ore only in the western part of the district, but the central and northern zones have been productive through the entire length of the tungsten belt. The major fractures extend east-northeast, but many minor fractures diverge from them to the northeast. On both sets of fissures premineral movement was nearly horizontal, and most of the ore shoots in the district were localized by changes in course of the veins or by junctions of branch veins and intersections of cross veins.

The tungsten-bearing fissures may change within a few feet from barren fractures to veins of fine-grained quartz and ferberite a foot or two in width. Long segments of the tungsten veins contain the horn quartz with no ferberite. Quartz is the only abundant gangue mineral, but some barite, sericite, adularia, goyazite, and clay minerals are associated with it. Pyrite, marcasite, scheelite, galena, and sphalerite are uncommon but are locally associated with the ferberite as late minerals. The ferberite found at the eastern end of the district is very fine grained but is progressively coarser grained in the ores obtained farther and farther west. The wall rocks of the veins were first strongly argillized during an early period of acidic alteration, which changed the rocks to dickite near the vein and beidellite at a little greater distance; immediately preceding ore deposition strongly potassic solutions changed the argillized rock adjacent to the veins to sericite, hydromica, and quartz, with minor amounts of adularia and barite.

The Magnolia district is about 5 miles west of Boulder, just south of the eastern end of the tungsten belt. It is notable for a wide variety of unusual telluride minerals. It lies entirely in Boulder Creek granite, and the ores occur in eastward-trending veins just west of the persistent northwesterly Livingston breccia reef. The greatest proved vertical range of a single ore shoot is about 400 feet, but within the district ore has been found through a vertical range of 1,600 feet. A small amount of ferberite ore has been found in some of the veins and is later than the gold tellurides.

The Gold Hill district, 3 to 8 miles northwest of Boulder, is noted for its rich gold-telluride ores. It is mostly within the northern part of a batholith of Boulder Creek granite, but schist is present in the western and northwestern parts of the district. The foliation of both schist and granite has a general north to northeast trend and dips steeply. Pegmatite dikes are abundant, and in places there are dikes of gneissic aplite, hornblende diorite, and Silver Plume granite. The pre-Cambrian rocks were cut during the Laramide revolution by a variety of porphyry dikes ranging in composition from diabase to alaskite. The ore deposits are closely related structurally to the early Laramide faults called breccia reefs; the most prominent are the Hoosier and Maxwell reefs, which trend northwest across the district. Others trend west, west-northwest, and north-northeast. Many of the ore deposits are found close to these breccia reefs, and nearly all are within 3,000 feet. Most of the vein fissures strike northeast and dip steeply southeast. They are filled chiefly with gold-telluride ores, but some contain valuable pyritic gold ore, and a few contain silver-lead ore. The principal ore minerals of the telluride ore are petzite and sylvanite, and free gold is common in places. Pyrite and chalcopyrite are the characteristic ore minerals of the pyritic gold veins, and the gold is largely associated with the chalcopyrite. In the silver-lead veins, argentiferous gray copper and galena are the chief ore minerals, but sphalerite is common in places. Most of the mines of the district are less than 600 feet deep, but a few are approximately 1,000 feet deep, and the ores have been mined over a vertical range of about 2,500 feet.

The Jamestown district is at the northeastern end of the mineral belt, about 9 miles northwest of Boulder. Schists and gneisses have been intruded by the pre-Cambrian Boulder Creek and Silver Plume granites, and these in turn were intruded by stocks and dikes during the Laramide revolution. A large stock of granodiorite and a small stock of sodic granite-quartz monzonite porphyry intrude the central part of the district, and the dikes range from diabase to alaskite in composition. Three strong breccia reefs of northwesterly trend cut through the district; the central one, the Maxwell reef, is cut by the granodiorite stock. The chief deposits are gold-telluride ore, fluorspar, pyritic gold ore, and silver-lead ore. The silver-lead deposits, which are the earliest, occupy veins of northwest trend and breccia zones. The chief ore minerals are argentiferous galena and tennantite. The fluorspar deposits are in breccia zones and northwesterly veins close to the porphyry stock. The breccia zones are lenticular in plan, and some appear to be pipelike. Much of the fluorspar has been brecciated and cemented by fine-grained fluorspar and gangue. The pyritic gold ores fill northeast veins, and the ore minerals are chiefly pyrite and chalcopyrite with free gold in places. The telluride veins also trend northeast and are filled with a variety of telluride minerals, of which krennerite, petzite, sylvanite, and altaite are the most common. Many of the mines are between 100 and 200 feet deep, but a few are between 400 and 500 feet. Ores have been mined over a vertical range of 2,350 feet. In recent years most of the output of the district has come from the gold-telluride ores of the Buena mine and from the fluorspar deposits.

The Dailey or Jones Pass district, about 7 miles northwest of Silver Plume, is almost entirely within a batholith of Silver Plume granite, but some schist is present in the eastern part of the district. On Red Mountain, a few dikes and a small stock of granite porphyry cut the granite during the Laramide revolution. The Berthoud Pass fault forms the eastern border of the district. Most of the veins trend north to northeast, but cross veins are common. The ore deposits include high-grade small lenticular or chimneylike shoots of silver-lead ore and larger shoots of low-grade pyritic gold ore, but most of the district's output has been molybdenum ore from the Urad mine. This ore occurs in nonpersistent quartz-pyrite-molybdenite veins in the vicinity of the granite porphyry stock.

The Cripple Creek district is about 20 miles southwest of Colorado Springs, and the total value of its output exceeds that of all other mining districts in the Front Range combined. The deposits lie in a denuded composite volcano that broke through the pre-Cambrian terrain near the contact of a small stock of Silver Plume granite with schist and Pikes Peak granite in late Oligocene or early Miocene time. The pre-Cambrian rock surrounding the volcano is capped locally by Tertiary sandstone, grit, and conglomerate and by some rhyolite, andesite, and phonolitic volcanic rocks. The volcanic throat is largely filled with phonolitic tuff and breccia, but many types of alkaline intrusives cut the fragmental rocks. Some of the breccia shows distinct bedding, and part of it accumulated on a nearly horizontal floor within the crater during intervals marked by widespread subsidence in the crater area. The intrusive rocks include latite, phonolite, syenite, lamprophyres, and basalt.

The volcano contains two islands, one of schist and one of granite, which separate the main crater from the subordinate Globe Hill crater on the northwest. The main crater separates downward into a group of subcraters or roots that were separate local sources of ore solutions. These solutions worked their way upward along relatively few fissures in the deeper part of the subcrater but gradually spread through the permeable parts of a network of connecting fractures as they approached the surface.

The major fracture zones trend north-northeast and west-northwest and are mostly steep. This network of fractures carries the gold-telluride ores for which the district is famous. The character of the country rock influenced the distribution, extent, and permeability of the fissures and thereby influenced the localization of ore. The fissures are most abundant in breccia and in the Pikes Peak granite adjacent to the crater. Most of the productive lodes are sheeted zones ranging from a few inches to as much as 100 feet in width. Most ore shoots are less than 500 feet long, and the downward persistence is roughly proportional to the horizontal extent, the ratio commonly being at least 3 to 1. Ore bodies have commonly been localized at the intersections or junctions of fissure zones, where the wall rocks of a vein change abruptly, along dikes, and in chimneylike masses of collapse breccia. The best ore shoots have been found in the breccia, but some shoots walled by granite end where the vein enters the breccia. The largest and deepest ore shoots are in areas overlying major sources of mineralization.

INTRODUCTION

Since 1926 the United States Geological Survey in cooperation with the Colorado Geological Survey Board and the Colorado Metal Mining Fund has been continuously studying the geology of Colorado's mineral deposits, and several reports have been published on individual mining districts in the Colorado Front Range and elsewhere. The gradual accumulation of information on different portions of the Front Range by the writers and others is slowly clarifying many of the local and regional problems of Front Range geology, and it is believed worth while to sum up the regional picture that has developed. The position of the individual mining districts in this picture has been of especial concern, and it is felt that they can be best understood when described as related portions of a geologic province rather than as individual entities.

The literature describing the geology and mineral deposits of the Front Range is scattered through many publications, a number of which are out of print and difficult of access. Although the descriptions of the districts in this report are not intended to serve as substitutes for detailed descriptions already published, they should be adequate to give the reader the general information essential to an understanding of the district. In addition to the information summarized from reports already published, much new material is presented here for the first time.

The importance of structure within the mineral belt of the Front Range was not as clearly recognized prior to 1930 as it has been since, and the maps of many districts previously studied have been somewhat revised in an effort to better interpret their geology. Descriptions of districts for which reports have been recently issued are summarized together with the others, but the descriptions, especially of their mines, are more condensed.

The facts ascertained by one of the writers in one area have often explained problems puzzling the other somewhere else, and it is hoped that the summary of the factors governing ore localization in deposits throughout the Front Range and descriptions of the various districts and some of their representative mines may help others similarly.

ACKNOWLEDGMENTS

The writers are deeply indebted to the late Mr. G. F. Loughlin of the Geological Survey for much time spent in a critical review of the manuscript of this report and the innumerable constructive suggestions made for its improvement. He was closely associated with the geologic work in Colorado since the inception of the cooperative program between the Geological Survey and the Colorado Metal Mining Fund, and his able supervision and sound advice both in the field and office helped immeasurably in carrying this study forward.

A large part of the credit for instigating the cooperative work of the Geological Survey in Colorado belongs to Mr. C. W. Henderson of the United States Bureau of Mines, Denver, Colo., and the continuance of this work for two decades was in no small part due to his friendly, unselfish interest. His death in January 1945 is an irreparable loss to the mining industry of Colorado and to his many friends. It is difficult to adequately acknowledge our debt to him, not only for the very tangible help given in the matter of statistical data on mine production, but also for the equally important intangible help—the pervasive good will created by the commendation of a distinguished engineer widely known and highly regarded by mining men throughout the West.

It is impossible to give proper credit to all who have contributed in some measure to this report. The published and unpublished work of the many geologists and engineers who have added to our knowledge of specific areas are mentioned at the appropriate place in the text. For ideas, encouragement, and help in the general task, which have been so freely given by Colorado geologists, engineers, and miners everywhere, the writers wish to express their gratitude and deep appreciation.

LOCATION, DRAINAGE, AND ACCESSIBILITY

The Colorado Front Range, as shown on plate 4, is a northward-trending mountainous uplift commonly 30 to 35 miles wide, extending north from Canon City to Wyoming, where it merges with the Laramie Range without a perceptible topographic break. The eastern

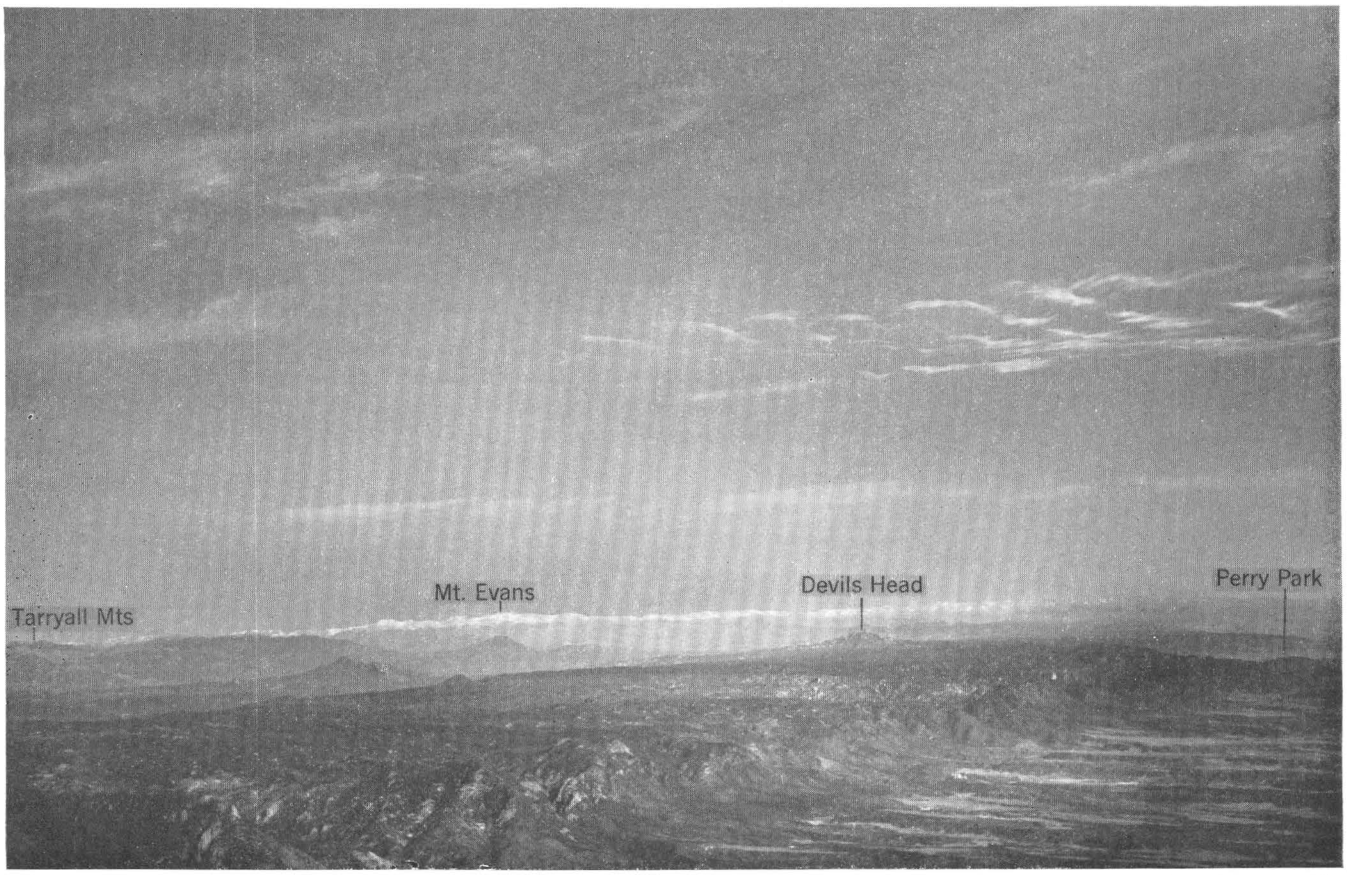


FIGURE 1.—Aerial view looking northwest toward Devils Head from over Colorado Springs at an altitude of 12,300 feet. Shows topographic contrast between crystalline rocks of the Colorado Front Range and the sedimentary rocks of the bordering plains. Note the broad benchlike compound erosion surface in front of the higher central part of the range. Courtesy of Geological Society of America.

border of the Front Range follows a slightly curved north-south line passing a short distance west of Colorado Springs, Denver, and Fort Collins, and the topography of the range stands in sharp contrast to the plains to the east. (See fig. 1.) The western boundary of the Front Range is much more irregular, and in some places there is little topographic distinction between the Front Range and some of the mountain ranges regarded as separate geologic units. North of the Arkansas River the west border of the Front Range, as considered in this report (pl. 4), extends from Cotopaxi northwestward along Badger Creek to Black Mountain, where it bends east around the southern border of South Park. At Hartzel it swings north, following the eastern and northern edges of South Park to Hoosier Pass at the head of the Blue River. From Hoosier Pass almost to Kremmling the valley of the Blue River forms the western boundary of the Front Range, which attains its greatest width, about 50 miles, in this region. The Colorado River flows south from La Poudre Pass along the eastern border of Middle Park to Granby, where it turns west in a broad valley through the southern part of Middle Park to Kremmling; south and east of this broad valley the Front Range rims Middle Park. Two of the strongest tributaries of the Colorado, the Williams River and the Frazier River, have cut wide reentrants that extend arms of Middle Park to the southeast for many miles into the main range. North of La Poudre Pass the valley of the Laramie River forms the western boundary of the Front Range.

The Continental Divide extends along the Front Range close to its western border from Hoosier Pass to La Poudre Pass, separating the drainage of the Colorado River from streams that drain northward into the North Platte River or eastward into the South Platte River. As shown in plate 4, most of the Front Range is drained by the Platte River and its tributaries. The extreme southern end of the Front Range is drained by the tributaries of the Arkansas River, but much of the range south of the latitude of Denver is drained directly by the South Platte River and its minor tributaries. Most of the streams flow nearly due east across the Front Range, rising near the crest, which is close to the western edge of the range. Streams of this type that are tributaries of the South Platte include Clear Creek, which leaves the mountains just west of Denver; Boulder Creek and its branches, which leave the mountains at Boulder; the St. Vrain Creek system, which leaves the mountains just west of Lyons; the Big Thompson River system, which leaves the mountains west of Loveland; and the Cache La Poudre River system, which leaves the mountains about 10 miles northwest of Fort Collins.

The highest and most rugged part of the Front Range is in its central part and extends north from South Park to the Cache La Poudre River. In this part the crest of the range is commonly between altitudes of 12,000 and 14,000 feet. In the higher parts of the Front Range differences in altitude between the stream levels and the interstream divides commonly range from 1,500 to 2,000 feet, though individual peaks may rise more than 3,000 feet above the nearby stream. Grays Peak, about 40 miles due west of Denver, is the highest peak in the Front Range and has an altitude of 14,274 feet. Torreys Peak, half a mile to the northwest of Grays, has an altitude of 14,264 feet, and Mount Evans, approximately 10 miles to the southeast, has an altitude of 14,260 feet. Longs Peak, 50 miles to the north, rises to an altitude of 14,255 feet, and Pikes Peak, 70 miles to the southeast, has an altitude of 14,107 feet. These are the only peaks in the Front Range that reach an altitude of more than 14,000 feet.

From the high country near the crest of the range, the mountain flanks slope steeply to the west, but east of the crest they descend more gradually and are characterized by much-dissected benches. (See figs. 1 and 2.) Close to the crest of the range the eastern slope may be as much as 500 feet to the mile, but near the eastern edge of the range the general slope is commonly less than 100 feet to the mile. Where one of these bench-like surfaces has been cut through by several streams, nearly accordant levels of the interstream divides form a striking feature of the landscape. Much of the topography of the Front Range is due to the dissection of these surfaces, most of which lie at an altitude of less than 10,000 feet. In the region where the bench-like surfaces merge with the higher country toward the crest of the range, the valley bottoms are commonly little below the general level of the interstream divides (fig. 3). Farther east, however, where the streams leave the mountain front, they have cut canyons that are as much as 1,500 feet deep.

The region just east of the Front Range is well served by railroads, and one standard-gauge railroad crosses the range a short distance west of Denver. The narrow-gauge railroads that formerly served the mining districts of the range have all been abandoned, and trucks now do most of the haulage. The southern part of the range is tributary to the main line of the Denver & Rio Grande Western Railroad, which passes through Canon City and follows the Arkansas River Valley west and north to Tennessee Pass near Leadville. In the Pikes Peak region the Colorado-Midland Railroad links Cripple Creek to Colorado Springs. The Denver & Salt Lake Railway, commonly called "The Moffat Road," follows the valley of South Boulder Creek west of Denver to East Portal and passes through the Moffat tunnel to the Fraser River. It follows the Fraser River north to its junction with the Colorado River, which it

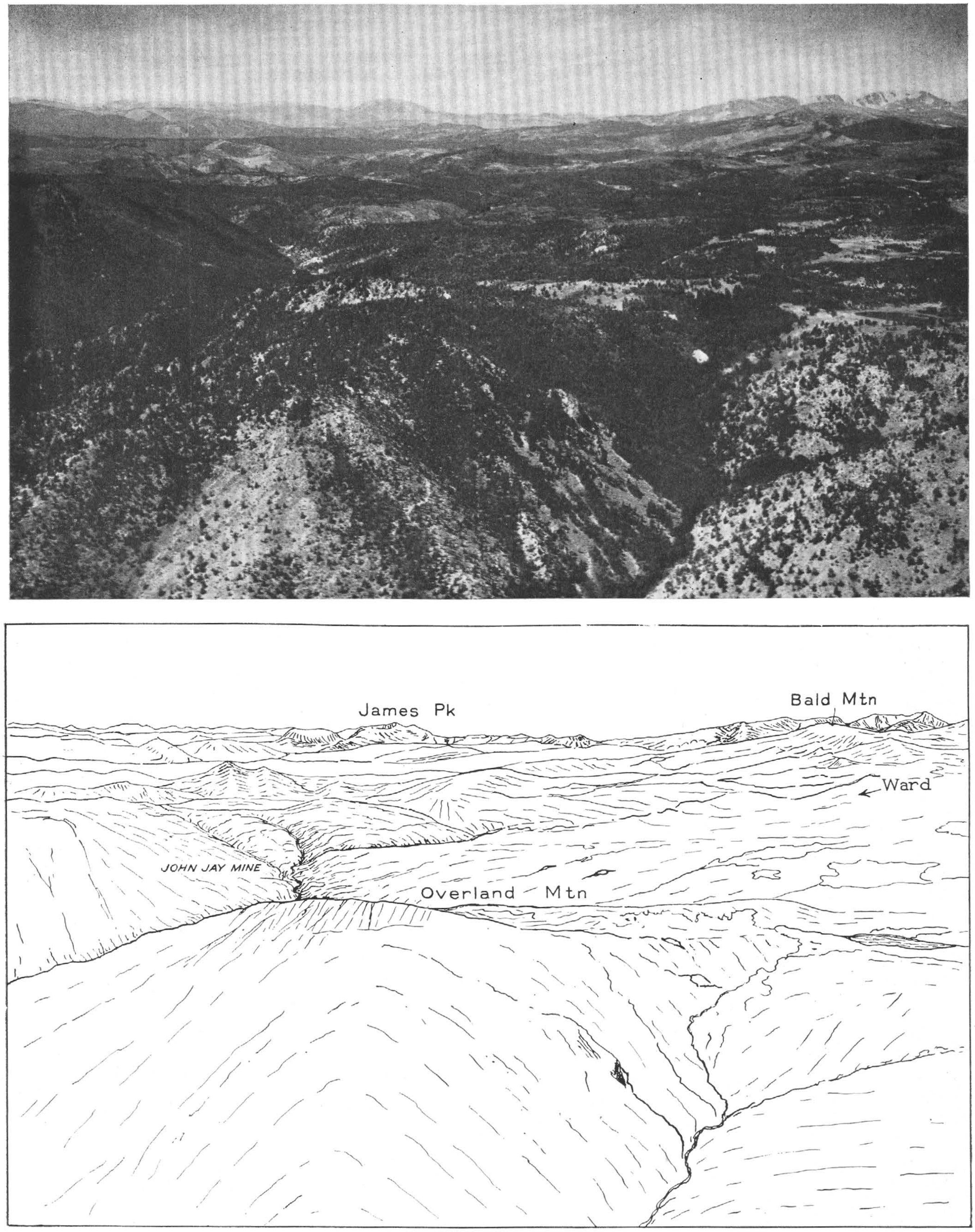


FIGURE 2.—Aerial view looking southwest across Overland Mountain toward James Peak from an altitude of 9,300 feet near Jamestown. Shows type locality of the Overland Mountain erosion surface and the transition belt where it merges with the higher erosion surfaces near the crest of the range. The dumps in the left middle ground are those of the John Jay mine. Courtesy of Geological Society of America.

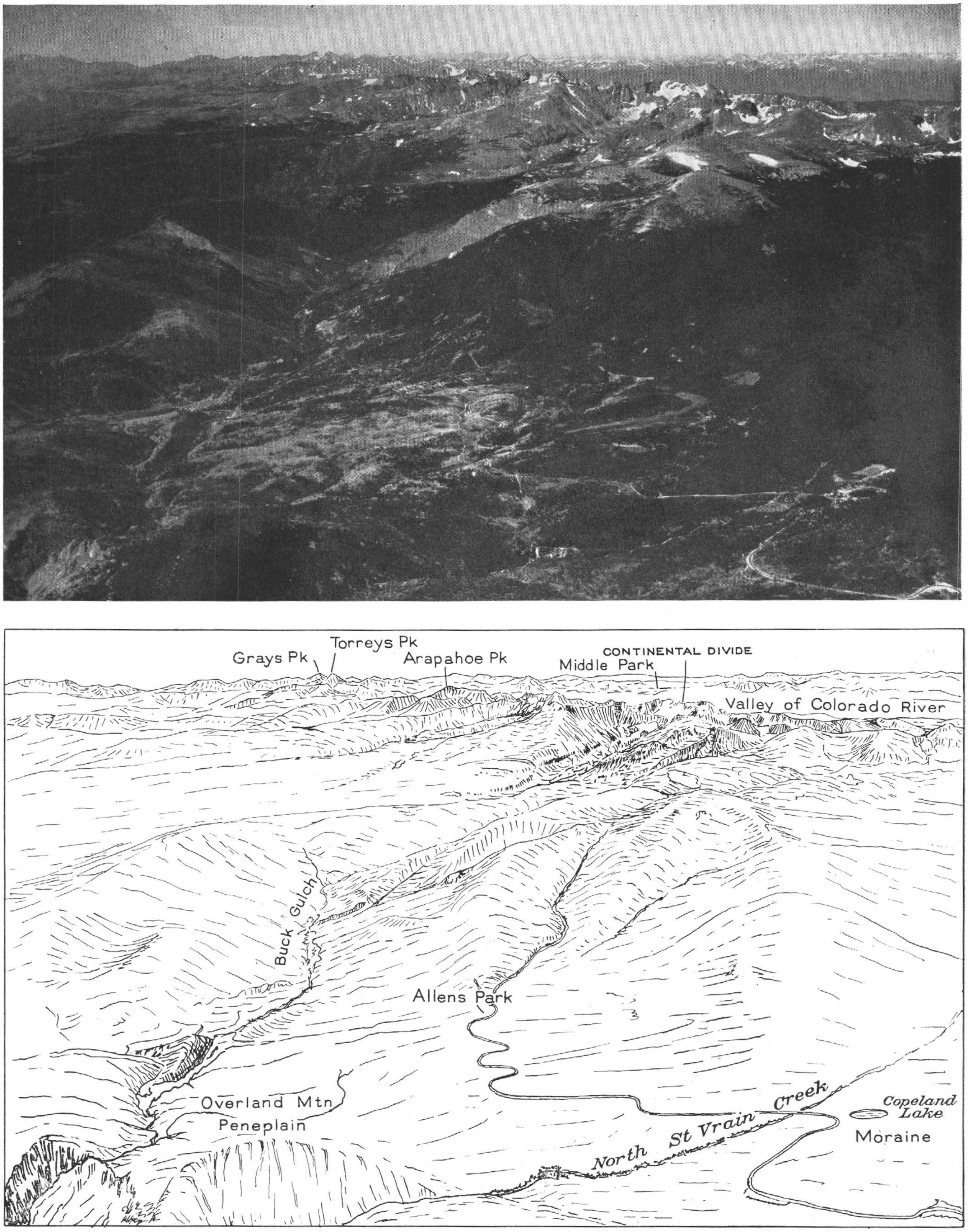


FIGURE 3.—Aerial view looking south-southwest across Allens Park from an altitude of 14,900 feet about 5 miles east of Longs Peak. The rugged topography characteristic of the Continental Divide is shown in the background, and the transition from the high glaciated country near the middle of the range to the benchlike erosion surfaces that border it is shown in the foreground. This transition zone almost coincides with the lower limit of glaciation.

follows westward to Bond, where it turns northwest to Craig, Colo., the end of the line. Relatively direct transportation to Utah smelters is provided by the cut-off line of the Denver & Rio Grande Western, which uses the tracks of the Denver & Salt Lake Railway as far as Bond and there passes on to its own right-of-way, which continues down the Colorado River to Dotsero, where it joins the main line to Salt Lake City.

The Front Range is well supplied with good automobile roads, but there are a few places where supplies have to be freighted several miles by pack train.

HISTORY AND PRODUCTION

Brief histories of the mining districts of the Front Range are included with the detailed discussions of the districts in the latter part of this report. For a general discussion of the history of mining in the Front Range and for many details of production up to 1923 the reader is referred to the general review by Henderson.[1] The total production to 1944 of the various counties included in the Front Range and the annual production figures from 1938 to 1943 for the counties and districts of the Front Range are given in the following tables.

Mine production of gold, silver, copper, lead, and zinc in counties of the Front Range, 1858 to 1944, inclusive, in terms of recovered metals[1]

[Compiled by U. S. Bureau of Mines]

County	Gold						Silver	
	Placer		Lode		Total		Fine ounces	Value
	Fine ounces	Value	Fine ounces	Value	Fine ounces	Value		
Boulder	2, 137. 84	$71, 963	1, 022, 656. 75	$24, 323, 630	1, 024, 794. 59	$24, 395, 593	8, 669, 709	$8, 019, 291
Clear Creek	139, 823. 10	2, 914, 408	1, 236, 688. 63	29, 118, 696	1, 376, 511. 73	32, 033, 104	60, 304, 485	54, 020, 483
Gilpin	47, 531. 91	1, 479, 550	4, 205, 111. 02	88, 202, 024	4, 252, 642. 93	89, 681, 574	11, 163, 693	8, 963, 404
Grand [2]	98. 91	2, 497	578. 77	12, 056	677. 68	14, 553	10, 044	7, 306
Jefferson	10, 713. 77	348, 544	1, 673. 37	38, 102	12, 387. 14	386, 646	11, 572	7, 803
Larimer and Jackson [2]	828. 39	17, 794	747. 80	20, 394	1, 576. 19	38, 188	3, 983	2, 714
Park [2]	256, 657. 40	6, 423, 464	1, 010, 625. 80	26, 900, 211	1, 267, 283. 20	33, 323, 675	7, 636, 627	7, 331, 725
Summit [2]	738, 926. 31	15, 627, 868	262, 782 07	5, 556, 572	1, 001, 708. 38	21, 184, 440	14, 356, 835	12, 237, 356
Teller	374. 48	12, 142	18, 496, 360. 98	400, 948, 065	18, 496, 735. 46	400, 960, 207	2, 102, 544	1, 364, 574

County	Copper		Lead		Zinc		Total value
	Pounds	Value	Pounds	Value	Pounds	Value	
Boulder	1, 686, 355	$226, 926	8, 635, 558	$478, 335	71, 700	$7, 493	$33, 127, 638
Clear Creek	14, 015, 120	2, 155, 068	190, 873, 619	8, 871, 818	33, 876, 221	2, 536, 568	99, 617, 041
Gilpin	26, 668, 287	4, 315, 040	38, 893, 980	1, 753, 904	822, 113	70, 443	104, 784, 365
Grand [2]	5, 171	805	13, 345	720			23, 384
Jefferson	327, 195	38, 950	11, 063	413	2, 000	216	434, 028
Larimer and Jackson [2]	235, 328	38, 647			30, 722	1, 659	81, 208
Park [2]	3, 015, 886	488, 344	57, 930, 015	2, 594, 738	7, 493, 532	623, 513	44, 361, 995
Summit [2]	1, 292, 549	181, 419	170, 961, 238	8, 066, 069	168, 671, 560	13, 693, 890	55, 363, 174
Teller	451	83	612	49			402, 324, 913

[1] Nineteen Forty-six Mining Yearbook, p. 24, Denver, Colo., Colorado Mining Association, 1946.
[2] Part of the production is from mines outside the Front Range.

Annual production of gold, silver, copper, lead, and zinc in counties and districts of the Front Range from 1938 to 1943, in terms of recovered metals

[Figures furnished by R. H. Mote, U. S. Bureau of Mines]

District	Year	Ore treated (short tons)	Gold			Silver			Copper (pounds)	Lead (pounds)	Zinc (pounds)
			Lode (fine ounces)	Placer		Lode (fine ounces)	Placer				
				Sluicing and hydraulic mining (fine ounces)	Dredges and draglines (fine ounces)		Sluicing and hydraulic mining (fine ounces)	Dredges and draglines (fine ounces)			
BOULDER COUNTY											
Central	1938	7, 468	402, 060			475					
	1939	7, 724	337, 600			1, 015			500		
	1940	19, 553	716, 900			1, 097				2, 100	
	1941	13, 498	775, 300			2, 936			300	14, 600	7, 000
	1942	2, 918	160, 600			360			400	4, 100	
	1943	16, 229	6, 100			3, 489			5, 400	94, 200	
Gold Hill	1938	55, 926	1, 178, 280	420		31, 779			78, 800	153, 500	
	1939	72, 494	1, 778, 100	200		29, 663			154, 200	72, 000	
	1940	53, 880	1, 534, 600			28, 748			106, 000	154, 400	
	1941	45, 470	1, 260, 100	700		24, 701			50, 000	130, 700	
	1942	24, 020	815, 600			9, 461			10, 600	118, 300	5, 700
	1943	1, 334	45, 700			433				13, 600	19, 600
Grand Island	1938	2, 350	40, 200	940		2, 421				8, 500	
	1939	1, 297	31, 500	1, 800		1, 868	3		100	4, 100	
	1940	839	27, 200			744				1, 800	
	1941	16, 953	289, 800		300	25, 851			2, 900	73, 600	4, 000
	1942	4, 474	122, 700			13, 836			2, 100	19, 700	
	1943	150	200			6, 328			800	2, 400	
Magnolia	1938	1, 821	82, 400			14					
	1939	2, 664	84, 100			56					
	1940	2, 801	142, 300			1, 042				1, 100	
	1941	1, 664	96, 000			388					
	1942	444	61, 200			3					
	1943										

[1] Henderson, C. W., Mining in Colorado: U. S. Geol. Survey Prof. Paper 138, 1926.

Annual production of gold, silver, copper, lead, and zinc in counties and districts of the Front Range from 1938 to 1943, in terms of recovered metals—Continued

District	Year	Ore treated (short tons)	Gold: Lode (fine ounces)	Gold: Placer: Sluicing and hydraulic mining (fine ounces)	Gold: Placer: Dredges and draglines (fine ounces)	Silver: Lode (fine ounces)	Silver: Placer: Sluicing and hydraulic mining (fine ounces)	Silver: Placer: Dredges and draglines (fine ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)
BOULDER COUNTY—Continued											
Sugar Loaf	1938	9,066	386,120	1,479	40,361	2,221	1	33	3,000	1,000	
	1939	9,975	431,000	2,536	3,164	5,685	2	4	900	5,000	
	1940	12,259	607,600			3,476				400	
	1941	7,114	366,200			5,493			600	4,700	
	1942	3,280	264,400			1,253				1,000	
	1943	814	73,200			730				2,000	2,400
Ward	1938	2,280	172,680			1,819			3,200	1,000	
	1939	7,586	223,400			1,749			6,300	1,900	
	1940	5,168	333,500			4,995			56,000	7,200	
	1941	5,259	284,500			3,406			49,200	1,400	
	1942	2,071	167,500			1,987			26,800	4,600	
	1943	1,222	97,900			1,125			13,800	800	
CLEAR CREEK COUNTY											
Alice	1938	71,611	494,180			29,083			306,300	200	
	1939	709	52,700			109					
	1940	1,267	56,000			97			400	400	
	1941	1,178	47,300			772			1,000	14,000	
	1942	1,129	40,000			699			800	16,000	
Argentine	1938	3,043	31,380			11,863			12,200	36,000	
	1939	771	16,200			3,191			7,500	31,600	
	1940	7,358	15,500			13,171			4,200	57,000	
	1941	3,770	5,300			21,614			2,100	43,000	
	1942	506				14,732				12,700	
	1943	754	5,300			1,838			1,500	88,600	38,000
Cascade and Ute Creek	1940	23	100			62				400	
	1941	415	9,800			879			3,465	2,993	
Dailey and Atlantic	1940	1				7				600	
Empire	1938	79,517	1,845,920	540		2,922			500	3,700	
	1939	75,124	1,638,600	100		2,870			700	700	
	1940	79,109	1,669,300			2,714			1,400	400	
	1941	74,173	1,461,200			6,445			68,500	300	
	1942	29,986	789,300			724			4,700	2,300	
	1943	10,651	250,000			758				4,200	2,300
Geneva Creek	1939	2	100			9				100	
	1940	1,803	5,000			772			300	500	
Griffith	1938	6,961	31,860	100		18,369			3,500	46,300	
	1939	3,065	35,500			7,033			8,000	49,800	
	1940	4,781	2,900			16,816			400	56,400	
	1941	739	4,200			10,908			500	67,000	112,000
	1942	9,700	5,100			133,314			5,100	417,000	462,000
	1943	9,018	6,300			145,243			6,200	335,400	448,000
Idaho Springs	1938	46,671	573,760	8,880		49,486	14		46,200	520,500	17,000
	1939	50,371	1,084,100	3,700		68,435	6		129,700	693,400	
	1940	97,507	1,530,100	1,540	13,260	112,306	3	35	183,200	933,900	
	1941	67,582	1,186,100	1,245	81,355	74,669	1	99	103,235	546,007	
	1942	39,504	617,100			30,611			56,100	193,300	
	1943	6,664	85,700	300		22,576			34,500	231,400	153,000
Montana	1938	6,677	116,420			12,389			49,300	27,000	
	1939	9,617	127,900			22,692			77,300	57,200	
	1940	1,658	11,300			4,988			1,400	73,800	
	1941	175	800			6,895			300	77,000	
	1942	6,161	5,300			22,164			3,300	247,100	
	1943	2,875	3,400			19,613			1,600	71,600	3,000
Trail Creek	1938	9,131	229,800			6,008			5,000	51,300	13,000
	1939	16,551	534,100			8,829			2,800	77,200	
	1940	27,675	523,200			11,351			6,700	227,600	
	1941	31,402	522,500			7,134			1,900	196,700	
	1942	27,154	353,700			4,895			2,300	135,300	
	1943	8,917	101,800			7,657			3,200	102,200	21,700
GILPIN COUNTY											
Northern	1938	10,059	134,160	4,120	322,900	1,219	6	288	800	20,000	
	1939	4,417	70,000	2,526	194,974	519	6	178	1,800	600	
	1940	4,384	43,100	887	8,913	540		7	5,200	200	
	1941	2,735	36,400	160	10,440	315		10		1,000	
	1942	854	15,200			581			6,400		
	1943										
Southern	1938	40,523	448,740	50,579	456,041	32,291	95	997	22,200	81,000	
	1939	17,228	441,200	52,502	328,198	49,616	103	787	106,200	187,400	
	1940	27,755	569,600	41,824	257,276	47,025	79	454	151,800	230,800	
	1941	26,043	795,600	18,709	494,691	16,723	42	876	138,000	38,000	
	1942	15,281	496,800	27,000		14,546	52		115,900	112,300	
	1943	6,873	136,500	1,700		22,109	3		95,200	237,000	131,000
JEFFERSON COUNTY											
	1938			7,180			14				
	1939			15,400			31				
	1940	1,764	9,300	14,700		1,149	31		114,000		
	1941	4,624	15,100	42,800		1,959	80		192,000		
	1942			43,200			73				
	1943	14	100	13,700		31	24		500	200	2,000

Annual production of gold, silver, copper, lead, and zinc in counties and districts of the Front Range from 1938 to 1943, in terms of recovered metals—Continued

District	Year	Ore treated (short tons)	Gold			Silver			Copper (pounds)	Lead (pounds)	Zinc (pounds)
			Lode (fine ounces)	Placer		Lode (fine ounces)	Placer				
				Sluicing and hydraulic mining (fine ounces)	Dredges and draglines (fine ounces)		Sluicing and hydraulic mining (fine ounces)	Dredges and draglines (fine ounces)			
LARIMER COUNTY											
Manhattan	1940	1	500			1					
	1941	8	1,700			7					
Masonville	1938	11	2,220			34					
	1940	5	600			10					
	1941	7	1,400			14					
	1942	7	800			3					
PARK COUNTY											
Alma Placers	1938			169,590	151,750		344	318			
	1939			20,023	295,377		40	623			
	1940			10,338	190,962		20	406			
	1941			2,274	267,626		6	562			
	1942			41,300			83				
	1943			600			1				
Beaver Creek	1938			3,284	37,016		5	82			
	1939			4,843	425,157		3	900			
	1940			7,077	538,823		7	1,163			
	1941			956	330,344		2	711			
	1942			2,930	190,670		7	415			
	1943										
Buckskin	1938	608	30,440	880		993	1		150	20,400	
	1939	56	2,200	1,600		408	3		700	6,800	
	1940	6,342	111,200	1,500		6,594	3		26,400	75,000	711,000
	1941	4,676	105,900	1,500		6,584	3		21,600	81,600	614,000
	1942	5,741	144,500	200		9,696			27,800	118,200	906,600
	1943	6,203	176,200			11,676			42,000	163,000	941,900
Consolidated Montgomery	1938	5,929	27,820	3,920		29,007	8				
	1939	2,784	92,900	800		3,129	3		500	1,000	
	1940	7,352	109,300			7,972			3,700	400	
	1941	3,700	40,200	500		1,724	3		1,500	800	
	1942	885	73,500			4,306			18,400	1,800	
	1943	996	35,900			2,416			4,400	15,000	21,100
Fairplay	1938			14,534	2,166		31	5			
	1939			11,348	54,952		21	116			
	1940			17,759	98,741		37	209			
	1941			12,732	1,004,368		26	1,996			
	1942			3,944	1,381,356		9	2,729			
	1943			800			3				
Hall Valley	1939	7				50			100	1,000	
	1940	3				21				1,200	
	1941	27	100			111			900	200	
Horseshoe	1938	11	20			147				3,000	
	1940	23				114				2,000	
Mosquito	1938	123,557	3,352,620	1,760		25,887	4		54,850	814,600	
	1939	125,894	3,363,800			33,317			67,700	1,069,200	
	1940	118,331	2,673,100	400		32,680			54,900	843,400	
	1941	104,386	2,294,000			18,924			55,000	655,400	
	1942	86,658	1,500,900			9,152			32,200	423,600	5,400
	1943	60,741	629,800			7,501			21,200	222,000	161,400
Pulver	1943	113	100						400		8,600
Tarryall	1938			8,578	64,442		15	44			
	1939	12	800	8,032	64,868	22	11	45			
	1940	9	600	5,773	75,627	4	8	82			
	1941	10	1,300	2,432	503,968		3	575			
	1942				397,700			433			
SUMMIT COUNTY											
Breckenridge	1938	1,020	42,720	33,320	108,160	27,166	88	274	850	43,700	21,000
	1939	1,748	63,200	41,801	84,199	10,224	101	228	2,500	71,000	98,000
	1940	3,842	30,700	21,294	84,806	12,472	55	267	400	60,800	23,000
	1941	1,260	32,500	21,185	68,215	11,901	55	201	300	35,600	39,000
	1942	82	6,600	9,221	111,779	235	25	290	100	400	
	1943	11,469	35,500	7,400		4,244	21		16,200	472,200	461,000
Montezuma	1938	2,124	400			16,284			2,550	259,000	10,000
	1939	252	500			5,071			1,500	73,700	
	1940	915	1,100			12,524			4,700	123,800	
	1941	1,641	1,400			13,808			5,300	178,900	45,000
	1942	1,127	2,000			7,768			1,800	195,600	96,600
	1943	1,360	1,300			5,985			2,100	118,000	126,500
TELLER COUNTY											
Cripple Creek	1938	498,357	14,518,560	2,980		15,492	3				
	1939	538,138	13,396,700	3,600		17,705	3				
	1940	572,554	12,893,200			29,828					
	1941	528,641	13,347,000			21,600					
	1942	377,995	10,445,500			15,660					
	1943	226,908	4,510,500			7,543					

PHYSIOGRAPHY

Although there are many physiographic surfaces recognized in the Front Range, each marking a distinct episode in the topographic development of the mountains,[2] the most prominent features are due to the dissection of five moderately smooth erosion surfaces that stand in benchlike relation to one another—the Flattop, Green Ridge, Cheyenne Mountain, Overland Mountain, and Bergen Park surfaces. (See fig. 4.) Large parts of each of these surfaces were reduced to gently sloping plains before a quickening of erosion again deepened the valleys and began a new cycle. The development of the surfaces formed after the Bergen Park stage was interrupted before erosion appreciably affected the interstream areas. The relation of supergene ores to the different physiographic surfaces is striking (see pp. 88, 89) and lends much economic significance to a problem commonly regarded as only of academic interest.

Surfaces standing high above the general level of drainage undoubtedly weather slowly and gradually undergo degradation even though remaining as interstream areas. This slow descent has been recognized by both Ashley[3] and Fenneman,[4] who believe that Appalachian erosion surfaces have been lowered by approximately 100 feet in a million years. This figure seems excessive when used in the Front Range. In the time since Wisconsin glaciation, presumably 10,000 to 20,000 years, weathering has hardly dulled the polish on glaciated surfaces, and nowhere is there evidence of the 1 to 2 feet of complete solution and wastage that these often-quoted figures would suggest.

The degree of weathering shown by the earliest Pleistocene or late Tertiary gravels that cap some of the interstream divides in the Front Range suggests that the wasting due to weathering unaided by mechanical erosion would be better measured in inches per million years rather than in terms of a hundred feet. The writers' appraisal of the rate of wasting of the flat interstream ridges differs by at least one order of magnitude from that of Ashley and of Fenneman. It is believed that the Eocene erosion surfaces, where unchanneled by later streams, are not more than a few hundred feet below their original datum.

There is some difference in opinion among physiographers as to the age, correlation, and physiographic interpretation of the erosion surfaces of the Front Range; for views of some other students of the region the reader is referred to articles by Davis,[5] Atwood,[6] Barbour,[7] and Powers.[8]

The oldest surface, the Flattop, is almost limited to the crest of the range where numerous remnants of the mature upland surface occur between altitudes of 11,500 and 12,500 feet. (See figs. 1, 3, and 4.) It is a smoothly undulating surface, with scattered monadnocks, which rise from a few hundred to 2,000 feet above its general level. Its type locality is on Flattop Mountain a few miles north of Longs Peak, but this surface can be easily recognized on Whale Peak just north of South Park, and south of Tarryall Mountain on the eastern side of South Park. It is believed that the high shoulders on Pikes Peak at an altitude of approximately 12,000 to 13,000 feet are parts of the Flattop peneplain. This surface was formed later than the Laramide revolution, as it truncates steeply tilted beds of the Middle Park formation. Several feet of deeply weathered soil and bedrock are preserved on this surface under a Miocene (?) volcanic flow near Iceberg Lake a few miles northwest of the type locality. (See fig. 5.) Away from the flow the surface has been modified by agents of high-altitude weathering since the eruption, and no soil is present. The Flattop surface formed earlier than the Green Ridge surface, which was completed before the beginning of Oligocene time. It has tentatively been assigned, therefore, to the early Eocene.

The Green Ridge surface forms prominent benches 1,000 to 2,000 feet below the Flattop surface and is well developed just south of its type locality, Green Ridge, in the northwestern part of the Front Range. (See fig. 4.) This surface commonly ranges in altitude from 10,500 feet close to the middle of the range to 8,500 feet near the eastern edge of the mountains. It is apparently much more perfectly developed than the Flattop peneplain, and over wide areas its differences in altitude are less than 300 feet per mile. Monadnocks are not common on this surface except close to the high country in the middle of the range, where unreduced or partly reduced remnants of the Flattop peneplain rise above the general level of the Green Ridge surface. In the Laramie quadrangle, just north of the Colorado-Wyoming line, the Green Ridge surface is definitely older than the basal Oligocene Chadron sandstone. As this surface is the most perfectly developed peneplain

[2] Van Tuyl, F. M., and Lovering, T. S., Physiographic development of the Front Range: Geol. Soc. America Bull., vol. 46, no. 9, pp. 1291–1349, 1935.

[3] Ashley, J. G., Studies in Appalachian Mountain sculpture, Geol. Soc. America Bull. 46, pp. 1395–1436, 1935.

[4] Fenneman, N. M., Cyclic and noncyclic aspects of erosion, Geol. Soc. America Bull. 47, pp. 173–185, 1936.

[5] Davis, W. M., The Colorado Front Range, a study in physiographic presentation: Assoc. Am. Geographers Annals, vol. 1, pp. 21–84, 1911.

[6] Atwood, W. W., and Atwood, W. W., Jr., Working hypothesis for the physiographic history of the Rocky Mountain region: Geol. Soc. America Bull., vol. 49, pp. 957–980, 1938.

[7] Barbour, G. B., Florissant depression and its physiographic significance (abstract): Geol. Soc. America Bull., vol. 49, pp. 1865–1866, 1938.

[8] Powers, W. E., Physiographic history of the upper Arkansas River Valleys and the Royal Gorge, Colo.: Jour. Geology, vol. 43, pp. 184–199, 1935; Erosion surfaces and glacial deposits within South Park, Colo. (abstract); Geol. Soc. America Bull., vol. 50, pp. 2003–2004, 1939.

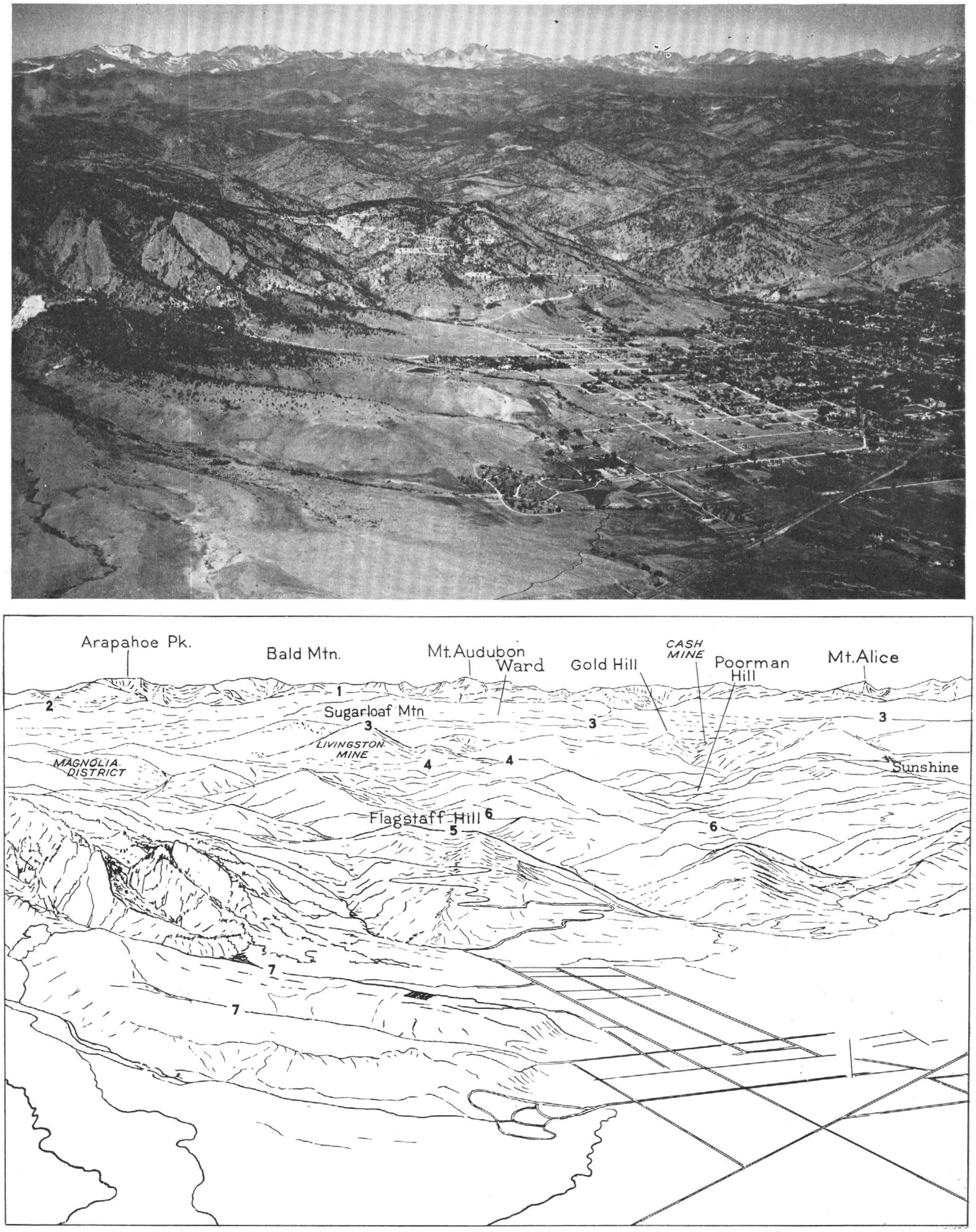


FIGURE 4.—Aerial view looking north-northwest from an altitude of 8,700 feet over a point 2 miles southeast of Boulder. Most of the erosion surfaces recognized in the Front Range are well represented. The Flattop surface (1) shows on the crest of Bald Mountain four miles east of the crest of the range; the Green Ridge surface (2) bevels Boulder County Hill in the extreme left background; the Overland Mountain surface (3) is widely developed in the middle distance on a level with the top of Sugarloaf; the Bergen Park surface (4) is represented by a somewhat dissected bench just in front of Sugarloaf; the type locality of the Flagstaff Hill berm (5) is conspicuous at the mountain front; the dissected Mount Morrison berm (6) shows on the low hills directly behind Boulder; and the Pleistocene high terraces (7) are prominent in the left foreground. Parts of several of the mining districts in the northeastern part of the mineral belt are visible, including Magnolia, Sugarloaf, Ward, Gold Hill, Poorman Hill, and Sunshine.

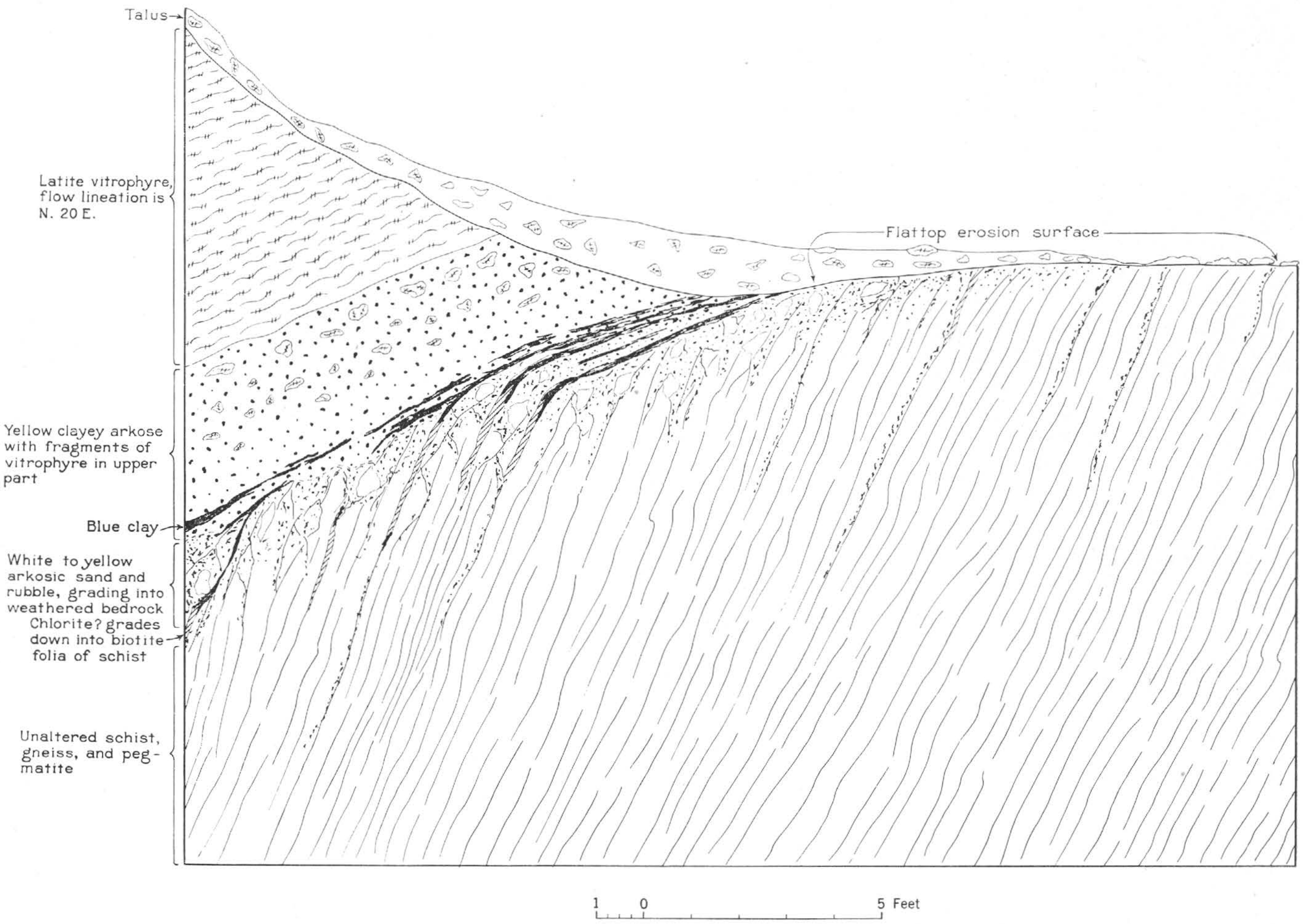


FIGURE 5.—Looking north at east contact of latite flow on Flattop erosion surface above Iceberg Lake on Trail Ridge road.

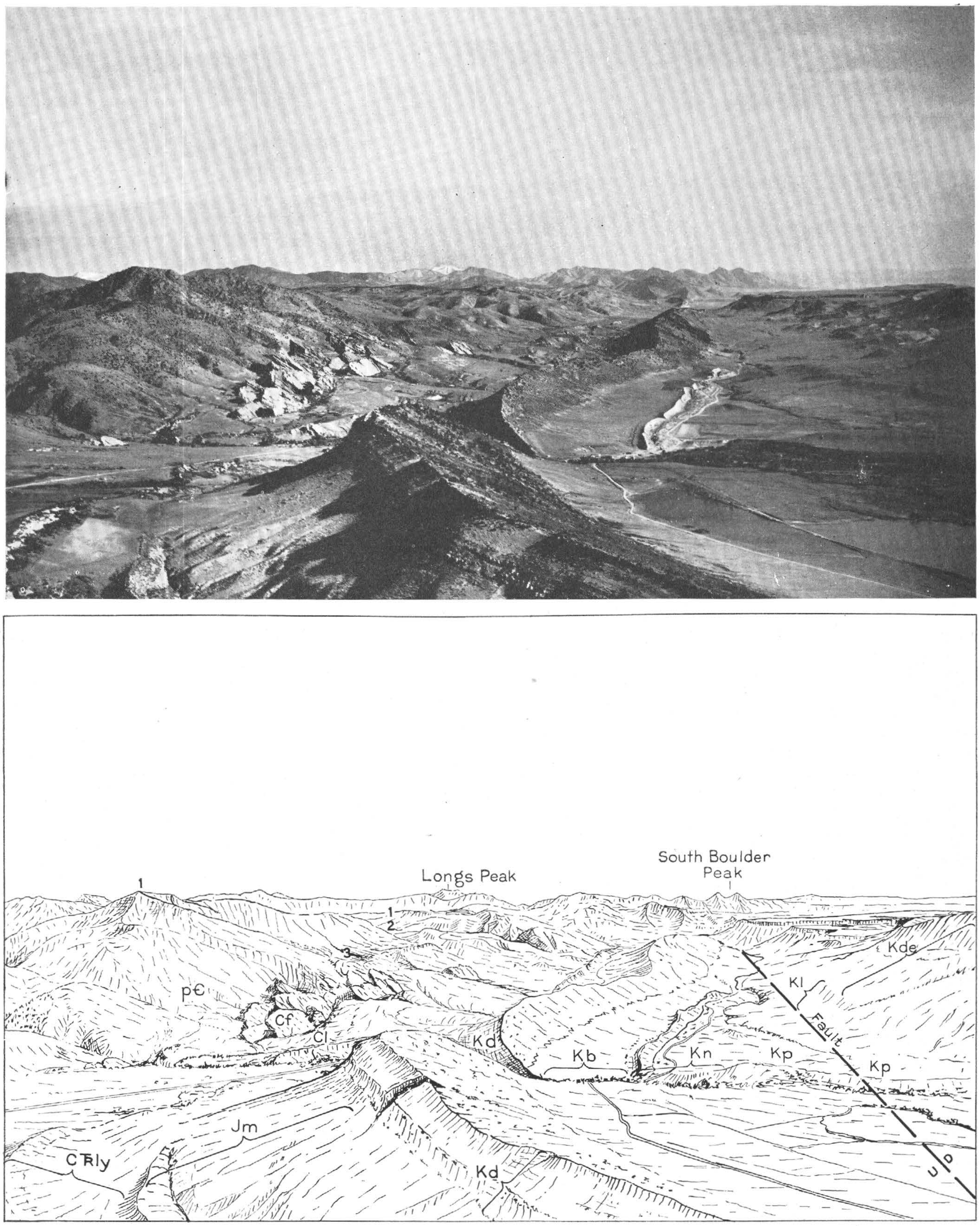
in the Front Range and is later than the Flattop peneplain but earlier than the lower Oligocene sedimentary rocks, its development is believed to have extended through most of Eocene time and to have been terminated by an uplift near the close of that epoch.

The conspicuous erosion surface north of Pikes Peak is the Cheyenne Mountain surface and may in part correspond to the Green Ridge surface in the northern part of the range, though it was probably developed in large part after the Green Ridge stage was interrupted.

The Cheyenne Mountain, Overland Mountain, and Bergen Park surfaces almost merge in the region north of Pikes Peak, and if this area is seen from a distance it presents a misleading appearance of uniformity (fig. 1), but detailed study shows that many episodes are recognizable in the sculpturing of this dissected plateau (fig. 4). The Cheyenne Mountain surface is intermediate in age and position between the Eocene Green Ridge and the Obligocene(?) Overland Mountain surface.

The Overland Mountain surface (see fig. 2), whose type locality is at Overland Mountain, about 2 miles northwest of Jamestown, appears as a broad, greatly dissected bench 5 to 15 miles wide on the eastern flank of the Front Range, where its altitude commonly ranges between 8,200 feet near the plains to about 9,000 feet near the middle of the range. Along the western slope of the Front Range the Overland Mountain surface is not conspicuous, but is best developed at altitudes between 10,000 and 10,500 feet, close to the mountain front in the west-central part of the range. The topography of the surface suggests that it had reached early maturity before it was interrupted by uplift. Differences in altitude ranging from 200 to 500 feet per mile are common, and partly reduced monadnocks of the Green Ridge or the Flattop surfaces rise in places more than 1,000 feet above the general level. On the eastern slope of the range the Overland Mountain surface is best preserved just east of the transition zone where it merges with or gives way abruptly to the older surfaces. Farther east erosion has cut valleys as much as 1,800 feet below the general level, and the surface is much more strongly dissected close to the mountain front than a few miles farther west.

The Bergen Park surface takes its name from a locality about 10 miles east of Idaho Springs, in a region where its gently undulating surface is well-preserved between altitudes of 7,500 and 7,800 feet. It is best



Kde, Denver formation; Kl, Laramie formation; Kp, Pierre shale; Kn, Niobrara formation; Kb, Benton shale; Kd, Dakota sandstone; Jm, Morrison formation; CRly, Lykins formation; Cl, Lyons sandstone; Cf, Fountain formation; pЄ, pre-Cambrian schists. 1, Bergen Park surface; 2, Flagstaff Hill berm; 3, Mount Morrison berm

FIGURE 6.—Aerial view looking north along the foothills from an altitude of 7,100 feet half a mile south of Morrison. Shows the common topographic expression of the post-Mississippian sedimentary formations and some of the younger erosion surfaces. Courtesy of Geological Society of America.

shown near the east front of the mountains (figs. 4 and 6), but it is recognizable locally as much as 15 miles to the west.

In the Laramie range of southern Wyoming, the Sherman peneplain, with which the Bergen Park surface is provisionally correlated, truncates lower Miocene strata, and its age is believed to be middle or upper Miocene.

In addition to the prominent erosional surfaces described above, the effects of several later cycles of erosion can be recognized at many places in the Front Range. Along most of the major streams remnants of a broad valley that cuts about 500 feet below the Overland Mountain surface are prominent near the mountain front. Flagstaff Hill, 2 miles southwest of Boulder, is a remnant of the surface developed during this erosion cycle and has been chosen as the type locality. (See fig. 4.) The Flagstaff Hill surface is probably of upper Miocene age.

A second series of rock benches occurs about 500 feet below the Flagstaff Hill surface along the major streams near the eastern margin of the range. These benches have been termed the Mount Morrison surface because of the prominent rock bench developed at an altitude of approximately 6,700 feet on the lower eastern slope of Mount Morrison, about 7 miles south of Golden. (See fig. 6.) At its type locality the surface truncates crystalline rocks and steeply dipping Pennsylvanian red beds. On the plains just east of the southern part of the Front Range the Mount Morrison surface underlies the gravels of the Nussbaum formation, whose age is probably Pliocene. A similar surface underlies the Pliocene Ogallalla formation in southern Colorado and northern New Mexico and is correlated with it. The age is thus probably early Pliocene.

A still lower series of accordant rock benches is prominent in the larger valleys near the eastern edge of the range and occurs at altitudes of approximately 6,000 feet in the middle part of the Front Range. The rock benches correspond to the highest of an extensive series of gravel terraces along the eastern border of the mountains. (See fig. 4.) Gravel deposits that formed during this stage of erosion are commonly coarse, of local origin, and have a fanlike structure. They suggest piedmont alluviation during an arid climatic cycle and are referred to early Pleistocene.[9]

Below the high-level fan terraces a series of three to five rock benches commonly capped by well-rounded gravels occurs on the plains (fig. 4) and along the major streams as far west as the eastern limit of glaciation. The lowest terraces are related to the outwash from two stages of Wisconsin glaciation. There is commonly a well-marked terrace intermediate between the high-level and low-level terraces, although there is no corresponding glacial till preserved in the Front Range. The writers believe that the intermediate terrace represents outwash from an otherwise unrecorded glacial stage corresponding in age to the intermediate glacial stage found in the San Juan Mountains by Atwood and Mather.[10] The gravels from the Wisconsin outwash filled the valleys of the larger streams to a depth of as much as 100 feet. In comparatively recent time the streams commenced degrading the gravel fill and cut shallow, narrow, steep-walled channels commonly less than 20 feet deep in it.

[9] Van Tuyl, F. M., and Lovering, T. S., op. cit.

GEOLOGY

As shown in plate 1, pre-Cambrian granite, gneiss, and schist make up most of the rocks exposed in the Front Range. The pre-Cambrian terrain is nearly everywhere bordered by steeply tilted Paleozoic rocks, but along the west side of the Front Range, near Breckenridge, steeply dipping Mesozoic rocks rest directly on the pre-Cambrian basement. Gently dipping Tertiary beds rest on the truncated edges of the Mesozoic and Paleozoic formations and lap onto the pre-Cambrian rocks in the northern part of the Front Range, and an extensive series of interbedded Tertiary tuffs and lavas rests upon pre-Cambrian, Paleozoic, and Mesozoic rocks in the southern part of the range. Middle Tertiary intrusive rocks are common in the southern part of the pre-Cambrian area and also in the Rocky Mountain National Park in the northwest-central part of the range. Eocene intrusive rocks are abundant in the central part of the range but uncommon elsewhere.

PRE-CAMBRIAN METAMORPHIC AND IGNEOUS ROCKS

Granite and granite gneiss are the most abundant pre-Cambrian rocks, but schists and gneisses representing much metamorphosed sedimentary rock occupy large areas. The northern and southern parts of the Front Range consist chiefly of granite, and the central part, in which most of the schist occurs, is cut by innumerable small granite masses and several stocks and small batholiths (pl. 1).

METAMORPHIC ROCKS

IDAHO SPRINGS FORMATION

The oldest rocks known in the Front Range are the schists and gneisses of the Idaho Springs formation (fig. 7, *A*, *B*), whose type locality is about 25 miles west of Denver. It consists chiefly of quartz-biotite schists and quartz-biotite-sillimanite schists, but quartzite, quartz schists, or quartz gneisses are common in

[10] Atwood, W. W., and Mather, K. F., Physiography and Quaternary geology of the San Juan Mountains, Colo.: U. S. Geol. Survey Prof. Paper 166, pp. 78–82, 1932.

some localities. A few thin lenticular beds of marble are found in the north-central part of the Front Range, and widely scattered masses of lime-silicates intergrown with garnet and magnetite suggest the metamorphism of limy beds in the central part of the range. The comparatively simple types of schist mentioned above are most abundant in regions that escaped the severe metamorphism that accompanied the intrusion of large granite masses. In many places extremely fluid granite magma developed injection gneiss on a large scale, and some parts of the Idaho Springs formation have been so thoroughly soaked with granitic material that they now resemble a primary granite gneiss. The Idaho Springs formation represents metamorphosed shaly sediment of unknown thickness. Although these rocks have been very closely folded and commonly contain thoroughly granulated feldspar and quartz grains (fig. 7, *C*, *D*), their original bedding planes are in most places parallel to the foliation.

Quartzite or quartz schist occurs in several localities and is common along the eastern margin of the mountains near the Big Thompson River, Turkey Creek, and in the Pikes Peak quadrangle. It was considered younger than the Idaho springs formation by earlier writers,[11] but the work of Fuller [12] and of Lovering [13] shows that the foliation and the bedding of the quartzite parallels the foliation of the supposedly much older mica schists of the Idaho Springs formation and that a perfect gradation exists between them. Quartzitic and limy members are common in the upper part of the formation in the transition zone between the sedimentary Idaho Springs formation and the overlying dominantly igneous Swandyke hornblende gneiss.

The full thickness of the Idaho Springs formation is unknown, and even its exposed thickness can be estimated only approximately because of the intricate folding that is present. The increase in apparent thickness due to crenulations and drag folding may more than double the actual thickness and commonly increases it by at least a third. The innumerable granitic seams present added appreciably to its volume during metamorphism, but this increase may have been compensated in large part by the shrinkage in the original sediment as its density became greater with the development of metamorphic minerals. In the vicinity of Geneva Creek a few miles east of Swandyke, where one of the thickest sections of metamorphic rocks in the Front Range is exposed, the Idaho Springs formation lying below the Swandyke hornblende gneiss has an exposed apparent thickness of about 20,000 feet, suggesting that the actual thickness is in excess of 15,000 feet.

[11] Van Hise, C. R., and Leith, C. K., Pre-Cambrian geology of North America: U. S. Geol. Survey Bull. 360, 1909. Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Pikes Peak folio (no. 7), 1894.

[12] Fuller, M. B., General features of the pre-Cambrian structure along the Big Thompson River in Colorado: Jour. Geology, vol. 32, no. 1, pp. 49–63, 1924.

[13] Lovering, T. S., Geologic history of the Front Range, Colo.: Colorado Sci. Soc. Proc., vol. 12, pp. 59–111, 1929.

SWANDYKE HORNBLENDE GNEISS

In its type locality at Swandyke, about 10 miles east of Breckenridge, the Swandyke hornblende gneiss consists chiefly of hornblende schist and hornblende gneiss interlayered with thin beds of quartz-biotite schist. (See fig. 8, *A*, *B*.) It shows the same degree of metamorphism as the Idaho Springs formation. Granulation of the feldspars is usual, the quartz grains are generally found crushed, and lit-par-lit intrusions of later aplite and pegmatite have converted large masses into an injection gneiss indistinguishable from that of the Idaho Springs formation. In most places the Swandyke hornblende gneiss consists of alternate layers of light-gray and dark-gray gneiss whose color reflects the varying amounts of hornblende contained in them. The abundance of hornblende, biotite, and labradorite and the presence of moderate amounts of quartz and magnetite suggest that much of the Swandyke hornblende gneiss represents metamorphosed quartz diorite. Its contacts are commonly parallel to the bedding and foliation of the Idaho Springs formation, and it probably originated in the form of sills in that formation or perhaps as flows, largely before the regional schistosity was developed. Although dikes of hornblende gneiss cut across the earlier formation at a few places, there is no direct evidence that any large part of the hornblende gneiss is intrusive. It is probable that parts of the Swandyke hornblende gneiss represent surface flows, for although no structures such as ellipsoidal or pillow structure have been found in the mineral belt, Leith [14] describes such structures from this formation near Tin Cup Pass about 15 miles west of Buena Vista. In some places, as on the Bergen Park-Echo Lake road southwest of Idaho Springs, the Swandyke hornblende gneiss locally is very calcic and grades into lenses of coarse calcite. Thin beds of quartzite and quartz-biotite schist are common in the calcic zones, and in a few places magnetite jaspilite is present. It is believed that these variants represent thin clastic and hot-springs deposits interlayered with dominantly volcanic material.

The thickness of the Swandyke hornblende gneiss at the type locality is approximately 6,000 feet. The lithologic character and structural relations indicate that the dioritic intrusives and related extrusives and the intercalated sediments were in part contemporaneous with and in part younger than the upper part of the Idaho Springs formation. The general distribution of the Idaho Springs formation and the Swandyke hornblende gneiss is shown on plates 1 and 2.

[14] Van Hise, C. R., and Leith, C. K., op. cit., p. 817.

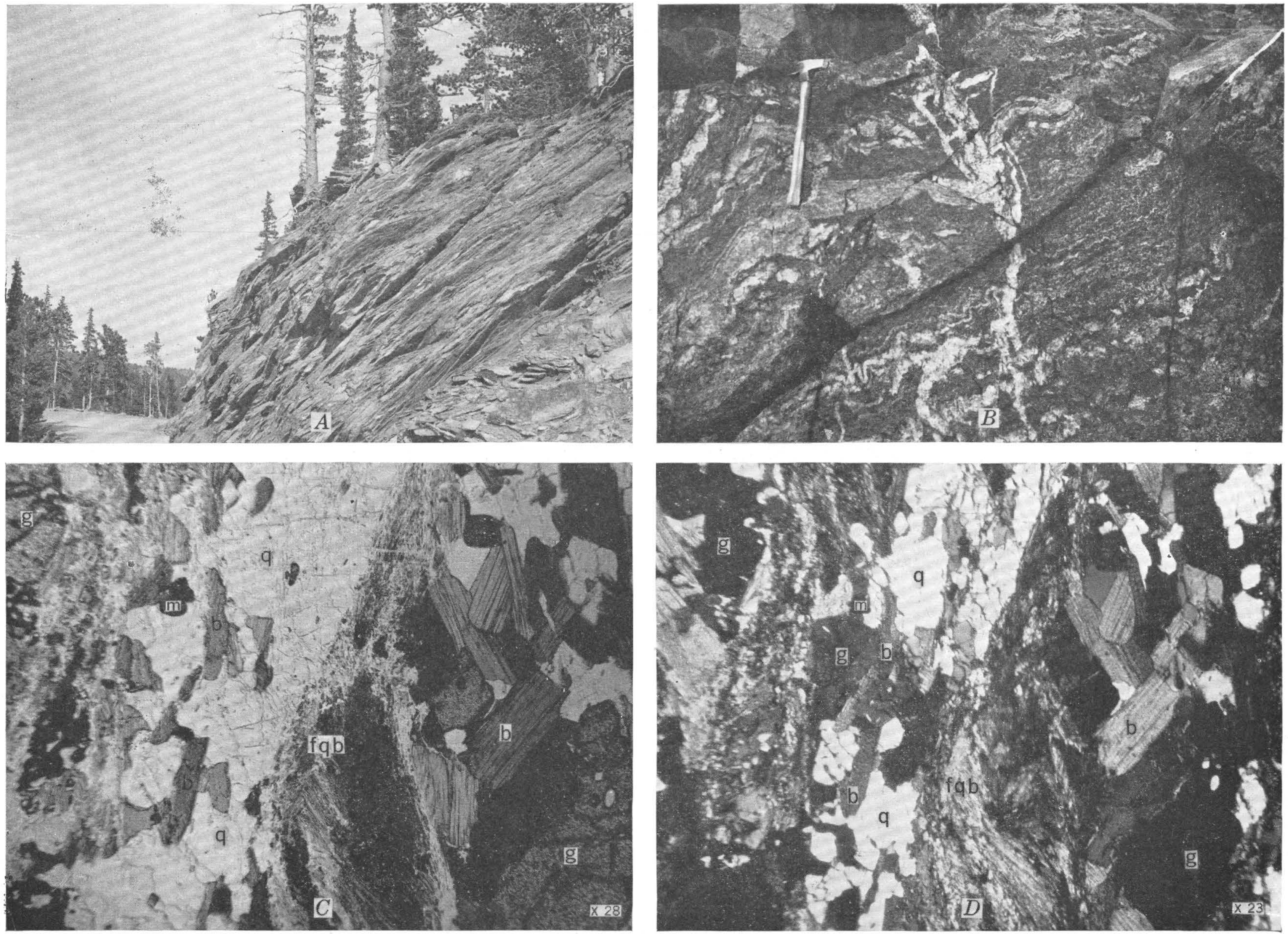


FIGURE 7.—*A*, Typical exposure of relatively unfolded Idaho Springs formation 3½ miles south of Idaho Springs on road to Echo Lake. *B*, Crenulated quartz-biotite-sillimanite schist of the Idaho Springs formation, with characteristic seams of white pegmatite. Near the crest of a large anticline on the northeast shoulder of Grays Peak at an altitude of 13,500 feet. *C*, Photomicrograph of quartz-biotite schist from Idaho Springs formation at Nederland. Original bedding (nearly vertical in photograph) is intersected by shear planes sloping down to right at about 45°, and these shears are cut by later shears sloping to left at 60°. *b*, Biotite; *g*, garnet; *m*, magnetite; *q*, quartz; *fqb*, crushed feldspar, quartz, and biotite. Plain light. *D*, Same as *C*. Polarized light.

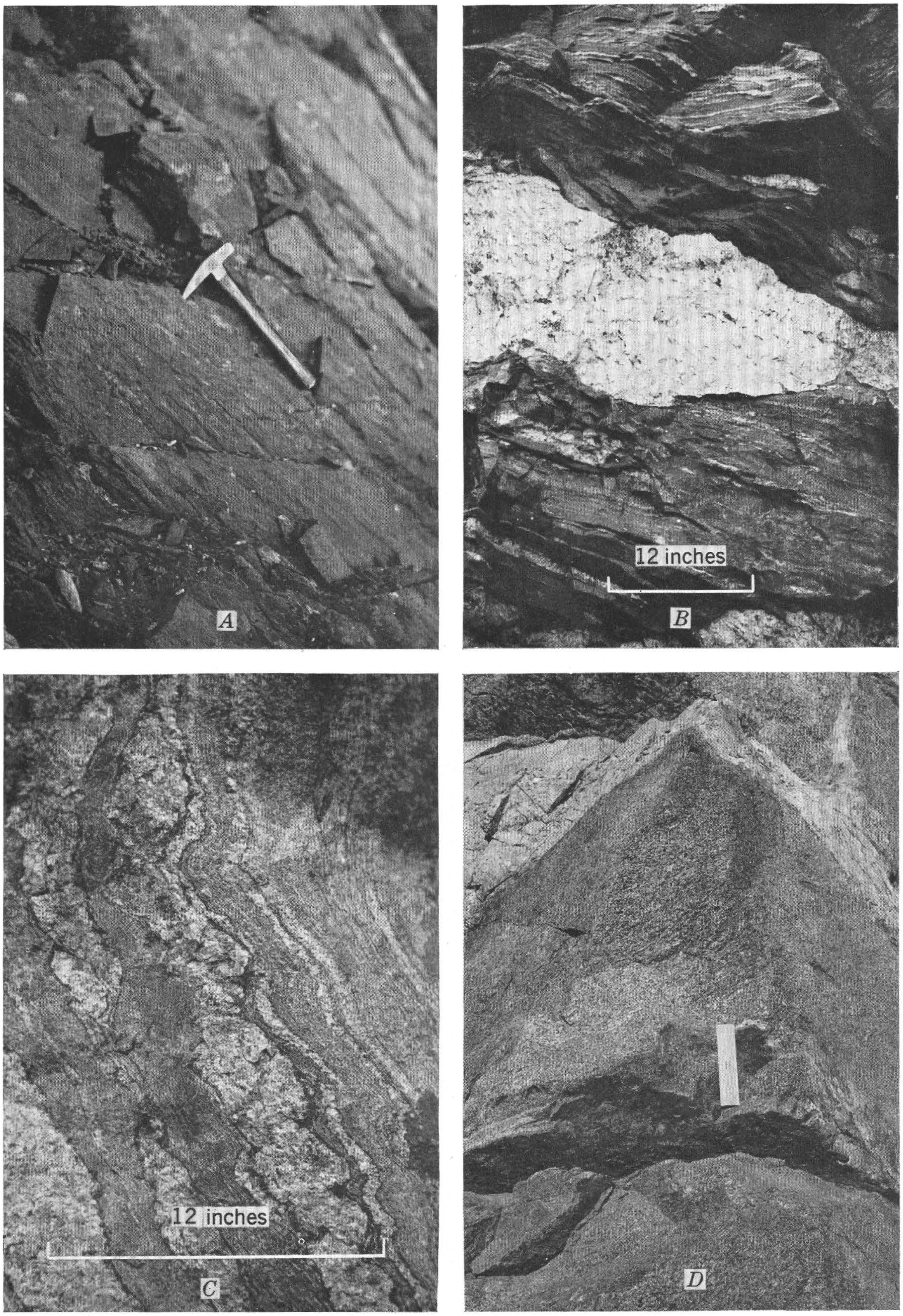


FIGURE 8.

QUARTZITE AT COAL CREEK

Near the mouth of Coal Creek there is a series of quartzites and conglomerates at least 14,000 feet thick, which is unlike any member of the Idaho Springs formation. The age and structure of these rocks has long been a subject of controversy. Some geologists [15] believe the quartzites to be older than most of the Idaho Springs formation, but the studies of the present writers have led them to concur with the geologists who believe the quartzites to be younger. As shown on the map of the mineral belt (pl. 2), the structure of the mass is that of an east-northeasterly syncline intruded by the Boulder Creek granite on the north and separated from the Idaho Springs and Swandyke hornblende gneiss formations to the south by a zone of strongly sheared Boulder Creek granite. The schist members show a lower grade of metamorphism than do the formations to the south, and the structure of the southeast side of the trough suggests drag by the downwarping of the syncline along an early fault. Taken together, these facts seem to indicate a younger age than that of the formations to the south. The quartzite at Coal Creek may be a remnant of a younger series of quartzites, slates, and schists corresponding in age to the Needle Mountains group of the San Juan Mountains, but it cannot be younger than middle pre-Cambrian. Faulting prior to the intrusion of the Boulder Creek granite may have caused some repetition of beds in the Coal Creek area, but, with due allowance for this possibility, the structure indicates a minimum thickness of 14,000 feet for this formation.

IGNEOUS ROCKS

An extensive series of granitic intrusives cuts the Swandyke hornblende gneiss and the Idaho Springs formation and is also younger than the quartzite at Coal Creek. The time intervals between the intrusions of the members of this series is unrecorded by any evidence of sedimentation in the Front Range, and in spite of some marked differences most of the intrusives are so related structurally and petrographically that they seem to belong to one great period of batholithic invasion. The most common and distinctive members of this series are described below.

[15] Adler, J. L., Geologic relations of the Coal Creek quartzite in Colorado. Unpublished thesis, University of Chicago, Chicago, Ill., 1930.

QUARTZ MONZONITE GNEISS

Aside from the very early pegmatites and aplites common in the Idaho Springs formation, the oldest igneous rock known to be later than the Swandyke hornblende gneiss and the Idaho Springs formation is the quartz monzonite gneiss of the Georgetown quadrangle.[16] It is a medium-grained, slightly porphyritic gray gneiss, whose composition ranges from quartz diorite to quartz monzonite. The gneissic structure is nearly everywhere well-developed and is marked by the parallel elongation and orientation of biotite, the slight mashing and elongation of the feldspars and quartz, and the alternating bands of biotite or hornblende and of quartz and feldspar (fig. 8, *C*). Hornblende is much less abundant than biotite but is not uncommon, and locally in the more massive varieties of the gneiss augite is present. Closely associated with the quartz monzonite gneiss in many places are lenticular bodies of gneissic quartz-orthoclase pegmatite and strongly foliated moderately fine grained gray granite gneiss. These rocks probably represent pegmatites and aplites derived from the quartz monzonite gneiss magma. The abundance of dark minerals and the pronounced gneissic structure set the quartz monzonite gneiss apart from the gneissic aplite and granite gneiss described below, but its aplitic facies are not easily distinguished from them. The smaller size of the biotites and the greater proportion of feldspar and quartz distinguished it from the strongly gneissic varieties of the Boulder Creek granite.

The intense lit-par-lit injection of inclusions of schist and hornblende gneiss by the quartz monzonite gneiss and the gradational borders between invading and invaded rocks suggest that assimilation played a part in the formation of the gneiss. Although some of the gneissic structure seems primary, marked granulation of both quartz and feldspars shows that the original structure was modified or intensified by shearing after the rock had become solid. No large bodies of quartz monzonite gneiss have been found in the Front Range, but small stocks are common near large masses of either the Pikes Peak granite or Boulder Creek granite. In these occurrences it is probably an early facies of the magma that formed the Boulder Creek

[16] Spurr, J. E., Garrey, G. H., and Ball, S. H., Economic geology of the Georgetown quadrangle, Colo.: U. S. Geol. Survey Prof. Paper 63, pp. 46–49, 1908.

EXPLANATION OF FIGURE 8

A, Typical Swandyke hornblende gneiss. Shows strike and dip of the foliation and pitch of the linear structure in the plane of foliation. The handle of the hammer indicates the linear structure pitching to the right at about 60°. Headwaters of the North Fork of Swan River 2 miles southwest of Montezuma.

B, Swandyke hornblende gneiss cut by a dike of pegmatite. Floyd Hill, 3½ miles east of Idaho Springs.

C, Quartz monzonite gneiss. The wavy light and dark bands of pegmatite and biotite-rich gneiss are characteristic of this rock. On Beaver Brook, 5½ miles southeast of Idaho Springs.

D, Boulder Creek granite half a mile north of North Boulder Creek on the Ward-Nederland road. The coarse grain and slightly gneissic texture characteristic of this dark gray granite are easily discernible. A "ghost" of schist lies about a foot below the 6-inch scale, and a dike of pegmatite cuts the granite about 2 feet above the scale.

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FIGURE 9.—*A*, Granite gneiss (gneissic aplite) in the Idaho Springs formation, seven-tenths of a mile north of Nederland. The seam of gneissic aplite which represents the granite gneiss formation underlies the scale and is bordered by a thin seam of pegmatite. The dark-colored strongly foliated schist with which the gneiss is interlayered is its common constituent. *B*, Gneissic hornblende diorite half a mile north of Nederland, near the center of a mass about 100 feet wide. The coarse-grained and slightly foliated structure of this outcrop is characteristic of the formation. *C*, Pikes Peak granite on the northeastern slope of Bison Peak about 12 miles southeast of Kenosha Pass. The primary gneissic structure developed in the coarse-grained Pikes Peak granite near the edge of the batholith shows well in this photograph. *D*, Typical coarse-grained Pikes Peak granite on the summit of Bison Peak. The rapid weathering of the granite along joints is shown in this view. This weathering gives rise to residual and balanced boulders characteristic of the areas where the Pikes Peak granite has been long exposed to mechanical and chemical weathering. The figure of the man in the circle gives the scale.

granite and the "Archean quartz monzonite" of the Georgetown quadrangle. Small lenticular masses of the gneiss are common in the Swandyke hornblende gneiss in many places. It is probable that they are older than the stocks of quartz monzonite gneiss and may be genetically related to the hornblende gneiss. It seems probable that the early injection gneiss of the Idaho Springs formation was formed in large part by the lit-par-lit injection of material from the quartz monzonite gneiss and granite gneiss magmas.

GRANITE GNEISS AND GNEISSIC APLITE

A fine-grained aplitic rock occurs abundantly in dikes and irregular bodies throughout the larger bodies of Boulder Creek granite. It is especially common at the borders of such masses and in the schists and metamorphic rocks nearby (fig. 9, *A*). It is a moderately fine grained distinctly gneissic rock containing much quartz and moderate amounts of orthoclase, microcline, and sodic plagioclase with minor amounts of biotite. The mode of occurrence of this gneissic aplite indicates a close genetic relation to the magma from which the Boulder Creek granite was derived, although no such relationship would be suspected where it occurs in separate bodies in the metamorphic rocks. In the Georgetown quadrangle, rocks that are indistinguishable from the gneissic aplite in most exposures were described as gneissoid granite by Ball [17] and were regarded by him as earlier than the Boulder Creek granite. The same formation was mapped as gneiss in the Central City quadrangle by Bastin.[18]

Unlike the quartz monzonite gneiss, most of the gneissic aplite or granite gneiss is rather fine grained, but at many places it grades into coarse-grained facies. Its texture suggests that it is mainly a metamorphosed aplite or pegmatite. In places the feldspars and quartz grains are granulated (fig. 10, *A*), but they do not commonly show the degree of metamorphism that is shown by the quartz monzonite gneiss. Dark minerals are not common in the gneissic aplite and its mineralogic character suggests its development from an alaskitic aplite magma. Dark minerals are somewhat more abundant in the granite gneiss. In most localities the gneissic aplite and granite gneiss are believed to be contemporaneous with the Boulder Creek granite, but some of the more highly foliated masses of granite gneiss are earlier and are probably related to the quartz monzonite gneiss. Thus it is apparent that the rocks mapped as gneissic aplite and granite gneiss are a lithologic unit but not an age group; they are believed to be indistinguishable minor members, similar in relationship, genetically associated with different major members of the batholithic complex.

Like the quartz monzonite gneiss, the granite gneiss and gneissic aplite are nearly everywhere parallel to the foliation of the metamorphic rocks.

QUARTZ DIORITE AND ASSOCIATED HORNBLENDITE

A quartz diorite is closely associated with some pegmatite and gneissic aplite in both time and place. Composite dikes formed by the interlacing of the three types of rock are common. Although individual dikes of the quartz diorite may be short, they commonly occur in linear zones that persist for a mile or more. The characteristic appearance of the coarse-grained somewhat gneissic, slightly weathered hornblende-quartz diorite is shown on figure 9, *B*. It is a medium-grained to coarse-grained unevenly granular rock containing prominent hornblende crystals set in a medium-grained matrix of gray feldspar. (See fig. 10, *B*.) Locally some quartz is visible, and biotite is not uncommon. In narrow dikes and near the edge of larger intrusive masses the rock commonly grades into gneissic hornblende diorite or even into hornblende schist. Another facies of this rock, occurring chiefly in small dikes, is composed almost entirely of hornblende and is therefore termed hornblendite.

The quartz diorite is approximately contemporaneous with the Boulder Creek granite, and its areal relation suggests that it and the gneissic aplite are complementary dike rocks related to the Boulder Creek granite magma. These rocks are much more common at the borders of the Boulder Creek granite stocks and in the metamorphic rocks nearby than elsewhere.

It is probable that much of the pre-Cambrian mineralization discussed on pages 67 and 68 is related to hornblendic diorite and gabbro, which have similar age relations to those of the quartz diorite and probably belong to this general group.

BOULDER CREEK GRANITE

The Boulder Creek granite ("Archean quartz monzonite" of the Georgetown quadrangle) [19] is commonly a dark-gray faintly banded rock that ranges in composition from a quartz monzonite to a sodic granite. Most of it is a coarse-grained primary gneiss, which is locally porphyritic; its platy structure is due chiefly to parallel crystals and schlieren of biotite and to a less extent to the parallel elongation of feldspar crystals (figs. 8, *D*, and 10, *C*). Near the centers of large masses the gneissic structure is not prominent, and rarely the color of the rock changes to pinkish-gray or pink, becoming indistinguishable from facies of the Pikes Peak granite. The gneissic structure, however, is nearly

[17] Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., pp. 49–51.

[18] Bastin, E. S., and Hill, J. M., Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colo.: U. S. Geol. Survey Prof. Paper 94, pp. 30–33, 1917.

[19] Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., pp. 51–54.

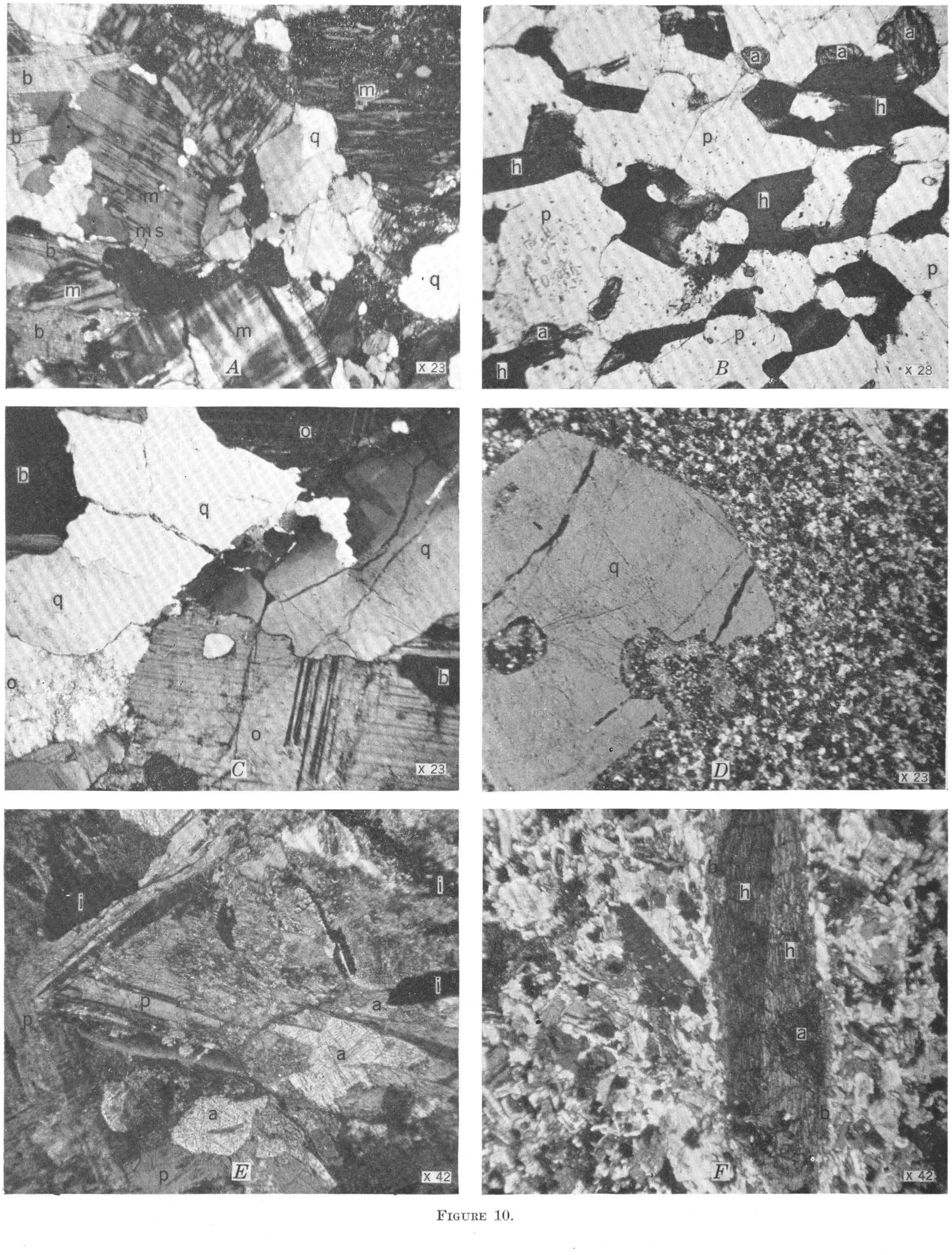
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FIGURE 10.

everywhere easily discernible; close to the borders of the masses it is so pronounced that locally the rock grades into a biotite-rich quartz monzonite gneiss. It is strongly crushed or granulated only in small bodies enclosed by schist adjacent to batholiths or large stocks. The larger masses exhibit less metamorphism than the granite gneiss bodies with which they are nearly contemporaneous. (Compare fig. 10, *A*, and *C*.) Locally inclusions of the older formations are abundant in the Boulder Creek granite, but rarely do they show much evidence of assimilation.

The Boulder Creek granite forms stocks and small batholiths whose regional distribution is satellitic to the larger batholiths of Pikes Peak granite. The best-known masses of Boulder Creek granite in the Front Range occur in the Georgetown quadrangle south of Idaho Springs and in the region west of Boulder extending north from Coal Creek to Lefthand Creek (pls. 1 and 2). If the gneissic structure is inferred to be primary and thus parallel to the walls of the magmatic chamber, the shapes inferred from a study of the platy and linear structures in the stock near Jamestown and the batholith west of Boulder are those, respectively, of an ethmolith or funnel-shaped intrusive and a chonolith or intrusive of wholly irregular form.

Chemical composition of the granites of the Front Range

Specimen	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O-	H_2O	TiO_2	CO_2
1. Boulder Creek granite from the fifth level of the Cold Spring mine close to the new shaft, about 3 miles northeast of Nederland	68.71	14.93	1.02	2.07	1.50	2.01	2.85	5.14	0.14	0.56	0.62	0.46
2. Local syenitic facies of the Pikes Peak granite, Ajax mine, level 6. Believed to be related to gneissic aplite.[1]	66.20	14.33	2.09	1.93	.89	1.39	2.58	7.31	.48	.83	.65	.36
3. Gneissic aplite near the breast of the Lilly tunnel, Clyde mine, about 2 miles north-northeast of Nederland	66.31	15.07	1.35	2.71	1.03	2.06	2.48	5.96	0.06	0.90	0.66	0.98
4. Pikes Peak granite from Sentinel Point, Pikes Peak, Colo.[2]	77.03	12.00	.76	.86	.04	.80	3.21	4.92	.14	.30	.13	----
5. Pikes Peak granite from Platte Canyon, Jefferson County, Colo.[2]	77.02	11.63	.32	1.09	.14	1.24	2.85	5.21	----	.35	----	----
6. Silver Plume granite, Silver Plume, Colo.[3]	67.38	15.22	1.49	2.58	1.12	2.12	2.73	5.41	.01	.39	.70	.18
7. Fresh pre-Cambrian Silver Plume granite from the Climax district, Colo.[4]	70.83	14.41	.35	2.94	.56	.64	2.44	6.21	.04	1.34	.24	----
8. Longs Peak granite, Longs Peak, Colorado.[3]	71.14	16.00	.00	.80	.13	.94	5.13	3.74	.09	.50	.17	.03
9. Longs peak granite from Sta. 191 South St. Vrain Highway [3]	70.85	15.14	.65	1.57	.64	.71	2.44	6.09	.06	.77	.31	.21
10. Mount Olympus granite, Glen Comfort [3]	71.40	16.34	.15	1.71	.31	1.40	4.59	3.24	.11	.22	.36	.09
Average of 4 and 5	77.02	11.81	.54	.97	.09	1.02	3.03	5.06	.07	.32	.06	----
Average of 6, 7, 8, 9, and 10	70.32	17.42	.53	1.92	.55	1.16	3.47	4.49	.06	.64	.36	.10

Specimen	P_2O_5	SO_3	S (total)	ZrO_2	Cl	F	FeS_2	MnO	BaO	SrO	Li O	
1. Boulder Creek granite from the fifth level of the Cold Spring mine close to the new shaft, about 3 miles northeast of Nederland	0.16	----	Tr?	----	----	----	----	----	----	----	----	100.17
2. Local syenitic facies of the Pikes Peak granite, Ajax mine, level 6. Believed to be related to gneissic aplite.[1]	.25	0	----	0.02	Tr.	(?)	0.12	0.13	0.18	Tr.	Tr.	99.74
3. Gneissic aplite near the breast of the Lilly tunnel, Clyde mine, about 2 miles north-northeast of Nederland	0.32	----	0.04	----	----	----	----	----	----	----	----	99.93
4. Pikes Peak granite from Sentinel Point, Pikes Peak, Colo.[2]	Tr.	----	----	----	----	0.36	----	Tr.	Tr.	----	Tr.	100.55
5. Pikes Peak granite from Platte Canyon, Jefferson County, Colo.[2]	----	----	----	----	----	----	----	----	----	----	----	99.85
6. Silver Plume granite, Silver Plume, Colo.[3]	.32	----	.06	----	----	----	----	.04	.14	----	----	99.82
7. Fresh pre-Cambrian Silver Plume granite from the Climax district, Colo.[4]	.15	----	.01	----	0.04	----	----	----	.02	----	----	100.22
8. Longs Peak granite, Longs Peak, Colorado [3]	.19	----	----	----	----	----	----	.01	----	----	----	98.90
9. Longs peak granite from Sta. 191 South St. Vrain Highway [3]	.30	----	----	----	----	----	----	.02	.06	----	----	99.98
10. Mount Olympus granite, Glen Comfort [3]	.36	----	----	----	----	----	----	.02	----	----	----	100.30
Average of 4 and 5	Tr.	----	----	----	----	.25	----	Tr.	Tr.	----	Tr.	----
Average of 6, 7, 8, 9, and 10	.26	----	.03	----	.01	----	----	.02	.04	----	----	----

[1] Geology and gold deposits of the Cripple Creek district, Colo.: U. S. Geol. Survey Prof. Paper 54, p. 45, 1906.
[2] U. S. Geol. Survey, Geol. Atlas, Castle Rock folio (No. 198), p. 3, 1915.
[3] Geol. Soc. America Bull., vol. 45, p. 320, 1934.
[4] U. S. Geol. Survey Bull. 846-C, p. 225, 1933.

NOTE.—Analyses 1, 3, and 7, by J. G. Fairchild; 2 and 4, by W. F. Hillebrand; 5, by H. N. Stokes; 6, by R. B. Ellestad; 8 and 10, by D. F. Higgins; 9, by T. Kameda.

EXPLANATION OF FIGURE 10

A, Photomicrograph of granite gneiss (gneissic aplite) from a dike in Boulder Creek granite near Cold Spring mine, Nederland. Primary gneissic structure as shown by elongation of biotite is nearly horizontal in picture. Slight secondary granulation is indicated by incipient mortar structure developed at edge of microcline crystals (*ms*). *b*, Biotite; *m*, microcline-perthite; *q*, quartz. Polarized light.

B, Photomicrograph of gneissic hornblende diorite half a mile northwest of Nederland. Primary gneissic structure nearly horizontal in photograph. *p*, Plagioclase (andesine); *a*, augite; *h*, hornblende. Plain light.

C, Photomicrograph of Boulder Creek granite from ridge half a mile east of junction of Middle Boulder and North Boulder Creeks. Primary gneissic structure indicated by quartz-oligoclase contact and by biotite is nearly horizontal in photograph. Slight secondary shearing shown by undulatory extinction of quartz in upper right. *b*, Biotite; *o*, oligoclase; *q*, quartz. Polarized light.

D, Photomicrograph of "white porphyry" of group 1 (fig. 12) from Leadville. Corroded phenocrysts of quartz (*q*) in fine-grained sericitized groundmass of orthoclase, quartz, and plagioclase (oligoclase).

E, Photomicrograph of diabase from dike on Hager Mountain northwest of Loveland Pass, representative of the diabasic dike rocks of group 2 (fig. 12). *a*, Augite; *i*, iron ore (ilmenite); *p*, plagioclase (labradorite). Polarized light.

F, Photomicrograph of porphyritic hornblende diorite of group 4 (fig. 12) from Swan River 2 miles south of Tiger, showing normal reaction series. Core of augite (*a*) bordered by hornblende (*h*), which in turn is completely rimmed by biotite (*b*). Crossed nicols.

PIKES PEAK GRANITE

The largest batholiths in the Front Range, such as the Pikes Peak granite and the Sherman granite, consist of coarse-grained, granular or porphyritic pink granite composed largely of microcline, orthoclase, quartz, and moderate amounts of biotite. Typical coarse-grained Pikes Peak granite is very uniform in composition (see analyses for specimens 4 and 5 in the preceding table) but local variants of this granite range from sodic granite verging on quartz monzonite to moderately potassic granite containing small quantities of oligoclase. The potassic granite resembles somewhat certain varieties of the later Silver Plume granite but is coarser-grained, and its biotite is more commonly alined parallel to the flow structure than is that in the Silver Plume granite. (See fig. 9, *C*.) Porphyritic facies of the Pikes Peak granite occur locally but are uncommon. The typical pink Pikes Peak granite contrasts strongly with the older gray Boulder Creek granite, but gradations from one rock into the other occur at some places. In small stocks, such as those present in the mineral belt, a primary gneissic structure parallel to the edges of the enclosing rock is evident and suggests the characteristic texture of the Silver Plume granite, from which it is easily distinguished by its much coarser grain. Such a texture is confined to the borders of comparatively small stocks.

The coarse, granular texture of the Pikes Peak granite makes it an easy prey to the agents of weathering, and on ancient erosion surfaces, where it has been long exposed to the elements, balanced residual boulders and grotesque erosion forms are characteristic of areas of this granite. (See fig. 9, *D*.) Such forms are rare or lacking in the Boulder Creek and Silver Plume granite terrains.

Pegmatites are not common within the Pikes Peak granite batholith but are moderately abundant near the edge and in the bordering schists. Beryl, topaz, fluorite, and other minerals of economic interest have been found in many of the pegmatites genetically related to the Pikes Peak granite. Samarskite, found at Devil's Head and almost certainly derived from a pegmatite genetically related to the Pikes Peak granite, was analyzed for its lead, uranium, and thorium content, and the ratio of lead to uranium and thorium indicated that it was formed approximately 1,000,000,000 years ago.[20] A comparison with lead-uranium ratios of rocks whose geologic ages are known suggests that the material analyzed corresponds with the late middle pre-Cambrian.[21]

Most of the southern half of the Front Range consists of Pikes Peak granite and is part of the largest single mass of granite at present known in Colorado. It is approximately 75 miles long from north to south and 30 miles long from east to west. Other moderately large batholiths of Pikes Peak granite are found in central Colorado west of the Front Range, and a few small batholiths or large stocks of it occur in the central part of the Front Range. The southern part of the Sherman granite batholith, which extends far north into Wyoming, crops out in the northern part of the Front Range. The lithologic features of the Pikes Peak granite and the Sherman granite and their relations to the older pre-Cambrian gneisses and schists are similar and suggest that they may be correlated.

SILVER PLUME GRANITE

In the Front Range there is a large number of comparatively small batholiths and stocks of pre-Cambrian granite later than the Pikes Peak and Sherman granites. Although the various stocks and small batholiths were not intruded simultaneously, their lithologic character, structural habit, and age relations indicate that they have the same general age. For purposes of description these granites are grouped together and regarded as variants of the last granite magma of a batholithic cycle. The Silver Plume granite is typical of them.

Most of the Silver Plume granite is a pinkish gray, medium-grained slightly porphyritic biotite granite, composed chiefly of pink and gray feldspars, smoky quartz, and biotite, but muscovite is present in some facies, and the percentage of biotite varies from place to place. Small masses of slightly more calcic granites are found in positions satellitic to the typical Silver Plume granite. The Mount Olympus granite of the Boulder and Loveland quadrangles represents this group. It is finer-grained than the Silver Plume, lacks the oriented feldspars, but locally contains small parallel biotite flakes. Differences in color in the late pre-Cambrian granites reflect different percentages of mineral constituents; some facies appear to be distinctly different formations, but gradations into typical Silver Plume granite can be found in nearly all of them. Although the size of crystals in the large masses of granite commonly range between a quarter of a centimeter and 1 centimeter, porphyritic facies containing crystals 2 centimeters in length occur locally. A conspicuous feature of the Silver Plume granite is the general parallelism of the tabular lathlike feldspar crystals (fig. 11, *A*). This flow orientation is practically limited to the feldspars, as the biotite and muscovite rarely show any parallelism. It is most pronounced in dikes and near the borders of stocks and is commonly parallel to the nearest wall of the intrusive mass. These late pre-Cambrian granites have a marked tendency to follow faults and cross fractures in schist and gneiss in con-

[20] Knopf, Adolph, and others, Physics of the earth, vol. 4. Age of the Earth: Nat. Research Council Bull., no. 90, p. 338, 1931.

[21] Idem., pp. 438–441.

trast to the concordant habit of the older intrusives. It is worthy of note that most of the granite batholiths of the Silver Plume were intruded in synclines in the schists but they themselves do not follow the foliation of the schists except locally.

As shown on plate 1, stocks and batholiths of Silver Plume granite are widely distributed in the Front Range, and most of the granite in the region between the Cache la Poudre River and Clear Creek belong to this late group. As used in this report, the Cripple Creek granite of the Pikes Peak quadrangle and the Longs Peak and Mount Olympus granites of the Estes Park region are included in the Silver Plume granite.

PEGMATITES AND APLITES

The pegmatites of the rocks earlier than the Boulder Creek granite were commonly injected along foliation planes in gneiss and schist and along joints, faults, and earlier intrusive contacts; they were responsible for much of the lit-par-lit injection of the metamorphic rocks. The later pegmatites cut across the foliation as commonly as they follow it.

As noted by Ball, the mineral composition of most of the pegmatites is closely related to that of their country rock. Most of the pegmatites contain biotite but little or no muscovite where they cut granite masses but contain muscovite and no biotite where their walls are schist. The tourmaline-bearing and sillimanite-bearing pegmatites occur in quartz-tourmaline-sillimanite schists. In the Georgetown quadrangle pegmatites containing allanite are restricted to the rocks of the Boulder Creek granite group. Pegmatites found in the hornblende gneisses and schists of the Swandyke hornbende gneiss contain much biotite and some hornblende, but muscovite has not been noted as a primary mineral in them. Where persistent dikes of pegmatite cross the contact of such dissimilar rocks as granite and quartz-sillimanite schists the mineralogic relations noted above are generally well shown.

Although the mineral composition of pegmatites of different ages is not distinctive enough to allow classification of many bodies, certain characteristic features are worthy of note. The early aplite and pegmatite seams injected into metamorphic rocks consist chiefly of quartz and oligoclase or quartz and microcline. Some of the pegmatites associated with the Boulder Creek and Pikes Peak granites contain a variety of minerals; oligoclase, orthoclase, microcline, quartz, biotite, muscovite, and magnetite are abundant, and locally tourmaline, garnet, allanite, epidote, corundum, sillimanite, apatite, hornblende, and rare-earth minerals occur. Oligoclase is more common than orthoclase in the pegmatites related to the Boulder Creek granite, but the reverse is true of the later pegmatites which are approximately contemporaneous with the Pikes Peak granite itself. The pegmatites associated with the Silver Plume granite are generally simpler in mineral composition than those associated with the Pikes Peak granite or the Boulder Creek granite, but in the Jamestown district some late pegmatites contain unusual rare-earth minerals. Orthoclase and microcline are more abundant than quartz in the pegmatites associated with the Silver Plume granite, and both biotite and magnetite are present in more than ordinary quantity.

The aplite directly related to the Silver Plume granite is more abundant than the pegmatite and commonly contains so little ferromagnesian mineral that it may be classed as alaskite. The individual aplite and pegmatite bodies rarely have a surface area of more than a square mile, and most of them have much less; however, some of the late facies of the Silver Plume, such as the Mount Olympus granite, approach the aplites in composition and texture and form moderately extensive masses of granite. Near the upper contact of a southward-pitching stock of Silver Plume granite in the Jamestown district irregular pegmatites bordering schist inclusions contain cerite, allanite, and very small amounts of pitchblende.[22] Some of the radioactive cerite was analyzed by J. G. Fairchild, and the ratio of lead to uranium and thorium indicated that its age is approximately 940,000,000 years.

PALEOZOIC, MESOZOIC, AND CENOZOIC SEDIMENTARY ROCKS

A girdle of outward-dipping Paleozoic and Mesozoic sedimentary rocks nearly surrounds the Front Range, but west of Canon City outcrops of the pre-Cambrian rocks that form the core of the range continue south to the Wet Mountains. The continental deposits of late Cretaceous and Paleocene age, formerly classed as basal Eocene, were infolded with the underlying earlier Mesozoic formations but unlike them are limited to local basins. Oligocene, Miocene, Pliocene, and Pleistocene formations also occur in these basins and in places overlap the steeply tilted beds of earlier age and rest upon pre-Cambrian rocks.

Although the region occupied by the Front Range has been completely submerged at least once since pre-Cambrian time, it has been a strong positive element throughout the Paleozoic and much of the Mesozoic era. The presence of a pre-Tertiary "high" in the Front Range region is shown by the marked overlap that occurs at its borders and by the accented unconformities between formations whose unconformable relations are inconspicuous away from the border of the range.

The thickness of the Paleozoic systems varies greatly but is commonly least close to the mountains. In some localities the thickness ranges from that of a mere film

[22] Goddard, E. N., and Glass, J. J., Deposits of radioactive cerite near Jamestown, Colo.: Am Mineralogist, vol. 21, p. 199, 1936.

at the edge of the crystalline rock to more than 10,000 feet a few miles away. In some localities the Mesozoic systems also thin as they are followed toward the mountains, but the change is much less impressive (pls. 5 and 6).

On the eastern border of the Front Range, Pennsylvanian beds rest on the pre-Cambrian complex from Wyoming south to Perry Park, 30 miles south of Denver, where Devonian(?) and Cambrian beds appear below it. From Perry Park south to Canon City the stratigraphic interval between the Pennsylvanian and the pre-Cambrian differs greatly from place to place; Cambrian, Ordovician, Devonian(?), and Mississippian formations are present but show great variation in thickness.

The oldest formations that cover the pre-Cambrian basement on the western slope of the Front Range, where it borders North Park and Middle Park, are red beds of Carboniferous or Triassic age. Locally the red beds disappear, and Jurassic, Cretaceous, or Paleocene beds rest directly on the pre-Cambrian. To the southwest along the southern edge of Middle Park and in the valley of the Blue River from Kremmling to Dillon, the Jurassic Morrison formation either rests directly on the pre-Cambrian basement or is separated from it by thin, nonpersistent, Pennsylvanian and Permian grits. Farther south, especially in the region between Breckenridge and South Park, the Pennsylvanian and Permian formations thicken rapidly. Near Hoosier Pass, just northwest of South Park, pre-Pennsylvanian Paleozoic formations appear. Although Cambrian, Ordovician, Devonian, and Mississippian beds persist along the western border of South Park and continue southward on the eastern side of the Arkansas Valley to the latitude of Canon City, they are lacking on the north and east sides of South Park (pl. 5). The irregular but consistent overlap of younger Paleozoic formations toward the high country of the present Front Range indicates that this general area was a persistent positive region during the entire Paleozoic era.

A part of the red-bed section along the eastern and northwestern flanks of the Front Range may be of Triassic age, but beds of this system are definitely absent on the western slope from Middle Park south to the Arkansas River. In contrast to the Triassic, the Jurassic rocks are nearly everywhere present, and the characteristic variegated shale of this system, occurring immediately below the basal sandstone of the Upper Cretaceous series, constitutes the most definite and useful marker in the stratigraphic section. Along the eastern border of the Front Range the Upper Cretaceous section reaches a thickness of 10,000 feet, and the western limit of this outcrop is nowhere more than a few miles distant from the pre-Cambrian. On the western slope the Cretaceous occurs close to pre-Cambrian exposures only in the deep structural basins of North Park, Middle Park, the valley of the Blue, and South Park and is much thinner than on the eastern slope.

Continental deposits of Upper Cretaceous and Paleocene age, formerly classed as basal Eocene, crop out extensively in the Denver basin and the Canon City embayment on the eastern side of the Front Range and in North Park, Middle Park, and South Park on the western side. Oligocene and Miocene deposits overlap upturned Paleozoic and Mesozoic formations in many places. On the western side of the range they are present in North Park, Middle Park, and South Park, and on the eastern flank they occur near the Wyoming line and in the Pikes Peak and Castle Rock quadrangles. Pliocene beds are probably present in many localities near the Front Range where Miocene beds are known, but fossils of Pliocene age have been definitely identified only in the Arkansas Valley, in South Park, and in the Tertiary basins adjoining the range just north of the Wyoming line.

Pleistocene till is common in the mountain valleys that head above an altitude of 10,000 feet and occurs down to an altitude of about 8,000 feet. Below this altitude glacial outwash is conspicuous along the major streams. Moderately extensive Pleistocene pediments border the mountains at many places and are especially well-developed near Colorado Springs.

PALEOZOIC

CAMBRIAN

Distribution.—The Sawatch quartzite is the only Cambrian formation present near the Front Range and is limited to the bordering region south of the latitude of Breckenridge. As shown on plate 5, its thickness differs greatly from place to place; locally the quartzite is absent. It is well exposed in Montgomery Gulch just southwest of Hoosier Pass near the main Fairplay-Breckenridge highway and in many valleys cutting the Mosquito Range to the south. An excellent section may be seen a few miles below Salida along the Arkansas River. It is absent throughout most of South Park and the southwestern part of the Front Range; but its absence, however, does not imply nondeposition but rather its removal during Paleozoic time from the borderland of the Old Front Range positive area.

On the eastern side of the range the Sawatch quartzite has been measured in Perry Park southwest of Castle Rock and in the Ute Pass graben north of and near Colorado Springs.[23] In the Canon City embayment to the southwest Cambrian beds are probably lacking.

[23] Brainard, A. E., Baldwin, H. L., Jr., and Keyte, I. A., Pre-Pennsylvanian stratigraphy of Front Range in Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 17, pp. 375–397, 1933.

Thickness and stratigraphic relations.—In the sections measured by Brainard, Baldwin, and Keyte on the eastern side of the range the maximum thickness was found in Perry Park, where the quartzite is slightly more than 100 feet thick. It thins to the south, and is only 45 feet thick near Colorado Springs. Across the range near Hoosier Pass the Cambrian is commonly 120 to 200 feet thick.[24] The quartzite everywhere lies with marked unconformity on the smoothly truncated pre-Cambrian igneous and metamorphic rocks. At Perry Park Devonian beds rest on the Cambrian, but elsewhere basal Ordovician beds overlie it disconformably.

An Upper Cambrian fauna equivalent to that of the Pilgrim shale of Montana and the Dresbach shale of Minnesota according to Bell[25] has been found recently near the base of the quartzite in the Minturn quadrangle about 30 miles west of the Front Range.[26] Upper Cambrian fossils have been known in the Peerless shale member at the top of the formation since the earliest geologic surveys of Colorado.

Lithology.—On the western slopes, where the section is more complete than on the eastern side, the Cambrian includes a thick lower quartzite and an upper shaly member—the Peerless member. The quartzite has a few thin white to gray limy sandstones alternating with white to pinkish or brownish quartzite which grade downward into gritty white quartzite and pebbly conglomerate near the base. The Peerless member includes thin beds of limy quartzite, limestone, and dolomite, in gray to pinkish shale. A few thin-bedded intraformational limestone conglomerates of pinkish color—the so-called red cast beds—occur near the top. On the eastern side of the range only the quartzite member is present.

ORDOVICIAN

Distribution.—Like the Cambrian, the Ordovician rocks are confined to the southern half of the Front Range. On the east and southeast sides, Ordovician rocks occur from Perry Park southward to Canon City; on the western side they are found in only a very few places among the sedimentary rocks cropping out close to the pre-Cambrian core. They appear a short distance farther west, however, in a belt of outcrops that extends southward from Hoosier Pass along the west side of South Park and the eastern side of the Arkansas Valley; but beds of this age are not present in the zone of marked overlap on the eastern side of South Park.

[24] Singewald, Q. D., and Butler, B. S., Preliminary geologic map of the Alma mining district: Colorado Sci. Soc. Proc., vol. 12, pp. 296–298, 1930.

[25] Identification and stratigraphic significance determined by Dr. Charles Bell.

[26] Lovering, T. S., and Tweto, O. L., Preliminary report on the geology and ore deposits of the Minturn quadrangle, 1944. On file in the offices of the U. S. Geological Survey at Washington and Denver.

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The Ordovician system is made up of three formations—the Manitou limestone, the Harding sandstone, and the Freemont limestone. Because of the unconformity at the top of the Ordovician and the marked disconformities at the bases of the middle and upper formations, all three show great variation in thickness from place to place, and all three are present in only a few localities on the southeast side of the Front Range and along the west side of South Park from Alma south to Salida. On the eastern slope of the range the relations and lithologic features of each formation are well shown north and northeast of Canon City along Oil Creek and Phantom Canyon, where the section is easily accessible. On the west side of the range a section is well exposed along the Hartsel-Buena Vista road near Trout Creek Pass. The Manitou limestone here is unusually thick.

Manitou limestone.—The type locality of the restricted Manitou limestone is at the narrows of Williams Canyon near Manitou Springs, where it is unconformably overlain by the Devonian(?) Williams Canyon limestone and rests with gradational contact on the Sawatch quartzite.[27] It is 218 feet thick at this place and consists of well-bedded reddish-gray dolomitic limestone, light-gray to buff at the top and brown and cherty at the base. The weathered surface has a distinctive sandy appearance; weathering accentuates the thin bedding and nodular character of the lower part and the massive bedding of the upper part. On the western side of the range the lithologic character is similar, but locally the formation contains thin beds of shale and sandy shale, and the dolomite is very siliceous in many places. The formation attains its maximum thickness of 314 feet at Trout Creek Pass.

The Manitou fauna suggests Beekmantown age, and it has therefore been assigned to the Lower Ordovician.[28]

Harding sandstone.—The Harding sandstone is well exposed in the Harding quarries, the type locality, near Canon City, where it is 86 feet thick. It consists chiefly of interbedded gray to reddish sandstone and green to brownish shale containing abundant fish plates. Some of the shales are calcareous and grade into thin limestone. It reaches its maximum thickness of 150 feet at Priest Canyon northwest of Canon City. The base of the Harding is a coarse-grained sandstone, which lies with pronounced disconformity on the older formation. On the west side of the range the Harding sandstone is present from Salida northward to the southern part of the Alma district, but it is absent near Hoosier Pass. The lithologic character of the formation differs from that shown on the eastern side of the range in that very little shale is present.

[27] Brainard, A. E., Baldwin, H. L., Jr., and Keyte, I. A., op. cit., p. 382.

[28] Idem.

According to Kirk,[29] the fauna of the Harding sandstone indicates Middle Ordovician age, and he tentatively correlates it with the Black River of the eastern United States. Brainard, Baldwin, and Keyte correlate the Harding with the Simpson sandstone of Oklahoma.[30]

Fremont limestone.—The Fremont limestone is named from Fremont County, but like the Harding sandstone its type section is at the Harding quarry at Canon City. Here it is separated from the Harding sandstone by an inconspicuous erosional unconformity. The break at the top of the Fremont limestone is of much greater importance, as Silurian beds are missing throughout Colorado and in the Front Range region both Devonian and Mississippian beds also are absent locally. Exposure to long-continued erosion before the younger beds were deposited upon it is reflected by abrupt variations in thickness and by the small area in which the Fremont limestone itself is present.

On the eastern side of the Front Range it is found only in the Canon City embayment, west of Phantom Canyon. It is absent in the Alma district, but appears a short distance to the south and thickens as it is followed from Trout Creek Pass to the Arkansas River near Salida, although missing a short distance to the east. At the type locality the formation is about 190 feet thick and attains a maximum thickness of 270 feet a few miles north in Priest Canyon.

The Fremont limestone is a gray to blue-gray medium-bedded, rough-weathering dolomitic limestone containing a few thin beds of brownish sandstone; it generally stands out as a cliff above the less abrupt slope of the softer Harding sandstone.

The basal part contains a fauna that suggests Trenton age, but the remainder has yielded fossils that may be as young as Richmond according to Brainard, Baldwin, and Keyte.[31] It is probably equivalent in large part to the Big Horn dolomite of Wyoming.

DEVONIAN

Rocks of the Devonian system are limited to the southern half of the Front Range and are known with certainty only on the western slope, where the work of Kirk and others has established the Devonian age of the Chaffee formation. The Williams Canyon limestone on the eastern slope is similar lithologically, and Brainard, Baldwin, and Keyte regard it as the equivalent of the lower part of the Chaffee of the western slope. Although the Mississipian Leadville limestone is nearly everywhere underlain by the Chaffee formation from Hoosier Pass southward to Salida, the Devonian(?) Williams Canyon limestone is less persistent and is missing between the Canon City embayment and the Colorado Springs area. Good sections of the Parting quartzite member of the Chaffee formation, as well as the overlying Dyer dolomite member, are exposed at Trout Creek Pass.

On the eastern slope the Williams Canyon limestone is well exposed at Williams Canyon near the Cave of the Winds at Manitou, and this has been selected as the type locality for the formation by Brainard, Baldwin, and Keyte.

Lithology and thickness.—The Chaffee formation is made up of the Parting quartzite and Dyer dolomite members. Like the other pre-Pennsylvanian formations, it thins and disappears within short distances both to the north and to the east of Hoosier Pass and does not crop out on the eastern side of South Park. The Dyer dolomite member nearly everywhere rests on the Parting quartzite member but locally lies on Ordovician rocks. Near Hoosier Pass the Parting quartzite member rests on the Lower Ordovician Manitou limestone, but, as it is followed south, first the Harding sandstone and then the Fremont limestone appears beneath it.

The Parting quartzite member ranges from a conglomeratic quartzite and sandy limestone to an impure shale containing interbedded quartzite layers. Near Hoosier Pass it is a cross-bedded conglomeratic quartzite or sandy limestone with a few shale partings, but to the southwest it contains more and more shale, and at Trout Creek Pass its shale is as abundant as its quartzite. The shale in the lower part is distinctly reddish, but the color of the member as a whole is gray or drab, though it commonly shows a pinkish or brownish hue where weathered. There is a marked variation in the thickness of the Parting quartzite member within short distances; on the western side of South Park it averages approximately 50 feet and ranges from 10 to 70 feet.

A section of fine-grained bluish-gray dolomite 40 to 100 feet thick and containing a few shale partings is found conformably overlying the Parting quartzite member. This dolomite was formerly classed as the lower part of the "Blue," or Leadville limestone, but the term Leadville is now restricted to the upper or Mississippian part of the "Blue limestone." The lower dolomite contains Devonian fossils in some localities and has been named the Dyer dolomite member of the Chaffee formation.[32] The Dyer dolomite member commonly weathers to buckskin brown and contrasts strongly with the bluish-gray surface of the weathered Leadville limestone. In the Leadville district on the west side of the Mosquito Range the Dyer reaches a maximum thickness of about 100 feet. As it is followed eastward across that range it thins; in the Alma district near Hoosier Pass it averages approximately 75 feet and locally is much thinner.

[29] Kirk, Edwin, The Harding sandstone of Colorado: Am. Jour. Sci., 5th ser., vol. 20, pp. 456–465, 1930.

[30] Brainard, A. E., Baldwin, H. L., Jr., and Keyte, I. A., op. cit., p. 385.

[31] Idem, p. 387.

[32] Behre, C. H., Jr., The Weston Pass mining district: Colorado Sci. Soc., Proc., vol. 13, no. 3, pp. 59–60, 1932.

On the eastern side of the Front Range the Williams Canyon limestone, the supposed equivalent of the Chaffee formation, crops out persistently beneath Mississippian limestone in the vicinity of Canon City and Colorado Springs. It consists of thin-bedded limestone with shale partings and a few thin sandstone layers. The color ranges from light brown to gray, and the formation has a maximum thickness of about 65 feet, averaging approximately 25 feet in most places. It is overlain unconformably by the Mississippian Madison limestone and is underlain by the Ordovician Fremont and Manitou limestones.

MISSISSIPPIAN

Like the earlier Paleozoic formations, the Mississippian is found bordering only the southern part of the Front Range. On the western side from Hoosier Pass south to Salida the Mississippian Leadville limestone is persistent on the western side of South Park. It is lacking to the north and east (pls. 5 and 6). On the eastern side the Mississippian Madison limestone crops out in the Ute Pass fault-fold west and north of Colorado Springs but is absent at Perry Park. It is lacking also in the northern part of the Canon City basin but is present in the Wet Mountains to the south. Good exposures of the Leadville limestone may be seen near the Hock Hocking mine about 2 miles west-southwest of Alma, and an excellent section of the Madison limestone is found near Manitou at the type locality of the Williams Canyon limestone.

Thickness and stratigraphic relations.—The Leadville limestone ranges from less than 50 feet in thickness near Hoosier Pass to approximately 300 feet at Weston Pass in the Mosquito Range. Farther south it reaches an even greater thickness. The erosion that preceded the deposition of the Pennsylvanian rocks cut deeply into the Leadville limestone in many places, and rapid changes in thickness from place to place are common. The absence of Mississippian beds on the eastern side of the Front Range, except in the small area near Colorado Springs, may be due chiefly to pre-Pennsylvanian erosion rather than to nondeposition. The Madison limestone reaches a maximum thickness of about 100 feet in Williams Canyon near Manitou.

Lithology.—At many places on the western side of the range the Leadville limestone has a thin bed of quartzite and breccia at its base, known as the Gilman quartzite member,[33] but this basal member is not everywhere present. The main part of the Leadville is dense bluish-gray massive dolomite that weathers to dark blue-gray blocky fragments. Some cherty layers that weather rusty brown and stand out in relief are present, and in places the upper part of the dolomite is distinctly sandy.

[33] Lovering, T. S., and Tweto, O. L., op. cit.

The Mississippian limestone of the southeastern Front Range is a gray or white slightly cherty limestone, whose upper part shows the effect of pre-Pennsylvanian weathering and solution. Brainard, Baldwin, and Keyte correlate it with the Madison limestone, which it resembles lithologically; the meager lower Mississippian fauna found at Manitou also suggests the equivalence of the two formations. The Leadville fauna is also lower Mississippian; it was regarded by Girty as approximately of upper Kinderhook and lower Burlington age.[34]

PENNSYLVANIAN AND PERMIAN OF THE EAST SLOPE

Distribution.—The lower Pennsylvanian Fountain formation crops out almost continuously on the eastern side of the range from the Wyoming line southward to Canon City, but on the western side Pennsylvanian exposures are much less continuous. Along the eastern side of North Park and Middle Park unfossiliferous red micaceous grit, which may be Permian, Pennsylvanian, or Triassic, lies between the Jurassic and the pre-Cambrian formations at most places, though it is absent locally. Along the south border of Middle Park and in the valley of the Blue north of Dillon the red grit is present in only a few localities. From Dillon southward to Salida, however, beds of definite Pennsylvanian age are present. The Pennsylvanian beds thicken greatly westward from the longitude of Hoosier Pass and feather out a short distance to the east. Thus the Pennsylvanian like the older Paleozoic systems is lacking along the northern and eastern side of South Park and also at many places along the southern edge.

Thickness and stratigraphic relations.—As already indicated, the Pennsylvanian is separated from the older and younger formations by conspicuous erosional unconformities. The thickness of the exposed Pennsylvanian of the eastern slope changes from a minimum of about 700 feet near Golden to a maximum of 4,500 feet near Colorado Springs. Seismic prospecting a short distance east of Denver indicates some 10,000 feet of pre-Cretaceous beds, most of which probably belong to the Pennsylvanian system (pl. 5). On the western slope the Pennsylvanian and Permian near Breckenridge increases from a feather edge to a thickness of more than 10,000 feet a few miles to the west. In North Park the Pennsylvanian (?) has a maximum thickness of about 2,000 feet.

Fountain formation.—The lower part of the Pennsylvanian system along the eastern side of the Front Range is called the Fountain formation. This formation takes its name from Fountain Creek, along which it is well exposed near Manitou. The formation is quite ir-

[34] Girty, G. H., The Carboniferous formations and faunas of Colorado: U. S. Geol. Survey Prof. Paper 16, pp. 217–229, 1903.

regular in thickness, owing to original differences in deposition. It reaches a maximum of about 4,500 feet near Colorado Springs but thins to less than 2,000 feet a few miles to the south and commonly ranges from about 1,500 to 2,500 feet of soft unjointed grits. North of Perry Park it rests directly on the pre-Cambrian rocks, but the contact is usually hidden in a swale between a hogback and the dip slope preserved on the underlying crystalline rocks to the west. (See fig. 11, *B*.)

The Fountain formation consists of coarse red gritty conglomerate and arkosic sandstone containing a minor amount of lenticular reddish and greenish shale. Cross bedding is prominent in many of the arkosic facies. At the base of the formation near Colorado Springs a unit about 90 feet thick, known as the Glen Eyrie shale member, is present. It contains thin beds of black plant-bearing coaly shale of lower Pottsville age. Both the shales and the coarser-grained rocks of the Fountain formation are distinctly micaceous, in strong contrast to the older Paleozoic rocks. The grits and conglomerates are made up predominantly of fragments of granite, quartz, feldspar, and mica from the pre-Cambrian rocks. Although red is the dominant color of the formation, white to gray layers of arkose are found locally; they probably reflect Pennsylvanian leaching of the ferric oxide that colors most of the formation. These beds are especially prominent in the upper part of the formation throughout the foothills belt, where the light-gray and light-red arkoses are well exposed in irregular, rocky hogbacks. (See fig. 6.) With the exception of the Glen Eyrie shale member, which is lacking to the north, the character of the Fountain formation remains remarkably constant throughout the eastern border of the Front Range.

Ingleside formation.—This younger Pennsylvanian formation is found above the Fountain formation in the northern part of Colorado. According to Lee,[35] the Ingleside, which he correlates with the Casper formation of Wyoming, is dominantly soft reddish sandstone and shale near Loveland but changes into a limestone as it is followed to the north. The formation increases in thickness from a mere film near Boulder to approximately 250 feet near the Wyoming-Colorado line. At the type locality, a short distance northeast of Fort Collins, the formation consists of three beds of limestone separated by layers of intensely cross-bedded red sandstone. The limestone is nearly pure and is extensively quarried for use in the beet-sugar factories nearby. The Ingleside formation rests with a slight unconformity on the underlying Fountain formation and is conformably overlain by the red micaceous Permian Satanka shale north of Ingleside, but to the south it is overlain unconformably by the Permian Lyons sandstone. The Satanka shale is approximately 181 feet thick just south of the Wyoming line at Soldier Canyon.

Lyons sandstone.—The light orange-red arkosic Lyons sandstone lies directly on the Fountain formation south of Loveland but rests on younger and younger beds as it is followed to the north. It ranges in thickness from 50 feet near the Wyoming line to approximately 200 feet at Morrison and Colorado Springs. In most places it is much more massive than the underlying Fountain formation and stands up in cliffs that are seamed with conspicuous joints, in marked contrast to the relatively unjointed grits beneath. At Lyons, the type locality, 10 miles north of Boulder, the formation is a fine-grained, cross-bedded quartzose sandstone, with a siliceous cement and a marked pinkish color, but to the south it becomes arkosic. This arkosic material shows evidence of a much greater degree of weathering and decomposition in the neighboring land surface at the time of deposition than does the material making up the Fountain formation. In places, as at Morrison, the Lyons sandstone is completely decolorized and easily mistaken for the white grits of parts of the Fountain. In spite of this deceptive appearance it can be traced southward to Colorado Springs and for nearly 30 miles farther. However, it thins and disappears to the west and has not been found in the Canon City embayment. No determinative fossils have been found in the Lyons sandstone, although some fossil footprints of amphibians occur at the type locality.

PERMIAN (?) AND TRIASSIC (?)

Lykins formation.—The Lykins formation conformably overlies the Lyons sandstone throughout the eastern border of the Front Range; it consists of poorly consolidated red sandy shales and siltstone with a few thin beds of limestone and gypsum. The thickness of the Lykins formation varies greatly from place to place, ranging from a minimum of about 200 feet in the Castle Rock quadrangle to a maximum of approximately 1,000 feet near Colorado Springs. Throughout most of its extent it is approximately 600 feet thick. Because of its softness and its position between hard resistant formations, the Lykins is marked by an almost continuous north-south valley between the hogbacks of the Dakota sandstone and the Lyons sandstone (fig. 6). Fossils regarded by Girty as having a Permian aspect have been found in the lower part of the formation, but the age of the upper part is uncertain. In northern Colorado the Lykins is unconformably overlain by the Jurassic Sundance formation, but to the south the Sundance wedges out, and the Jurassic Morrison formation overlies the Lykins throughout most of the eastern foothills of the Colorado Front Range.

[35] Lee, W. T., The correlation of geologic formations between east central Colorado, central Wyoming, and southern Montana: U. S. Geol. Survey Prof. Paper 149, pp. 6–8, 1927.

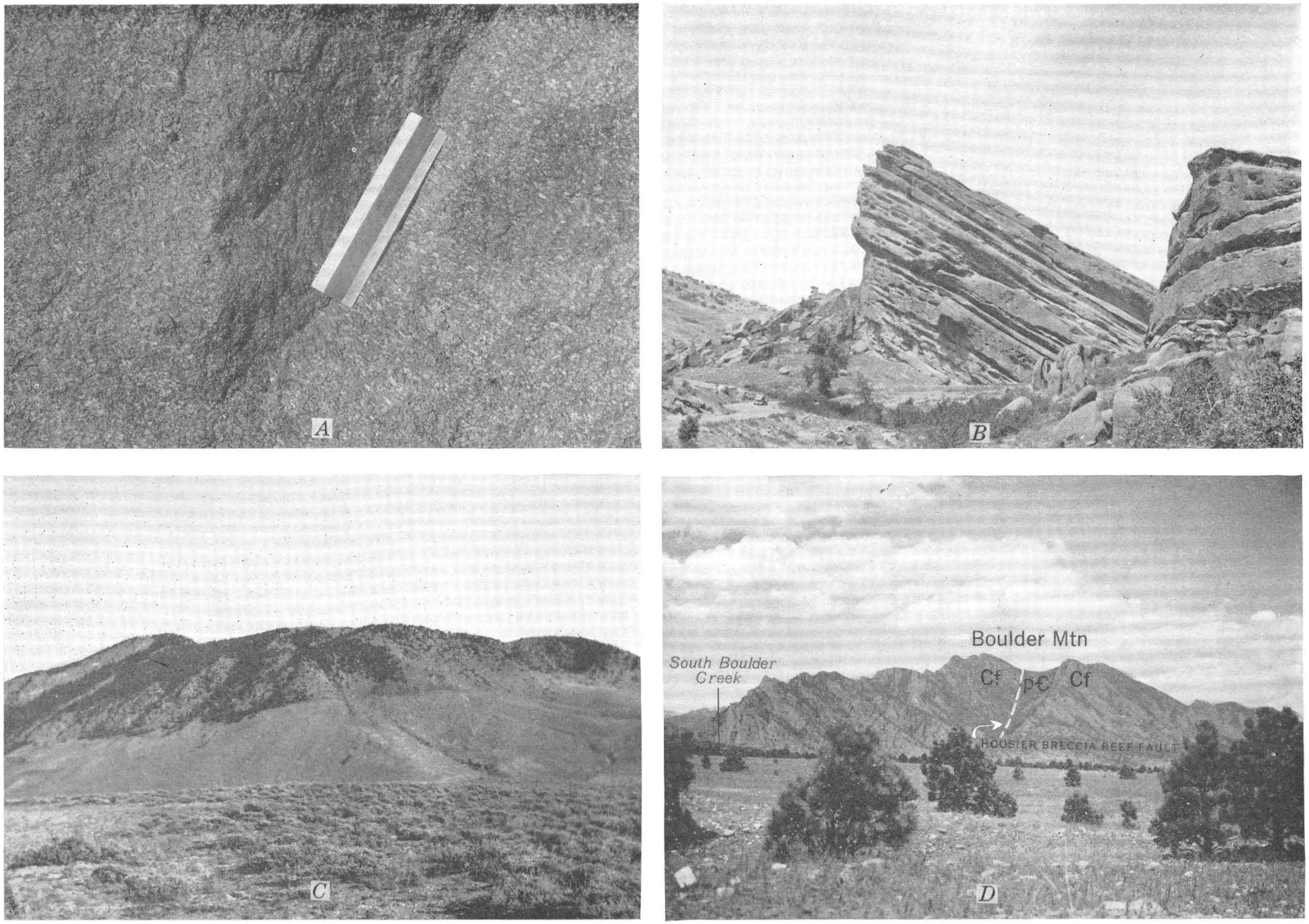


FIGURE 11.—*A*, Silver Plume granite in a dike cutting the Boulder Creek granite in Gordon Gulch, 3 miles northeast of Nederland. The parallel arrangement of the feldspar crystals characteristic of this formation is well shown. *B*, Basal Fountain formation in Red Rock Park north of Morrison. The weathering of the soft shale layers interbedded with the arkosic grit of the formation and its freedom from joints is illustrated in this exposure. The slope to the left is pre-Cambrian rock from which the Pennsylvanian has been stripped by erosion. *C*, Klippe of pre-Cambrian granite resting on Cretaceous shale, 5 miles north of Kremmling. The crystalline rocks are marked by wooded slopes and stand in contrast to the sage-covered shale beneath. This is a part of the Williams Range underthrust. *D*, View of Boulder Mountain, looking northwest, showing the usual topographic expression of the steep northwesterly echelon faults in the foothills region. Cf, Fountain formation; p€, pre-Cambrian granite.

PENNSYLVANIAN AND PERMIAN OF THE WEST SLOPE

On the western side of the Front Range few fossils have been found in the red beds bordering North Park and Middle Park; the beds have therefore been classed as Pennsylvanian and Permian and as Triassic by different writers. Beekly [36] correlated the red beds of North Park with the Triassic Chugwater formation of Wyoming. The Chugwater has also been correlated with the Lykins formation on the eastern side of the range. The presence of a thin remnant of limestone beneath the red beds in North Park suggests the relationship of the Lykins to the Ingleside formation on the eastern front. In North Park, however, the limestone rests directly upon the pre-Cambrian, and as no fossils have been found in it its age remains in doubt. From this somewhat inadequate evidence, it is suggested that the equivalent of the lower Pennsylvanian Fountain formation is lacking in North and Middle Parks but that parts at least of the younger Pennsylvanian beds are present.

In North Park the red sandstones and shales have an aggregate thickness of approximately 1,000 feet and are overlain by the Jurassic Morrison formation. To the south along the border of Middle Park, red arkosic grits containing some micaceous shale underlie the Morrison formation and are strikingly similar to the known Pennsylvanian rocks of the Mosquito and Gore Ranges to the west. Reddish and purplish-brown micaceous grit of doubtful age crops out locally along the southern border of Middle Park and also occurs in the valley of the Blue, but so far as known it is everywhere less than 500 feet thick north of Dillon. To the south of Dillon the Pennsylvanian and Permian beds thicken rapidly, and near Hoosier Pass [37] and along the western border of South Park [38] they are approximately 10,000 feet thick. They thin eastward in a remarkably short distance, however, and at Georgia Pass, about 10 miles northeast of Hoosier Pass, Pennsylvanian and Permian rocks are missing, Cretaceous quartzite resting directly upon the pre-Cambrian Swandyke hornblende gneiss.

Many efforts have been made to separate the Pennsylvanian and Permian of the western slope into distinct formations, but, as noted by Lovering [39] in his discussion of the Pennsylvanian and Permian of the Breckenridge district, most of these attempts have been without conspicuous success, and much confusion has resulted. Where the deposits are well developed the lower part has been called the Weber (?) formation; it consists predominantly of gray grit and dark-colored shales and limestones. The Maroon formation overlies the Weber (?) formation and has been separated from it chiefly through color distinctions. The lower part of the Maroon is generally dark-red, but in the upper beds this color gives place to a brilliant brick-red. Limestones are much more common in the lower than in the upper part, and throughout the formation the grit and sandstone are strongly crossbedded and may grade into limestone, dolomite, shale, or conglomerate within a short distance along either the strike or dip. The upper brick-red portion was formerly known as the "Wyoming series," but the term Maroon formation has been adopted for the Permian and Pennsylvanian (?) beds lying above the Weber (?) formation. The limestones carry an unmistakably Des Moines fauna in the lower 4,500 feet of the Maroon formation 15 miles west of Dillon,[40] but diagnostic fossils have not been reported from higher beds.

In South Park Gould recognized five divisions of the Pennsylvanian and Permian. According to him the Pennsylvanian Weber (?) formation is approximately 1,725 feet thick. The lower 950 feet of section consists of dark-gray to black shale with interbedded limestone; this is followed by a sandstone 250 feet thick, above which the section is dominantly dark-gray to black shale but contains a few thin beds of sandstone and limestone. Locally, thin algal limestones are common near the top of the formation. It seems conformably overlain by the Coffman conglomerate member of the Maroon formation, which ranges from 20 to 1,000 feet in thickness. This member is an arkosic conglomerate with some shale and sandstone. The shale is gray, buff, or black in color, and the conglomerate is light-colored. Overlying the Coffman is the Chubb siltstone member. It consists of gray to reddish-brown siltstone, which is argillaceous and calcareous near the base but chiefly sandstone in the upper part. It is about 1,827 feet thick. This member does not show the rapid lateral changes that the underlying Coffman conglomerate member exhibits and persists with little change in thickness throughout the western border of the park.

The Pony Spring siltstone member overlies the Chubb and is nearly 6,000 feet thick. It consists of gray to light-red siltstone, with interbedded gray-green sandstone and gray-green shale. Five of the individual sandstone strata that occur in the Pony Spring siltstone member are remarkably uniform in thickness and lithologic character and can be followed for considerable distances along the strike. Some of the upper sandstones are calcareous, but limestone is not noted in this member. Above the Pony Spring siltstone member undifferentiated strata of the Maroon formation are known to occur, but they were not given a separate

[36] Beekly, A. L., Geology and coal resources of North Park, Colo.: U. S. Geol. Survey Bull. 596, pp. 23–26, 1915.

[37] Ransome, F. L., Geology and ore deposits of the Breckenridge mining district, Colo.: U. S. Geol. Survey Prof. Paper 75, p. 30, 1911.

[38] Gould, D. B., Stratigraphy and structure of Pennsylvanian and Permian rocks in Salt Creek area, Mosquito Range, Colo.: Am. Assoc. Petroleum Geologists Bull., vol. 19, pp. 971–1009, 1935.

[39] Lovering, T. S., Geology and ore deposits of the Breckenridge mining district of Colorado: U. S. Geol. Survey Prof. Paper 176, pp. 4–6, 1934.

[40] Lovering, T. S., and Tweto, O. L., op. cit.

name. "Strata occur in the northern part of the area east of the Trout Creek fault which are considered to be younger than the Pony Spring siltstone member. These are mapped as part of the Maroon formation on the basis of lithologic similarity to the Maroon in the type locality." [41] The undifferentiated Maroon strata, whose total thickness is estimated at approximately 5,000 feet, are dark purplish-red and maroon shales and siltstones with interbedded cream to gray arkosic sandstones and conglomerates.

The Maroon formation has been ascribed to the Permian chiefly because of the occurrence of *Walchia piniformis* and *W. gracilis* in the Pony Spring siltstone member of South Park and of *Walchia* and related fossil plants in the valley of the Eagle River. David White regarded these plants as diagnostic of the Permian, but the recent work of Elias [42] on a flora of unquestioned Permian aspect but containing undoubted Pennsylvanian plants and lying between formations of known Pennsylvanian (Des Moines) age throws doubt on the diagnostic value of the plants used by White in assigning a Permian age to the Maroon formation. Further doubt is engendered by Donner's discovery [43] of a *Walchia* flora about 30 miles west of Kremmling similar to that of Gould's, as this flora occurred between unfaulted beds of lower Pennsylvanian fossiliferous marine limestone, about 1,125 feet above the base of the Pennsylvanian grit.

In a general way it seems probable that the lower part of the Fountain formation as represented by the Glen Eyrie shale member is approximately equivalent to the Weber (?) formation of the western slope and that the Fountain itself is comparable to the Coffman conglomerate member of Gould and part of his Chubb siltstone member; also, that the Lyons and Lykins are in general equivalent to Gould's Pony Spring siltstone member of South Park. Pennsylvanian and Permian beds similar in character to those of South Park are found in the region farther south and are especially well shown in the valley of the Arkansas River near Wellsville.

MESOZOIC

TRIASSIC

Rocks of Triassic age do not occur on the western slope of the Front Range and are not certainly recognized on the eastern slope, although, as noted above, some of the upper beds of the Lykins formation may be Triassic.

JURASSIC

Entrada sandstone.—According to Lee,[44] the light-colored cross-bedded sandstone of the Jurassic Sundance formation is present from Boulder northward to Wyoming, and thin remnants of it occur to the south of Boulder, but Reeside [45] does not believe these beds to be the true marine Sundance. Reeside correlates this sandstone with the Entrada sandstone of the western slope, which is believed to be equivalent to only the basal part of the Sundance.[46] On the western slope the Entrada sandstone has been identified in South Park by field parties of Northwestern University working under the direction of C. H. Behre, Jr.[47]

It is probably also present in the Breckenridge district, where an orange-yellow sandstone below the Morrison formation and lithologically similar to the Entrada sandstone was included in the Maroon formation by Lovering.[48] Entrada sandstone is not known south of South Park or north of Breckenridge; the formation in this restricted area is part of a tongue that extends southeastward from State Bridge and tapers rapidly in South Park. Good exposures of the Entrada sandstone may be seen in Boxelder Canyon north of Fort Collins, near Garo in South Park, and on Gibson Hill near Breckenridge.

The Entrada sandstone is composed of clean quartz sand remarkable for the intermingling of two very different sizes of sand grains and the scarcity of grains of intermediate size. Its color ranges from light gray through orange yellow to salmon pink. Many small varicolored chert grains are present in the basal bed in some localities. The thickness of the formation attains a maximum of about 125 feet near Boxelder Canyon but is less than 50 feet on the western slope.

Morrison formation.—The Upper Jurassic Morrison formation is widespread in the Front Range region and is almost everywhere present beneath the Cretaceous Dakota group. Along the northern and eastern edge of South Park it is missing, and here the Dakota quartzite rests directly on the pre-Cambrian basement. Because of its shaly composition, good exposures of the Morrison formations are rare, but on the eastern slope it may be seen to advantage at its type locality 12 miles west of Denver (fig. 6) and just west of Canon City. In South Park it is well exposed at Red Hill between Fairplay and Como, and a good section can be seen also along the Colorado River just west of Hot Sulphur Springs.

[41] Gould, D. B., op. cit., p. 996.

[42] Moore, R. C., Elias, M. K., and Newell, N. D., A "Permian" flora from the Pennsylvanian rocks of Kansas: Jour. Geology, vol. 44, pp. 1–31, 1936.

[43] Donner, H. F., Geology of the McCoy area, Eagle and Routt Counties, Colorado: Geol. Soc. America Bull., vol. 60, pp. 1215–1248, 1949.

[44] Lee, W. T., op. cit., p. 16.

[45] See Wilmarth, M. G., Tentative correlation of the named geologic units of Colorado: U. S. Geol. Survey chart, June 1, 1931.

[46] Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., Correlation of the Jurassic formations of parts of Utah, New Mexico, and Colorado: U. S. Geol. Survey Prof. Paper 184, pp. 26, 46, 1936.

[47] Personal communication.

[48] Lovering, T. S., op. cit., p. 6.

The thickness of the Morrison formation is 200 to 260 feet at most places on the western side of the range, but, as noted above, it tapers out in the region southeast of Breckenridge. On the eastern slope it has its minimum thickness of about 200 feet in the Castle Rock quadrangle and thickens both northward and southward. It is 277 feet thick at the type locality,[49] but near the Wyoming line it attains its maximum thickness of about 350 feet. At Canon City the beds classed as Morrison by petroleum geologists [50] include 310 feet of sandstone and variegated shale above 110 feet of arkosic conglomerate ascribed to the Jurassic Todilto limestone. As the Todilto is now included in the Morrison formation as its basal member,[51] the correlation of the arkose with the Todilto limestone member, if correct, would indicate a thickness of 420 feet at this place. The writers believe that this arkose, which is overlapped by the undoubted Morrison formation a short distance to the west, is of Pennsylvanian and Permian age and should be correlated with the upper part of the Maroon formation.

At most places the base of the Morrison formation is a persistent light-colored slightly conglomeratic sandstone, 10 to 20 feet thick, containing many differently colored grains and small pebbles of chert. Above this member the formation consists dominantly of variegated shale but contains several interbedded limestones and sandstones. The banded shale — pink, green, purple, gray, and black—which entirely lacks visible clastic mica, gives the Morrison a distinctive and easily recognized lithologic character.

From the Wyoming line southward to Lyons the Morrison formation rests with slight unconformity on the thinning Entrada sandstone. From Lyons to Bardeen, 20 miles south of Colorado Springs, the Morrison is underlain by the Lykins formation, except where thin local remnants of the Entrada sandstone are present. As the formation is followed westward from Bardeen it is found to overlap successively the older formations and to rest unconformably on the red arkose of the Fountain formation at Canon City. A few miles farther west it laps over the pre-Pennsylvanian formations and rests directly on the pre-Cambrian basement.

On the western slope of the Front Range the Morrison formation in most places rests directly upon pre-Cambrian rocks, although a short distance farther west it lies unconformably upon Mesozoic and Paleozoic formations. It is missing in the Georgia Pass area, however, and has apparently been overlapped by the Cretaceous Dakota quartzite a short distance to the west.[52]

[49] Waldschmidt, W. A., and LeRoy, L. W., Reconsideration of the Morrison formation in the type area, Jefferson County, Colo.: Geol. Soc. America Bull., vol. 55, p. 1100, 1944.

[50] De Ford, R. K., Surface structure, Florence oil field, Fremont County, Colo.: Structure of typical American oil fields, vol. 2, pp. 78–79, Am. Assoc. Petroleum Geologist, 1929.

[51] Baker, A. A., Dane, C. H., and Reeside, J. B., Jr., op. cit., p. 9.

[52] Lovering, T. S., Geology and ore deposits of the Breckenridge district: U. S. Geol. Survey Prof. Paper 176, p. 8, 1934.

Fossils are relatively rare in the Morrison formation, although the beds are famous for the vertebrate fossils that have been found at the type locality and in the region north of Canon City.

LOWER AND UPPER CRETACEOUS (DAKOTA GROUP)

Purgatoire formation.—Fossiliferous marine beds of Lower Cretaceous age are known along the southeastern border of the Front Range from Colorado Springs to Canon City and have been correlated with the Purgatoire formation of southeastern Colorado. The two members recognized at Colorado Springs, the Lytle sandstone and the Glencairn shale, are included in the Dakota group. The characteristic Comanche fossils found near Canon City become less and less abundant to the northeast, and few diagnostic species have been reported north of Colorado Springs.[53] The excellent exposures along the hogbacks held up by the Purgatoire and Dakota formations make stratigraphic correlation to the north relatively certain, even in the absence of definite Comanche fossils; on the basis of lithology, therefore, the Purgatoire has been mapped separately in the Castle Rock quadrangle. Farther north, the Lytle sandstone member and the overlying Glencairn shale member have been mapped as the lower part of the Dakota sandstone, but the continuity of outcrop leaves little doubt that the beds of Purgatoire age extend continuously along the Front Range into Wyoming, where they make up the Cloverly formation. (See pl. 1, Prof. Paper 149.)[54] The lithologic similarity of the Dakota group on the western slope of the range leads to the conclusion that here, too, the basal quartzite and middle shale are probably of Lower Cretaceous age, although it is quite possible that the beds are facies equivalents but not age equivalents. These members are nearly everywhere present but are absent at the northeastern edge of South Park, east of Georgia Pass, where the overlying quartzite rests on pre-Cambrian gneiss. Both members of the Purgatoire formation may be seen to advantage at the toll gate of the Corley Mountain Highway 2 miles south of Colorado Springs, but good exposures can be found at nearly every stream cut in the pronounced hogback that marks the Dakota sandstone throughout much of the length of the Front Range (fig. 6).

The Lytle sandstone member consists of a white sugary sandstone, conglomeratic at the base, which grades upward into a buff cross-bedded sandstone. Above this sandstone the gray and black shale of the Glencairn shale member appears interbedded with a

[53] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, Castle Rock folio (no. 198), p. 6, 1915. Reeside, J. B., Jr., The fauna of the so-called Dakota formation of northern central Colorado and its equivalent in southeastern Wyoming: U. S. Geol. Survey Prof. Paper 131–H, 1923.

[54] Lee, W. T., Correlation of geologic formations between east-central Colorado, central Wyoming, and southern Montana: U. S. Geol. Survey Prof. Paper 149, pl. 1, 1927.

few thin layers of sandstone. Some of the gray shale is a fire clay of high quality and is mined at several places.

The thickness of the Lytle sandstone member commonly ranges from 100 to 150 feet and that of the Glencairn shale member from 150 to 200 feet.

Dakota sandstone and quartzite.—The persistent Dakota group is present on both the eastern and western slopes of the Front Range and everywhere displays a striking lithologic similarity. As noted above, the Dakota group includes beds of Lower Cretaceous age, and only the upper sandstone should be classed as Dakota sandstone or quartzite of Upper Cretaceous age in most places. On the western slope the thickness ranges from approximately 20 feet of conglomeratic quartzite at Georgia Pass to 240 feet in the valley of the Snake River a few miles east of Dillon. On the eastern side of the range the thickness ranges from 300 feet at Perry Park to 425 feet at Spring Canyon north of Loveland. Almost everywhere the lower quartzite, the intermediate member comprising interbedded shale and quartzite or sandstone, and the upper quartzite are easily recognized. Each member shows a considerable range in thickness from place to place. On the western slope the lowest member is commonly the thickest of the three, but on the eastern slope the shale is thicker. The upper quartzite or sandstone usually ranges from 50 to 100 feet in thickness but is locally somewhat thinner or thicker than these prevailing limits. The sandstone is a light-colored well-washed quartz sand with a siliceous cement. The crest of the pronounced hogback that usually marks the Dakota outcrop is held up by the resistant upper sandstone (fig. 6).

UPPER CRETACEOUS

Benton shale.—Like the Dakota group, the overlying Benton shale is present on both the eastern and western slopes and, unlike the older formations, is nowhere overlapped by younger marine beds. East of Dillon, in the Snake River Valley, it lies disconformably on the Dakota quartzite, and the contact of the two formations is marked by a thin bed of conglomerate 6 to 18 inches thick. The most abundant pebbles in the conglomerate consist of Dakota quartzite, but some schist, granite, and limestone fragments are present. In most localities there is no evidence of a hiatus between the deposition of the two formations, however. The thickness of the Benton shale averages about 350 feet but ranges from 165 feet in North Park to 675 feet along the northeastern border of the Front Range.

The formation consists predominantly of dark-gray to black clay shales containing a few fossiliferous concretions and a limy or sandy bed with a Carlile fauna at its top. South of Castle Rock the beds containing the Carlile fauna are shaly, and an intermediate limestone zone appears marked by the Greenhorn fauna. On the western slope the Carlile horizon is marked by an oolitic brownish limestone with a distinct petroliferous odor.

Niobrara formation.—As shown on plate 1, the Niobrara formation is present in all the deeper synclines bordering the Front Range. It conformably overlies the Benton shale and comprises 350 to 800 feet of limestone and limy shale. On the eastern slope the 15-foot bed of greenish sandstone found at the top of the Benton is sharply set off from the basal limestone of the Niobrara formation, but on the western slope, where the uppermost member of the Benton is a limestone, the division between it and the overlying basal limestone of the Niobrara is less easily defined. This basal member, which is 15 to 20 feet thick in most places, commonly crops out in a low ridge, which seems a subdued reflection of the great Dakota hogback a short distance away (fig. 6). Most of the formation consists of dark-brown to gray calcareous shale that weathers white or grayish-yellow. Within the limy shale thin layers of limestone occur, and in some places moderately persistent *Ostrea*-bearing limestones about a foot thick are found in the upper part of the section. The change from the limy shales of the Niobrara formation to the black clay shales of the Pierre shale is inconspicuous, but the black limy shales and thin-bedded limestones at the top of the Niobrara are generally indicated by the presence of numerous lenses and veinlets of secondary white calcite.

Pierre shale.—The Pierre shale conformably overlies the Niobrara formation and attains a maximum thickness of about 10,000 feet south of Boulder. Its thickness is only 2,200 to 2,600 feet in South Park [55] but is more than 4,000 feet 25 miles northeast, near Dillon. Because of its soft character, good exposures of the Pierre shale are uncommon, but a nearly complete section can be seen along the Denver & Salt Lake Railway about 7 miles north of Golden. The regional variations in thickness are not large (pl. 6). The Pierre consists dominantly of somber-colored shales that weather a drab greenish-gray. A few beds of bentonite, shaly limestone, and calcareous sandstone are present in the lower half of the formation, but nearly all the lower part of the section is clay shale. South and east of Colorado Springs the shale contains vertical pluglike reefs of limestone through a stratigraphic thickness of about 600 feet in what is called the Teepee Buttes zone. In this region, where the Pierre is only 3,600 feet thick, this zone is 1,200 feet above the Niobrara formation and crops out for more than a hundred

[55] Johnson, J. H., Stratigraphy of northeastern and east-central parts of South Park, Colo.: Am. Assoc. Petroleum Geologists Bull., vol. 19, p. 1341, 1935.

miles to the east of Colorado Springs.[56] The shales of the upper half are more arenaceous than those below, and in the upper thousand feet, locally called the transition zone, yellowish limy and sandy shales are common. This zone was formerly classed as a part of the Fox Hills formation, but the name Fox Hills has now been restricted to the sandstone overlying the shale.

Fox Hills sandstone.—The Fox Hills sandstone overlies the Pierre shale conformably and, like it, is of marine origin. The Fox Hills sandstone has not been definitely recognized on the western slope but is present in the Cretaceous of the eastern flank throughout the length of the range. Its base is marked by a buff to brown sandstone containing numerous large gray to brown hard sandy concretions. The lower concretionary member is overlain by a series of light-gray to brown sandstones and sandy shales. The top of the formation is taken as a horizon above which the rocks are predominantly brackish-water deposits accompanied by coals and lignitic shales and below which they are predominantly marine.[57] The Fox Hills sandstone as thus restricted has a thickness of approximately 250 feet. This sandy zone in the Upper Cretaceous sequence lies at higher and higher horizons as it is traced to the east and is probably a near-shore facies of the retreating Upper Cretaceous sea. The basal sandstone is composed of moderately clean quartz sand north of Boulder, but to the south it becomes increasingly arkosic, and at Colorado Springs it is marked by conglomeratic layers containing pebbles of pre-Cambrian granite as much as 2 inches in diameter.

Laramie formation.—The Laramie formation is mainly limited to the eastern side of the Front Range, but a wedge of coal-bearing sandstones containing a flora thought to be Laramie underlies much of the Denver formation in South Park.[58] It has not been found elsewhere on the western side of the range. In South Park its maximum thickness is 300 feet, but in the Denver basin it averages about 600 feet. Because of the strong erosional unconformity between it and the overlying continental Cretaceous beds, the thickness of the Laramie formation ranges from less than 250 feet to more than 1,200 feet.

The lower 200 feet of the formation is sandstone, interbedded with some shale and fire clay, and contains workable beds of subbituminous coal. Above the basal coal-bearing sandstone the Laramie formation consists dominantly of shale with only a few thin beds of sandstone and coal. In South Park some beds of tuff and volcanic debris are included in the upper Laramie by Stark and his coworkers; this age would make them the earliest record of the igneous activity that accompanied the Laramide revolution in the Front Range.

MESOZOIC AND CENOZOIC

UPPER CRETACEOUS AND PALEOCENE

Arapahoe and Denver formations.—The coarsely clastic beds that overlie the Laramie formation with marked erosional unconformity on the eastern slope were formerly designated basal Eocene but are now classed as Upper Cretaceous and Paleocene. These beds are obviously of continental origin and include conglomerates, tuffs, tuffaceous sandstones and shales, lignite, and, near Golden, interbedded basaltic lavas. The conglomerates below the beds containing andesitic debris were originally called the Arapahoe formation, but the division was arbitrary and has been difficult to use. The term Denver formation has been used for the tuffaceous deposits above the Arapahoe in the Denver basin. Farther south the equivalents of the Arapahoe and Denver have been called the Dawson arkose, and in South Park they have been included in the Shoshone group of Cross. The maximum thickness of these deposits on the eastern slope is approximately 2,000 feet, but in South Park they reach a thickness of more than 7,000 feet, and in Middle Park and North Park the equivalent Middle Park formation exceeds 5,000 feet.[59]

The sequence in the Denver basin is richest in volcanic debris in the lower part, and pre-Cambrian waste becomes more and more abundant with increasing distance above the base. Rhyolite is found near the base in South Park, andesitic flows at this horizon in Middle Park, and basalt flows a few hundred feet above the base near Golden. Subaerial rhyolite tuff and a rhyolite flow consisting of welded tuff occur at the top of the Dawson arkose just below the Oligocene beds south of Castle Rock. Elsewhere the upper part is made up of arkose and micaceous shale.

The Arapahoe and Denver formations and their equivalents were apparently formed in the early stages of the Laramide revolution, when the Front Range area was arching itself well above the surrounding region but before the severe folding and faulting that marked the climax of the Laramide revolution. The andesitic pebbles near the base of the sequence give the first evidence of volcanic activity after pre-Cambrian time. The sedimentary structures within the Denver forma-

[56] Lavington, C. S., Montana group in eastern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 17, pp. 397–410, 1933.

[57] Lovering, T. S., Aurand, H. A., Lavington, C. S., and Wilson, J. H., Fox Hills formation, northeastern Colorado: Am. Assoc. Petroleum Geologists Bull., vol. 16, pp. 702, 703, 1932.

[58] Stark, J. T., Johnson, J. H., Behre, C. H., Jr., Powers, W. E., Howland, A. L., Gould, D. B., and others, Geology and origin of South Park, Colorado: Geol. Soc. America Mem. 33, p. 56 et seq., 1949. See also Washburne, C. W., The South Park coal field: U. S. Geol. Survey Bull. 381, p. 308, 1910.

[59] Behre, C. H., Jr., and others, The geologic history of South Park, Colorado: New York Acad. Sci. Trans., ser. 2, vol. 4, no. 1, p. 2, 1941. Beekly, A. L., Geology and coal resources of North Park, Colo.: U. S. Geol. Survey Bull. 596, p. 49, 1915. Lovering, T. S., The Granby anticline, Grand County, Colo.: U. S. Geol. Survey Bull. 822, p. 75, 1931.

tion and the localization in areas adjacent to the Front Range indicate that the volcanic waste had its origin in the Front Range itself. In harmony with this origin the formation is limited to intermontane basins and to the plains immediately east of the range. (See pls. 1 and 5.)

J. B. Reeside, Jr. in a written communication to the writers notes: "The earlier work disclosed dinosaur remains in the Araphoe formation and the lower part of the Denver formation and a supposedly uniform flora throughout the deposits." More recent work,[60] however, has shown that the Araphoe formation and the basal part of the Denver formation and the lower part of the Dawson arkose contain all of the dinosaur remains and a Cretaceous flora and that the overlying part of the Denver and of the Dawson contain a primitive mammalian fauna and a Paleocene flora. The boundary between the Cretaceous and Tertiary therefore falls within what has hitherto been considered to be one formation of early Tertiary age.

CENOZOIC

TERTIARY AND QUATERNARY

Oligocene.—Beds containing Oligocene fossils are known in South Park, the Denver basin, and Middle Park. On the eastern side of the range just south of the Wyoming line and in Middle Park and South Park on the western side of the range soft tuffaceous shales, sand, and algal limestone make up the Oligocene. Richards[61] measured several hundred feet of light-gray to light-tan tuffaceous sands and clays in the valley of Troublesome Creek, near Kremmling in Middle Park, and found both Oligocene and late Miocene or early Pliocene fossils in it within a few rods of each other. It is probable that most of his "Troublesome formation" is Oligocene and locally was reworked during Miocene and early Pliocene time. Equivalent strata are also found east of South Park at Florissant, where the recent work of Gazin and Brown indicates these famous fossiliferous lake beds to be of upper Oligocene or basal Miocene age,[62] but south of Denver this epoch is represented by a coarse boulder conglomerate and arkosic sandstone known as the Castle Rock conglomerate. The gravel apparently had its source to the northwest and contains fragments of many volcanic rocks probably derived from the mineral belt. It also contains a small amount of finely divided gold, which has locally been reworked by modern streams into small placers. In South Park, Stark and others report fossils of Chadron and White River age in their Antero formation, which has a maximum thickness of 2,000 feet.

The Oligocene beds rest with angular unconformity on the older rocks.

Miocene.—Beds of Miocene age are known in Middle Park and along the eastern border of the range just south of Wyoming. In the region northwest of Granby the interbedded conglomerate, arkosic sandstone, shale, tuff, and lava of lower Miocene age, which are correlated with the Arikaree formation, attain a thickness of several hundred feet.[63] There they appear conformable with the underlying light-colored clay shales assigned to the Oligocene White River formation, but they overlap these shales and lie with angular unconformity on the steeply tilted Cretaceous formations. These beds are similar to the sandstone and conglomerates of the North Park formation 30 miles to the north, in the area just north of Michigan Creek, described by Gorton.[64] The North Park formation has a thickness there of 800 feet, and its upper part is interbedded with andesite flows derived from the Specimen Mountain volcanic center a few miles southeast; no volcanic rocks are represented in the conglomerate below the andesite. No fossils have been found in the conglomerate closer than those at Granby. A lower Pliocene *Hipparion* is reported from the North Park formation in the Saratoga basin 50 miles to the northwest,[65] but the relation of the North Park formation in the Saratoga Basin to that in the Cameron Pass area is unknown.

Along the Colorado-Wyoming line east of the Front Range the Arikaree formation consists of coarse sand and gravel with interbedded tuffaceous clays and a few thin limestone beds. Its thickness is less than 300 feet in most places.

Pliocene.—Vertebrates of late Miocene or early Pliocene age have been found in South Park by Stark and his coworkers, but the fossils occur in thin and discontinuous lake-bed deposits. *Procamelus* bones of similar age have been found in Middle Park by Richards.[66] Several hundred feet of shale and limestone of unquestioned Pliocene age occur in the Arkansas Valley near Salida a short distance southwest of South Park, but no other Pliocene deposits close to the Front Range have been identified in Colorado.

Pleistocene.—Small areas of pre-Glacial(?) gravel, such as those southeast of Nederland and east of Idaho Springs, occur here and there in the Front Range and may be of Tertiary age, but their exact age is in doubt. Early and late glacial deposits are widespread in the higher mountains but have not been distinguished sep-

[60] Gazin, C. L., Paleocene mammals from the Denver Basin, Colo.: Washington Acad. Sci. Jour., vol. 31, pp. 289–295, July 1941. Brown, R. W., Cretaeceous-Tertiary boundary in the Denver Basin, Colo.: Geol. Soc. America Bull., vol. 54, no. 1, pp. 65–86, 1943.

[61] Richards, A. H., Geology and structure of the Kremmling area, Colorado. Unpublished doctoral thesis, University of Michigan, 1941.

[62] Gazin, C. L., A marsupial from the Florissant beds (Tertiary) of Colorado: Jour. Paleontology, vol. 9, pp. 57–62, 1935.

[63] Lovering, T. S., op. cit. (U. S. Geol. Survey Bull. 822), p. 74.

[64] Gorton, K. A., Geology of the Cameron Pass area, Grand, Jackson, and Larimer Counties, Colo. Unpublished doctoral thesis, University of Michigan, 1941.

[65] Love, J. D., Geology along southern border of the Absaroka Range, Wyo.: Geol. Soc. America, Special Paper no. 20, 1939.

[66] Richards, A. H., op. cit.

arately on the geologic maps (pls. 1 and 2). In general, the glacial drift is found along the larger streams up to altitudes of approximately 9,000 feet on the western slope and 8,000 feet on the eastern slope (fig. 3). Distribution of the early drift suggests icecap glaciation, whereas the later (Wisconsin) drift is limited to the steeper-sided valleys. Three well-developed terraces, locally covered by terrace gravels to a depth of as much as 30 feet, are common in the major valleys below the limits of glaciation. The upper terrace is apparently contemporaneous with the early period of glaciation, and the lower terrace with an early stage of Wisconsin glaciation. It seems possible, therefore, that the intermediate terrace should be correlated with an otherwise unrecorded glacial stage, whose drift was reworked by later more extensive glaciers. Within the areas of pre-Cambrian rock, the thickness of the present gravel downstream from the terminal moraines is rarely more than 20 to 30 feet. In the valley of the Blue River on the western slope the gravel has an average thickness of approximately 60 feet and is nearly as thick in the important tributary stream valleys, such as the Snake River and the Swan River. The glacial moraines themselves show a great range in thickness and reach a maximum of about 150 feet near Breckenridge.

Most of the material deposited by the early glaciers was removed by later erosion. Remnants of the early till and outwash gravel occur well above the level of the present valley bottoms in many places. This early drift is commonly weathered more deeply than that of Wisconsin age. It is made up of unsorted boulders of pre-Cambrian rocks and Tertiary intrusives in a matrix of brownish-yellow sand and sandy clay. The early glacial deposits are not abundant, but nearly all the higher mountain valleys are occupied by thin discontinuous bodies of alluvium, late glacial till, and valley-train gravel. The poorly sorted material that makes up this late drift is fresh in most places and little weathered, but much-weathered boulders are not uncommon in it. Subangular boulders as much as 20 feet in diameter intermingled with small boulders, pebbles, and clay occur in the late glacial moraines. Fluvioglacial deposits are conspicuous, both above and below the terminal moraines of the Wisconsin glaciers. They are made up chiefly of moderately well-rounded pebbles and sand, but small boulders are not uncommon.

LARAMIDE IGNEOUS ROCKS

EXTRUSIVE ROCKS

DISTRIBUTION

The volcanic activity that presaged the Laramide revolution and the formation of the mineral deposits of the porphyry belt is recorded in the lava flows, andesitic conglomerates, and the beds of tuff, found in the Denver and Middle Park formations. Flow rocks of this age seem limited to South Park, Middle Park, and the Denver basin; they have not yet been positively identified within the Front Range itself. In South Park the Basin Ridge group of Stark and others is made up of andesites, rhyolites, and pyroclastics that are clearly of Denver age; their Thirtynine Mile series of volcanics is earlier than the Oligocene beds of their Antero formation; and their Buffalo Peaks andesite flows are believed by Behre to have been formed earlier than lower Oligocene beds and later than the Flattop erosion surface in the Mosquito Range west of South Park.[67] It is possible that the early rhyolites southwest of Pikes Peak are of similar age.

At the base of the Middle Park formation,[68] near Granby, andesite flows alternate with beds of breccia and conglomerate, but Cretaceous and Paleocene extrusive rocks have not been found to the north. Although sills of andesite and rhyolite of Upper Cretaceous age are found in the Denver formation of South Park, no interbedded flow rocks have been noted. The margin of the Upper Cretaceous and Paleocene Dawson arkose, which lies just south of the Front Range in the region between Canon City and Colorado Springs, contains no interbedded lava. As this formation is traced northward from Colorado Springs, however, more and more volcanic material is recognized, and in the region between Palmer Lake and Sedalia [69] interbedded rhyolite appears in the upper part. Farther north, in the vicinity of Golden, basalt flows are interbedded with the lower part of the Denver formation.[70]

SOURCES

The Ralston diabase dike, a short distance northwest of the Table Mountain basalt flows, seems to be the intrusive equivalent of the flows. The andesitic lavas represented by pebbles in the Denver formation are peculiar, highly aluminous rocks of distinctive chemical character but are essentially identical in chemical composition with some of the granular intrusive rocks found in the Lake Albion stock west of Ward (pl. 7). The Lake Albion stock is believed to mark the volcanic throat through which were erupted the lavas that were the source of the andesitic pebbles in the Denver formation east of the range.

[67] Stark, J. T., Johnson, J. H., Behre, C. H., Jr., Powers, W. E., Howland, A. L., Gould, D. B., and others, op. cit., pp. 95–110, and Behre, C. H., Jr., oral communication.

[68] Lovering, T. S., Granby anticline, Grand County, Colo.: U. S. Geol. Survey Bull. 822, p. 73, 1931. Cross, Whitman, The post-Laramie beds of Middle Park, Colo.: Colorado Sci. Soc. Proc., vol. 4, pp. 192–213, 1895.

[69] Richardson, G. B., U. S. Geol. Survey Geol. Atlas, Castle Rock folio (no. 198), pp. 9, 10, 1915.

[70] Johnson, J. H., Geology of the Golden area, Colorado: Colorado School of Mines Quart., vol. 25, pp. 18–21, July 1930. Emmons, S. F., Cross, W., and Eldridge, G. H., Geology of the Denver Basin, Colorado: U. S. Geol. Survey Mon. 27, 1896.

Scattered dikes and plugs of augite andesite occur at many places in the Front Range and may also mark early volcanic conduits. The porphyry of Mount Silverheels, south of Hoosier Pass, is very similar in composition to the andesitic pebbles in the Denver formation of South Park; it contains hornblende rimmed with augite and magnetite—a paragenetic relation characteristic of magmas undergoing a rapid loss of volatiles while solidifying. The Mount Silverheels stock is believed to lie in the volcanic throat through which was ejected the lava represented in the nearby Denver beds.

The interbedded lavas of the Middle Park formation feather out to the north of Sulphur Springs and increase in thickness to the south. Their source is unknown but probably is close to the southeastern border of Middle Park.

In the Castle Rock quadrangle the rhyolite flows and the welded rhyolite tuff associated with them show conspicuous flow lines oriented in a south-southwest direction. These volcanic rocks can be traced southward to within a few miles of Monument, but farther south they have been removed by erosion. No source for this rhyolite is known in the plains region, and silicic intrusives of Cretaceous or Paleocene age are rare in the Front Range southwest of Monument. The summit of Pikes Peak marks the position of a nearly vertical stock of coarsely porphyritic granite similar in appearance to some of the porphyritic quartz monzonite of the mineral belt associated with the Laramide revolution. South of the peak a linear series of outcrops of this granite, known as the Windy Point granite, shows almost horizontal contacts with the underlying and earlier Pikes Peak granite. The lithologic character and age relations strongly suggest that the porphyritic granite is of Cretaceous or Tertiary rather than pre-Cambrian age. On Pikes Peak, close to the edge of the stock, a few fragments of a schistose silicic rock are present that are unlike any of the pre-Cambrian rocks of the region. It is believed that they represent slightly metamorphosed fragments of the lining of a volcanic conduit through which the Windy Point granite rose. The composition of the Windy Point granite, the rhyolite, and the slightly silicified welded rhyolite tuff are very similar and suggest a genetic relation. (See the following table.)

Analyses of Windy Point "granite" and of rhyolite and rhyolite tuff from the Dawson arkose

Specimen	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O-	H_2O+	TiO_2	P_2O_5	MnO	BaO	Li_2O	F	CO_2	Rb
1. Windy Point granite, Middle Beaver Creek [1]	73.51	13.28	0.94	0.97	0.05	1.11	3.79	5.22	0.16	0.62	0.18	Tr.	Tr.	Tr.	------	0.55	------	------
2. Windy Point granite, Beaver Creek [1]	75.17	12.66	.23	1.40	.05	.82	2.88	5.75	.16	.66	.10	0.03	Tr.	0.03	Tr.	.31	------	------
3. Rhyolite pebbles from upper part of Dawson arkose, partial analysis [2]	73.75	------	------	------	------	------	3.75	5.83	------	------	------	------	------	------	------	------	------	------
4. Slightly silicified rhyolite tuff from top of rhyolite sheet, upper part of Dawson arkose, 2.8 miles southeast of Castle Rock [3]	82.16	8.27	.75	.16	.15	.59	2.19	3.94	.89	1.04	.28	.02	.034	------	None	------	None	None

[1] U. S. Geol. Survey Geol. Atlas, Colorado Springs folio (No. 203), 1916.
[2] U. S. Geol. Survey Geol. Atlas, Castle Rock folio (No. 198), 1915.
[3] R. C. Wells, analyst.

INTRUSIVE ROCKS

DISTRIBUTION

Most of the intrusive rocks that may be referred with confidence to the Paleocene and Eocene epochs are limited to a narrow belt extending southwestward across the Front Range from Boulder to Breckenridge, and it is within this belt that most of the early Tertiary mineral deposits of the Front Range occur. A few intrusives of comparable age occur also in a northeasterly zone extending from Radial Mountain in Middle Park through Cameron Pass to the Manhattan-Home mining district; they form a faint counterpart paralleling the main porphyry belt about 35 miles to the northwest. Ore deposition accompanied the intrusion of some of the stocks in the Radial Mountain-Home belt, but so far as known the mineralization there was not intense. As already noted, late Cretaceous and Paleocene volcanic conduits now marked by porphyritic stocks are scattered sparsely through the mountains from Pikes Peak to Estes Park, but only in the vicinity of the Lake Albion stock is there any evidence of an accompanying mineralization.

MODE OF INTRUSION

In the sedimentary formations that border the pre-Cambrian rocks the sills and concordant steeply dipping intrusive sheets far outnumber the cross-breaking dikes, but no laccolith has been found. Near Breckenridge and in the Tarryall district several large porphyritic intrusives are in part cross-breaking and in part parallel to the bedding, but they probably grade into true stocks at no great depth. Within the pre-Cambrian terrane, intrusives that break across the foliation of the country rock are as common as those that are concordant. As shown on plates 1 and 2 and figure 2, the northwestern side of the main porphyry belt is marked by a line of stocks which range in size from less than 2 square miles to slightly more than 15 square miles. Dikes and small irregular cross-breaking bodies are almost entirely limited to a strip ranging in width from 2 to 10 miles, just southeast of the line of stocks. The scarcity of dikes to the northwest and their abundance to the southeast indicates the presence of relatively shallow magmatic reservoirs below the surface just southeast of the stocks. It is in the strip containing the porphyry dikes and small irregular intrusive bodies that most of the early Tertiary ore deposits of the Front Range occur. The linear structure within the stocks that have been studied by the writers indicates that most of them were intruded upward at a steep angle. The Montezuma quartz monzonite apparently becomes larger with depth, but other stocks, such as the granodiorite at Jamestown,[71] apparently show no change in cross section for some distance below the surface, and a few bodies, such as the quartz monzonite at Jamestown, apparently diminish in size with increasing depth. Some stocks, such as those of Mount Albion, Pikes Peak, and Mount Silverheels, probably occupy old volcanic throats, but many others were roofed with pre-Denver rocks and probably forced their way in by stoping and intrusive faulting.

The linear structure within the dikes shows that some moved vertically and others almost horizontally. In several places the tops of dikes and in other localities the bottoms of dikes have been seen. The tops of some dikes are marked by brecciation of the country rock for a distance of several yards, but at the tops of other dikes the country rock shows almost no evidence of fracturing, even adjacent to the dike. The earliest intrusives show structure concordant with the country rock much more commonly than do the later, and among the latest of the intrusives explosion breccia is common.

COMPOSITION

The intrusives of the Laramide revolution have a general similarity throughout the Front Range and especially within the porphyry belt, but they show a moderately wide range in composition (pl. 7). A few intrusive bodies are as mafic as augitite, some are as silicic as alaskite, and some are as aluminous as bostonite, but most of them lie between monzonite and quartz monzonite in composition. The sequence, type of rock, and composition of most of these rocks are shown in plate 7 and figure 12. On the western slope the composition of most of the intrusives in the porphyry belt lies between that of augite diorite and quartz monzonite porphyry. In this area the mineral deposits contain chiefly complex lead-silver-zinc ores. Northeast of Silver Plume, in addition to the intermediate rocks, more alkalic groups are found, and alkalic syenite, alkalic trachyte, and bostonite are common. In the area of the more alkalic rocks pyritic gold ores as well as the older complex sulfide ores occur. Scattered through the northeastern half of the mineral belt are short dikes and small irregular bodies of biotite latite, biotite monzonite, and latitic intrusion breccia; these rocks seem limited to the areas in which gold-telluride veins are found. Rocks of extremely mafic character occur just west of the tungsten belt and near its eastern edge. Those in the Caribou stock at the west end may be syntectic and due to the reaction of gabbro magma with limy pre-Cambrian inclusions, but the limburgite at the eastern end of the tungsten belt cannot be thus explained.

PETROGRAPHY

The petrography of the igneous rocks of the Front Range associated with the Laramide revolution has been described briefly by Lovering,[72] and more detailed descriptions of them may be found in district reports.[73] Study of the composition and age sequence of the rocks shows that they fall into distinctive groups. The relations of the rocks to one another and to ore stages are shown in figure 12 and have been discussed in detail by Lovering and Goddard.[74] It seems unnecessary to repeat the detailed descriptions of the rock groups here, but the salient features of the petrography are given in the tabular summary below. Under the microscope the appearance of representatives of most of the different groups in the porphyry belt recognized by the writers is quite distinctive. The photomicrographs of rocks belonging to these groups, figures 10, *D*, *E*, *F*, 13, and 17, *A*, *B*, illustrate their characteristic features and together with plate 7, figure 12, and the tabular summary on page 46 should give the reader adequate understanding of their petrography.

Comparatively little is known about the Radial Mountain-Home belt of porphyritic intrusive igneous rocks. Granodiorite, diorite, and quartz monzonite groups are present, and most of the rock is apparently close to granodiorite in composition.

AGE AND ORDER OF INTRUSION

The interbedded tuffs and volcanic rocks of the Upper Cretaceous and Paleocene Denver and Middle Park

[71] Goddard, E. N., The influence of Tertiary intrusive structural features on mineral deposits at Jamestown, Colo.: Econ. Geology, vol. 30, pp. 370–386, 1935.

[72] Lovering, T. S., op. cit. (Prof. Paper 178), pp. 30–40.

[73] Petrographic descriptions of all the different types of the igneous rocks found in the porphyry belt are not available in a single volume but may be found in the following reports. Ransome, F. L., Geology and ore deposits of the Breckenridge mining district, Colo.: U. S. Geol. Survey Prof. Paper 75, 1911. Spurr, J. E., Garrey, G. H., and Ball, S. H., Economic geology of the Georgetown quadrangle, Colo.: U. S. Geol. Survey Prof. Paper 63, 1908. Bastin, E. S., and Hill, J. M., Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colo.: U. S. Geol. Survey Prof. Paper 94, 1917. Worcester, P. G., and Crawford, R. D., The geology of the Ward region, Boulder County, Colo.: Colorado Geol. Survey Bull. 21, 1920. George, R. D., and Crawford, R. D., The main tungsten area of Boulder County, Colo.: Colorado Geol. Survey 1st Ann. Rept., 1908. Stark, J. T., Johnson, J. H., Behre, C. H., Jr., Powers, W. E., Howland, A. L., Gould, D. B., and others, Geology and origin of South Park, Colorado: Geol. Soc. America Mem. 33, 1949.

[74] Lovering, T. S., and Goddard, E. N., Laramide igneous sequence and differentiation in the Front Range, Colo: Geol. Soc. America Bull., vol. 49, no. 1, pp. 35–68, 1938.

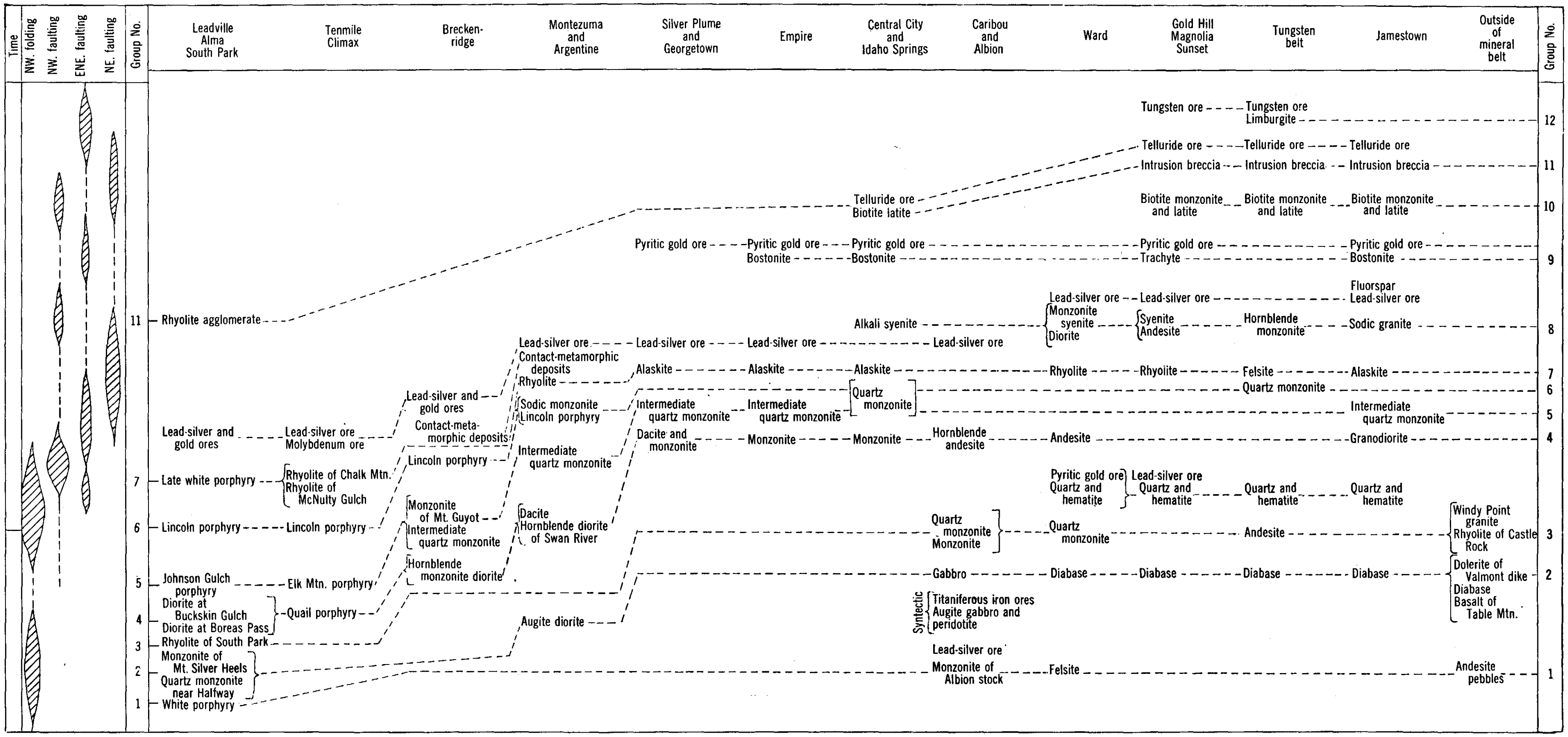


FIGURE 12.—Correlation chart of the Laramide igneous rocks of the Front Range, showing their relation to the major structural events of the Laramide revolution.

Tabular summary showing chief textural and mineralogic characteristics of various groups of Laramide igneous rocks of the Front Range

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8	Group 9	Group 10	Group 11	Group 12
Names	Monzonite of Albion stock, felsite of Ward	Diabase (Iron dike), gabbro of Caribou, augite diorite	Monzonite and quartz monzonite of Caribou, quartz monzonite and andesite of Ward	Hornblende monzonite, diorite, dacite, monzonite, andesite, granodiorite	Quartz monzonite of Mt. Guyot and intermediate quartz monzonite	Quartz monzonite porphyry of the Lincoln type; sodic quartz monzonite	Alaskite, rhyolite, felsite	Alkalic syenite, monzonite and diorite, and sodic granite	Bostonite, trachyte	Biotite monzonite	Biotite latite and biotite latite intrusion breccia	Limburgite. Basalt? of Ward
Occurrence	Stocks and dikes	Stocks and extensive dikes	Stocks and dikes	Large stocks and persistent dikes	Dikes, sills, and stocks	Sills, dikes, and small stocks	Dikes and a few plugs	Stocks and dikes	Dikes and a few stocks	Dikes	Small dikes	Small dikes
Color	Gray to greenish-gray to grayish-white	Greenish-gray to dark-gray to black	Light-gray to greenish-gray	Gray to dark greenish-gray	Light to dark-gray	Light to dark-gray	Grayish-white to white, chalky, or porcelanic	Light-gray to grayish-brown	Pinkish-gray to lilac-colored or reddish-brown	Dark gray to greenish-gray	Slate-gray to brownish- or greenish-gray	Greenish-black
Texture	Felsitic to granitoid, porphyritic in places	Medium granular, some facies porphyritic, grain size 0.25 3 mm.	Medium granular, some fine-grained and porphyritic	Fine to medium-granular, some facies porphyritic; seriate fabric	Small phenocrysts in aphanitic to fine-grained groundmass; some medium, equigranular	Coarsely porphyritic, fine- to medium-grained groundmass; in part, equigranular	Aphanitic, with a few very small phenocrysts	Largely porphyritic with aphanitic groundmass and large feldspar phenocrysts	Small phenocrysts in aphanitic, trachytoid groundmass	Small phenocrysts in aphanitic groundmass	Small biotite phenocrysts in aphanitic to glassy groundmass	Slightly porphyritic, groundmass glassy to aphanitic
Deuteric alteration	Slight to strong in places	Slight to moderate	Absent to moderate	Absent or slight	Slight to strong	Slight to moderate	Slight to moderate	Slight to strong	Strong	Strong	Strong	Moderate
Special features	High alumina content				Small hexagonal quartz and biotite phenocrysts	Unusually large orthoclase phenocrysts, maximum 2 inches						

	Mineralogy	G1 Groundmass	G1 Phenocrysts	G2 Groundmass	G2 Phenocrysts	G3 Groundmass	G3 Phenocrysts	G4 Groundmass	G4 Phenocrysts	G5 Groundmass	G5 Phenocrysts	G6 Groundmass	G6 Phenocrysts	G7 Groundmass	G7 Phenocrysts	G8 Groundmass	G8 Phenocrysts	G9 Groundmass	G9 Phenocrysts	G10 Groundmass	G10 Phenocrysts	G11 Groundmass	G11 Phenocrysts	G12 Groundmass	G12 Phenocrysts
Essential minerals	Quartz																								
	Orthoclase													Sanidine	Sanidine			Anorthoclase and orthoclase						Glass	
	Plagioclase	Oligoclase		Oligoclase-andesine to labradorite		Andesine to labradorite		Andesine-labradorite		Oligoclase-andesine	Oligoclase to andesine	Albite to andesine	Albite to andesine	Albite-oligoclase	Albite-oligoclase	Albite-oligoclase to oligoclase	Albite to oligoclase	Oligoclase	Oligoclase	Oligoclase	Oligoclase to andesine	Oligoclase to labradorite	Andesine to labradorite	Glass	
	Muscovite																								
	Biotite																								
	Hornblende																								
	Augite																								
	Olivine																								
Accessory minerals	Magnetite and ilmenite																								
	Titanite																								
	Apatite																								
	Zircon																								
	Allanite																								
Secondary minerals	Epidote			d. a.	d. a.	d. a.				d. a.	d. a.	d. a.	d. a.								d. a.				
	Chlorite	d. a.	d. a.	d. a.	d. a.	d. a.		d. a.	d. a.	d. a.	d. a.	d. a.	d. a.								d. a.	d. a.	d. a.		
	Sericite	d. a.	d. a.	d. a.	d. a.	d. a.		d. a.	d. a.	d. a.	d. a.	d. a.	d. a.	d. a.	d. a.	d. a.	d. a.	d. a.	d. a.	d. a.	d. a.	d. a.	d. a.		
	Calcite			d. a.	d. a.					d. a.	d. a.					d. a.	d. a.			d. a.	d. a.	d. a.	d. a.	d. a.	d. a.
	Hornblende			d. a.	d. a.			d. a.																	
	Pyrite			d. a.		d. a.										d. a.									
	Serpentine																								
	Magnetite									d. a.															
	Titanite			d. a.																					
	Biotite							d. a.																	
	Limonite and hematite																	d. a.	d. a.				d. a.		

Shading shows relative amounts and range of minerals within each group

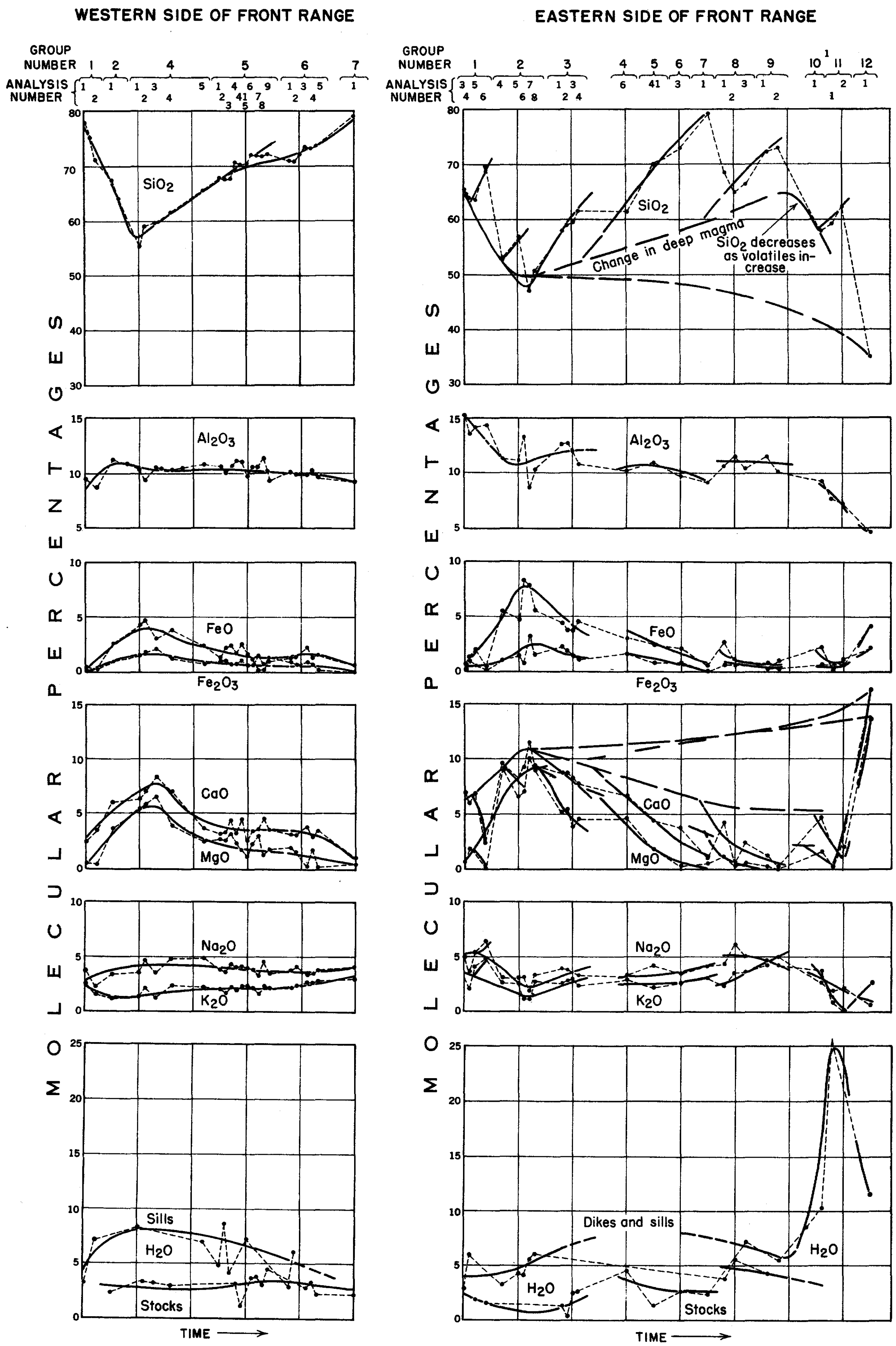
Small amounts

Moderately abundant

Abundant

Dots indicate relative amounts of accessory minerals. If more than 3 per-cent, they are shown by shading

d. a., deuteric alteration (Alteration resulting from the fluids contained in the intrusive itself)



CHEMICAL ANALYSES OF LARAMIDE IGNEOUS ROCKS OF THE FRONT RANGE

All analyses have been recalculated from weight percent to molecular percent. Plotted points indicate number of molecules in 100 represented by various oxides in each analysis. Heavy lines show general compositional trends of differentiating magmas.

WESTERN SIDE OF FRONT RANGE

1. 1, Mount Zion porphyry, Prospect Mountain, Leadville district. M. 12, p. 326.
   2, White porphyry, California Gulch, Leadville district. P.P. 148, p. 45.

2. 1, Quartz monzonite porphyry, Mount Silverheels northeast of Alma. C.G.S. 31, p. 45.

4. 1, Diorite porphyry, Boreas Pass. C.G.S. 31, p. 45.
   2, Diorite porphyry, Wellington mine, Breckenridge district. P.P. 75, p. 62.
   3, Hornblende-mica porphyrite, Buckskin Gulch, Leadville district. M. 12, p. 340.
   4, Diorite porphyry, Wellington mine, Breckenridge district. P.P. 75, p. 62.
   5, Diorite porphyry, McNulty Gulch, Tenmile district. P.P. 14, p. 174.

5. 1, Quartz monzonite porphyry, north of Halfway, Tarryall district. C.G.S. 31, p. 45.
   2, Evans Gulch porphyry, Evans Gulch, Leadville district. P.P. 148, p. 51.
   3, Quartz-hornblende-mica porphyrite, Gold Hill, Tenmile district. A.R. 14, pt. 2, p. 227.
   4, Quartz monzonite porphyry, near Halfway, Tarryall district. C.G.S. 31, p. 45.
   41, Quartz monzonite porphyry, Mount Guyot, Breckenridge district. P.P. 75, p. 58.
   5, Quartz porphyrite, Sugarloaf, Tenmile district. A.R. 14, pt. 2, p. 227.
   6, Quartz monzonite porphyry, Little French Creek, Tarryall district. C.G.S. 31, p. 45.
   7, Quartz monzonite porphyry, Mineral Ranch Hill, Tarryall district. C.G.S. 31, p. 45.
   8, Diorite porphyry, Copper Mountain, Tenmile district. B. 148, p. 176.
   9, Gray porphyry, Johnson Gulch, Leadville district. M. 12, p. 332.

6. 1, Lincoln porphyry, Mount Lincoln, Leadville district. M. 12, p. 332.
   2, Quartz porphyrite, Chicago Mountain, Tenmile district. A.R. 14, pt. 2, p. 227.
   3, Quartz monzonite porphyry, Brewery Hill, Breckenridge district. P.P. 75, p. 45.
   4, Granite porphyry, McNulty Gulch, Tenmile district. B. 148, p. 176.
   5, Quartz monzonite porphyry, Brown's Gulch, Breckenridge district. P.P. 75, p. 45.

7. 1, Nevadite, Chalk Mountain, Leadville district. M. 12, p. 589.

EASTERN SIDE OF FRONT RANGE

1. 3, Andesite pebbles from lower part of Denver formation, Table Mountain, Golden, Colo. B. 148, p. 159.
   4, Andesite pebbles from lower part of Denver formation, Table Mountain, Golden, Colo. B. 148, p. 159.
   5, Monzonite, Lake Albion stock. Courtesy E. E. Wahlstrom, analyst, Boulder, Colo.
   6, Syenite, Lake Albion stock. Courtesy E. E. Wahlstrom, analyst, Boulder, Colo.

2. 4, Early basalt of Table Mountain, Golden, Colo. M. 27, p. 308.
   5, Basalt of Table Mountain, Golden, Colo. M. 27, p. 306.
   6, Diabase of "Iron dike," Sugarloaf, Gold Hill district. B. 228, p. 187.
   7, Gabbro, 1 mile south of Caribou. P.P. 94, p. 43.
   8, Dolerite, Valmont dike, east of Boulder. M. 27, p. 301.

3. 1, Monzonite, Caribou district. P.P. 94, p. 43.
   2, Monzonite, Caribou district. P.P. 94, p. 43.
   3, Monzonite, Caribou district. P.P. 94, p. 43.
   4, Quartz monzonite, 1 mile south of Caribou. P.P. 94, p. 43.

4. 6, Granodiorite, Jamestown district. J. G. Fairchild, analyst, U.S.G.S.

5. 41, Quartz monzonite porphyry, Mount Guyot, Breckenridge district. P.P. 75, p. 58.

6. 3, Quartz monzonite porphyry, Brewery Hill, Breckenridge district. P.P. 75, p. 45.

7. 1, Nevadite, Chalk Mountain, Leadville district. M. 12, p. 589.

8. 1, Hornblende monzonite, Nederland district. J. G. Fairchild, analyst, U.S.G.S.
   2, Alkali syenite, Idaho Springs district. P.P. 63, p. 134.
   3, Alkali granite quartz monzonite, Jamestown district. J. G. Fairchild, analyst, U.S.G.S.

9. 1, Trachyte, Sunset district. C.S.S. 6, p. 228.
   2, Bostonite, Idaho Springs district. P.P. 63, p. 134.

10. 1, Biotite monzonite, Nederland district. J. G. Fairchild, analyst, U.S.G.S.
    2, Biotite latite, Idaho Springs district. P.P. 63, p. 134.

11. 1, Biotite latite intrusion breccia, Nederland district. J. G. Fairchild, analyst, U.S.G.S.

12. 1, Limburgite, Nederland district. J. G. Fairchild, analyst, U.S.G.S.

The analyses for which the analyst is listed have not been published previously.

Abbreviations: A. R., Annual report of the U. S. Geol. Survey; B, bulletin of the U. S. Geol. Survey; C.G.S., bulletin of the Colorado Geol. Survey; C.S.S., Proceedings of the Colorado Sci. Soc.; M, monograph of the U. S. Geol. Survey; P.P., professional paper of the U. S. Geol. Survey.

formations record the beginning of the igneous activity that culminated with the formation of the porphyry belt. The relation of the intrusives to faults formed during the Laramide revolution shows that intrusion continued intermittently throughout the considerable span of time during which the Laramide revolution was in progress. It is difficult to date the latest dikes precisely, but there is no reason to believe that they are much later than the other porphyritic rocks. The pitchblende ores of the Central City district, which are closely associated with the bostonite and sodic quartz monzonite porphyries of the mineral belt, have a lead-uranium ratio indicating an age of approximately 60,000,000 years, suggesting an early Tertiary age. This information harmonizes with the other evidence of the Paleocene and early Eocene age of the intrusives of the porphyry belt.

The presence of interbedded tuffs and lavas at the base of the Denver formation in South Park and their absence at this horizon in the Denver basin suggest that either sedimentation began earlier in the Denver basin than on the western slope or that igneous activity occurred earlier on the western slope than in the eastern drainage area. Broad regional studies [75] support the conclusion that igneous activity began in the west and progressed slowly toward the eastern front of the Rocky Mountain system. Thus, it is probable that correlation of similar rocks in different parts of the Front Range is not a correlation of time equivalents but rather of facies equivalents. During the Laramide revolution orogenic movements of definite types occurred in the same order, though not necessarily synchronously, over wide areas. The igneous rocks of the Laramide revolution on the western slope seem involved in more orogenic movements than the corresponding members of the igneous sequence on the eastern slope. (See fig. 12.) This fact suggests that orogenic movements may have been more nearly contemporaneous in different parts of the Front Range than the correlative igneous rocks. The general order of Laramide orogenic events is suggested in figure 12 and is summarized below.

1. The intrusion of sills and dikes of felsite porphyry (fig. 10, *D*) and hornblende andesite in the southwestern part of the porphyry belt during late Laramie and early Denver time, while dikes and stocks of aluminous augite andesite were being intruded in the central part of the rising Front Range arch, with attendant extrusive activity.

2. The beginning of folding and faulting along northwesterly axes throughout the Front Range, accompanied by the intrusion of dikes and small irregular stocks of porphyritic augite diorite on the western slope and extensive northwesterly dikes of gabbro and diabase (fig. 10, *E*), on the eastern slope; also by the extrusion of basalt and mafic andesite from many scattered vents in the central part of the Front Range.

3. The intrusion of rhyolite and some quartz monzonite porphyry in South Park, the intrusion of porphyritic hornblende-quartz monzonite and andesite in the region near Ward and the extrusion of rhyolite and rhyolite tuff from the Pikes Peak volcanic vent somewhat later, near the close of Denver and Dawson time.

4. The culmination of northwesterly faulting and overthrusting and the intrusion of stocks and sills of porphyritic hornblende diorite (fig. 10, *F*) and hornblende monzonite in the southwestern part of the mineral belt; also the intrusion of stocks and dikes of porphyritic granodiorite (fig. 13, *A*), hornblende monzonite, hornblende diorite, and of andesite porphyry in the northeastern half of the porphyry belt. It is probable that the porphyritic rocks of the Radial Mountain-Home belt were intruded at about this time also.

5. The intrusion of hornblende and biotite-quartz monzonite porphyries as sills and dikes throughout the porphyry belt.

6. The intrusion of coarsely porphyritic biotite-quartz monzonite of the Lincoln porphyry type (fig. 13, *B*) in the southwestern half of the mineral belt and the intrusion of medium-grained biotite-quartz monzonite porphyries in the northeastern half of the belt, together with sodic quartz monzonite and latite porphyries. The great bulk of the porphyritic rocks in the southwestern half of the mineral belt were intruded during epochs 4, 5, and 6.

7. The intrusion of rhyolite (fig. 13, *C*), alaskite, and felsite porphyries throughout the mineral belt and formation of lead-silver ores in the region from Caribou southwestward.

8. The intrusion of alkalic syenite, alkalic diorite, and sodic granite (fig. 13, *D*) in the northeastern half of the mineral belt, followed by pyritic gold and sparse lead-silver-zinc mineralization.

9. The intrusion of bostonite porphyry (fig. 13, *E*) and alkalic trachyte porphyry in the northeastern half of the mineral belt, followed by extensive pyritic gold mineralization.

10. The intrusion of biotite latite (fig. 13, *F*) and biotite monzonite porphyries rich in volatiles in the northeasternmost portion of the mineral belt.

11. The injection of latitic intrusion breccias (fig. 17, *A*) in dikes and pipes in the northeastern half of the mineral belt, followed almost immediately by gold-telluride mineralization.

12. Intrusion of limburgite (fig. 17, *B*) dikes in the tungsten belt followed by the formation of tungsten ore bodies.

[75] Ore deposits of the Western States (Lindgren volume), pp. 152–180, Am. Inst. Min. Met. Eng., 1933.

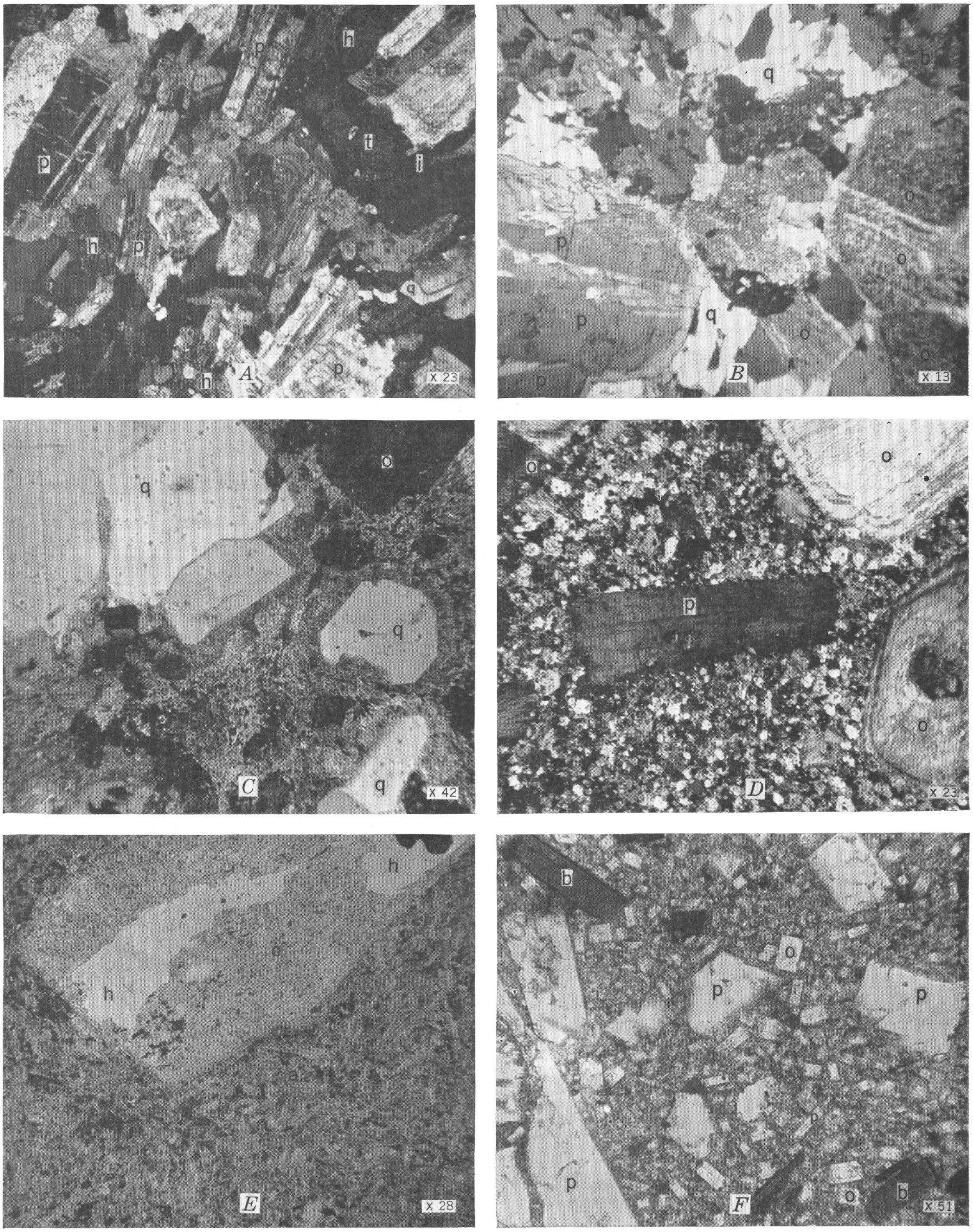


FIGURE 13.

AGE RELATIONS IN THE RADIAL MOUNTAIN-HOME BELT OF PORPHYRITIC ROCKS

At the head of the Cache la Poudre and Laramie Rivers, near Cameron Pass, a series of Miocene lavas rests on erosion surfaces cut chiefly in the pre-Cambrian rocks. The surfaces range in age from the Eocene Flattop peneplain to the Miocene Overland Mountain surface. A mile south of Cameron Pass, according to Spock [76] at an altitude of approximately 10,400 feet, an ancient erosion surface bevels hornblende gneiss and an intrusive rhyolite dike and is covered by an obsidian flow. Neither the writers nor Gorton [77] have been able to verify this interesting observation; the only obsidian found by them in the area described by Spock is an obsidian dike that lies between walls of pre-Cambrian gneiss and dips gently to the north where it is well exposed. Gorton's work shows that the granodiorite at Lake Agnes, 2 miles south of Cameron Pass, is part of a large stock that extends many miles farther south along the crest of the Never Summer Range. It is later than a great overthrust fault that underlies the entire north end of the range except where cut out by the stock; the fault has a known horizontal displacement of more than 6½ miles. The granodiorite was beveled by erosion and covered with volcanics from the Specimen Mountain Volcano, which is pre-Pleistocene according to Wahlstrom,[78] and is probably later than lower Miocene, as Gorton discovered that the earliest flows in the area are interlayered with beds of conglomerate about 800 feet above the base of the formation provisionally correlated with the lower Miocene conglomerates of the Granby area 25 miles to the south (see p. 41).

It seems probable that the granodiorite at Lake Agnes immediately followed the stage of overthrusting that marked the culmination of the Laramide revolution. Some lead-silver-zinc mineralization attended the intrusion of the stock, but the deposits in the Never Summer Range have not been worked for several decades and have not been studied as yet.

Northeast of Cameron Pass there are many dikes and small stocks probably intruded at the time of the Laramide revolution, ranging in composition from diorite to quartz monzonite, but their relation to the late Tertiary volcanoes has not been ascertained. They are especially abundant in the Manhattan district, about 20 miles northeast of the pass, and are associated with some mineral deposits. In that district they are cut by an erosion surface believed to be early Miocene; the intrusives are therefore tentatively associated with the Laramide revolution. The intrusive rocks of the Manhattan district are chiefly hornblende monzonite porphyries (see pp. 285–286).

DIFFERENTIATION

The variation in chemical composition in the rock series of the mineral belt is shown in plate 7, which indicates the general course of magmatic differentiation. As the detailed discussion of differentiation in the mineral belt already published [79] may not be readily available to some readers, the general conclusions reached are repeated below.

The succession of igneous rocks of the Laramide revolution suggests the widespread fusion of a deep crystalline substratum at the time the early augite diorite was intruded on the western slope and the olivine gabbro was intruded on the eastern slope. This deep magma was the parent of the many types of porphyritic rocks found throughout the mineral belt; its composition approximated that of the augite diorite under the western part of the range but was more mafic to the east, where its composition was that of an olivine gabbro. A very slow cooling of the deep-source magma allowed time for nearly complete reaction between the liquid and the crystals that formed from it. Apparently neither crystal settling nor crystal zoning was important in changing it during solidification. Instead, the com-

[76] Spock, L. E., Jr., Geological reconnaissance of parts of Grand, Jackson, and Larimer Counties, Colo.: New York Acad. Sci. Annals, vol. 30, pp. 195, 196, 240, 241, 1928.

[77] Gorton, K. A., Geology of the Cameron Pass area, Grand, Jackson, and Larimer Counties, Colo. Unpublished doctoral thesis, University of Michigan, 1941.

[78] Wahlstrom, E. E., Structure and petrology of Specimen Mountain, Colo.: Geol. Soc. America Bull., vol. 55, pp. 77–90, 1944.

[79] Lovering, T. S., and Goddard, E. N., Laramide igneous sequence and differentiation in the Front Range of Colorado: Geol. Soc. America Bull., vol. 49, pp. 35–68, 1938.

EXPLANATION OF FIGURE 13

[Groups referred to are those shown in fig. 12]

A, Photomicrograph of porphyritic granodiorite typical of rocks of group 4 from stock half a mile south of Jamestown. The primary alinement of feldspars responsible for the platy structure of the intrusive is clearly shown. *i*, Ilmenite; *h*, hornblende; *p*, plagioclase (andesine); *q*, quartz; *t*, titanite. Crossed nicols.

B, Photomicrograph of porphyritic quartz monzonite from center of large stock 2 miles northeast of Montezuma, typical of Lincoln porphyry, group 6. Note fresh appearance of plagioclase and deuteric alteration of orthoclase. *b*, Biotite; *o*, sericitized orthoclase; *p*, plagioclase (andesine); *q*, quartz. Crossed nicols.

C, Photomicrograph of rhyolite porphyry of group 7 from dike 1 mile north of Argentine Pass. The phenocrysts have borders of fine-grained oriented quartz in the groundmass. *o*, Sericitized orthoclase; *q*, quartz. Crossed nicols.

D, Photomicrograph of sodic granite porphyry of group 8 from dike three-eighths of a mile south of Jamestown. Fresh plagioclase and deuterically altered zoned orthoclase in microgranular groundmass of quartz and orthoclase. *p*, Plagioclase (albite-oligoclase); *o*, orthoclase. Crossed nicols.

E, Photomicrograph of bostonite of group 9 from dike 750 feet north of reservoir, Central City. Phenocryst of orthoclase in groundmass of anorthoclase blades, which show marked flow structure. *a*, Anorthoclase, *o*, orthoclase; *h*, hole in slide. Plain light.

F, Photomicrograph of biotite latite porphyry of group 10 from dike in the Stanley mine west of Idaho Springs. Note fragmentation of plagioclase and abundance of biotite. Groundmass is partly glass. *p*, Plagioclase (andesine-oligoclase); *o*, orthoclase; *b*, biotite. Plane polarized light.

position of the residual liquid changed during crystallization of the magma in almost exactly the reverse of the way that it changed during the period of magma generation, when the crystalline substratum was gradually being fused. Thus the curve of solidification was almost the reverse of the curve of liquefaction. Withdrawal of portions of the changing residuum of the slowly solidifying magma into shallow reservoirs and further differentiation by the subtractive processes of crystal settling, crystal zoning, and filter-pressing occurred several times in the eastern part of the range and gave rise to distinct differentiation series: Diorite, monzonite, quartz monzonite, granite, alaskite, lead-silver-zinc ores; alkalic syenite, bostonite, pyritic gold ores; and biotite monzonite, biotite latite, latitic intrusion breccia, gold-telluride ores, and tungsten ores. On the western slope the differentiation series ranging from porphyritic diorite through porphyritic quartz monzonite to granite porphyry represents subtractive differentiation in comparatively shallow hearths and is closely comparable in its physical chemistry to the corresponding differentiation series on the eastern slope. The late differentiates of the olivine gabbro magma, however, were much more alkalic than those of the augite diorite magma because of the initial difference in composition of the parent magma. Although most of the differentiation was due to crystal settling, zoning, and filter-pressing, some desilication of the magma in the shallow hearths occurred locally during the emanation of silica-rich volatiles that were absorbed by reactive roofs. This process probably explains some of the late dikes and the corrosion of the early quartz phenocrysts that is so conspicuous in many of the late porphyries. Locally the departure of volatiles and the accompanying desilication was accompanied by remelting of the magmatic shell or crust and by the formation of a composite stock whose rock facies differed only slightly from one another in composition.

In each successive differentiation series and in each succeeding member within a differentiation series an increasing concentration of volatiles is evident.

POST-EOCENE IGNEOUS ROCKS

EXTRUSIVE ROCKS

The post-Eocene extrusive rocks of the Front Range occur chiefly in two widely separated areas. Miocene extrusives occur in the region drained by the headwaters of the Cache la Poudre and Colorado Rivers near the northwestern part of the Rocky Mountain National Park, and Oligocene and Miocene lavas are widespread in the southwestern part of the Front Range in the region west of Cripple Creek between the Arkansas River and the South Platte River. Interbedded lower Miocene bone-bearing conglomerates prove that the lower part of the lava series of the Rocky Mountain National Park region is of Arikaree age, but the age of the upper members is less certain. The amount of erosion undergone suggests that very few of them can be later than early Pliocene. The Tertiary rocks of this region include trachyandesite (?), rhyolite, obsidian, basalt, and rhyolitic and andesitic tuffs and agglomerates according to Spock,[80] but the work of Wahlstrom [81] indicates that Spock's trachyandesite is more properly termed quartz latite. With the exception of this rock the flows are limited in extent, and the succession differs somewhat from place to place.

The oldest volcanic rock in the region, according to Gorton,[82] is basalt, which was followed successively by andesite, tuff and agglomerate, quartz latite, rhyolite, and obsidian. The andesite is interlayered with conglomerates that are probably of lower Miocene age (see p. 41). The tuffs and agglomerates were spread on a land surface of much relief and were covered by latitic lava flows. The basalt and andesite flows are comparatively small, and the most extensive lava fields are made up of several flows of dense dark-colored quartz latite and amygdaloidal lavas younger than the tuffs and older than the rhyolite of Lulu Mountain, just east of Cameron Pass. Most of the rhyolites are white to light-gray porphyritic felsites, but spherulitic rhyolites occur locally. On Lulu Mountain the rhyolite flows aggregate 900 feet in thickness and form a mesa covering 5 square miles; the quartz latite flows underlying the rhyolite aggregate are approximately 800 feet thick. The center of this volcanic activity was probably at Specimen Mountain, 12 miles northwest of Estes Park.[83]

Specimen Mountain is a deeply eroded pre-Pleistocene volcano according to Wahlstrom, and the extensive series of pyroclastics and flows found in the surrounding region probably came from this vent. Near the volcanic throat the flows and breccia beds are strongly tilted and faulted, but the volcanic rocks a few miles north show little fracturing. The composition of the extrusive rocks ranges from quartz latite to silicic rhyolite, and the intrusive volcanic plug is rhyolite. The volcanic rocks were spread on a surface of moderately strong relief; 3 miles east of the volcano, at Iceberg Lake, an ancient northeastward-trending valley, cut 500 feet below the Flattop peneplain to an altitude of 11,500 feet, was filled with rhyolite.

The late Tertiary lavas of the southern Front Range can be followed southward into the Wet Mountains and westward into the Arkansas Valley near Salida. As the lavas in these two localities are commonly believed to be eastern outliers of the great San Juan volcanic field, the extrusives in the southern Front Range seem

[80] Spock, L. E., Jr., op. cit. pp. 195–241.
[81] Wahlstrom, E. E., op. cit.
[82] Gorton, K. A., op. cit.
[83] Wahlstrom, E. E., op. cit.

to mark the extreme northeastern extension of the Tertiary volcanics that had their greatest development in the San Juan Mountains of southwestern Colorado.

In the region between Cripple Creek and Salida and north of the Arkansas River the earliest Tertiary volcanic rocks are nearly everywhere light-colored tuffs, generally subaerial but locally water-laid. Overlying them with erosional unconformity is a dark-colored andesitic and basaltic breccia, which in many places lies directly upon pre-Tertiary rocks. The light-colored late Oligocene or early Miocene water-laid tuffs of the Florissant lake beds are overlain by this type of breccia; according to Cross [84] they probably record the earliest volcanic activity of the volcanic center that lies west of the Pikes Peak quadrangle. The early tuffs found farther west and southwest are also of Oligocene age [85] and are tentatively correlated with the Florissant lake beds by the writers.

The andesitic and basaltic breccia covers an area of more than 100 square miles in the western half of the Pikes Peak quadrangle and the southern half of the adjoining Black Mountain quadrangle; it ranges in thickness from a mere film to more than 2,000 feet. It is a poorly bedded subaerial deposit that includes fine-grained tuffs, agglomerates, and moderately coarse breccias, and locally contains interlayered flows of olivine basalt. In the southwestern part of the Pikes Peak quadrangle, where it is thickest, the lower part is made up of rocks whose composition ranges from that of olivine basalt to that of pyroxene andesite; its upper part is made up of rocks of more salic character, such as hornblende andesite and trachyte.

The breccia is cut by dikes of augite andesite and is locally covered by flows of the same rock. These dikes and flows are in turn cut by dikes, sheets, and irregular masses of hornblende and mica andesite.

A light-colored porphyritic trachyte covers rather large areas in the Black Mountain quadrangle in the southern part of South Park and in the central western part of the Pikes Peak quadrangle south of Lake George, where it occurs as flows on pre-Tertiary rocks and on the andesitic and basaltic breccia to whose uppermost beds it has contributed some debris. South of Hartsel the trachyte rests on light-colored beds of Oligocene arkose, tuff, and marly limestone, which in turn rest on the basaltic and andesitic breccia.

In addition to the widespread Oligocene tuffs and breccias described above there are local areas of tuffs that mark volcanic centers. Belonging to this type are those found near Cripple Creek, in the Bare Hills area, about 15 miles to the west, and near Signal Butte about 10 miles north of Florissant. The tuffs of the Cripple Creek volcano are phonolitic, but those of the other localities are andesitic.

Ash-gray or pink rhyolite is widely distributed as small remnants of surface flows; in the southwestern part of the Pikes Peak quadrangle northwest of Canon City it has a marked banded spherulitic structure and is locally interbedded with rhyolitic tuffs. In many places this rhyolite filled narrow shallow gorges cut in the early tuff or in the basaltic and andesitic breccia. Its age relationship to most of the volcanic rocks is not certainly known, though it is younger than the Florissant lake beds and earlier than the Cripple Creek phonolites.

INTRUSIVE ROCKS

With the possible exception of the few post-ore dikes in the mineral belt that are referred to the Eocene but that may be later, the post-Eocene intrusives of the Front Range are limited to the regions of Miocene extrusives in the Rocky Mountain National Park region and in the southern portion of the Front Range.

In the southern part of the Front Range there are many dikes of andesite and related rocks cutting the Oligocene and Miocene volcanics. The dikes of basalt found in the andesitic and basaltic breccia are the oldest Tertiary intrusives recognized in the region. The breccia is also cut by many dikes of augite andesite, which are for the most part younger than the basalt dikes. Hornblende and biotite andesite dikes cut the augite andesite dikes. The rhyolite of the Cripple Creek district is probably contemporaneous with the rhyolite flows to the southwest and is older than the phonolite series of the adjacent volcano. Neglecting intermittent subsidence, the order of events recorded in the Cripple Creek crater as worked out by Lindgren and Ransome [86] and by Loughlin and Koschmann [87] is as follows: (1) Intrusion and extrusion of phonolite in explosive volcanic outburst with the resultant formation of the phonolitic breccia in the volcanic neck; (2) intrusion of dikes, sills, and irregular masses of latite-phonolite (23 percent of the intrusives) and small necks and dikes of syenite and trachyphonolite; (3) intrusion of phonolite dikes and plugs (73.5 percent of the intrusives); (4) intrusions of dikes of vogesite and monchiquite; (5) dikes of trachydolerite; (6) intrusion of pipe of basaltic breccia ("Cresson blowout") and accompanying local dikes of basalt; and (7) deposition of gold ores. (See description of Cripple Creek district on pp. 291–298 for further details.)

[84] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Pikes Peak folio (no. 7), p. 2, 1894.

[85] Stark, J. T., Johnson, J. H., Behre, C. H., Powers, W. E., Howland, A. L., and Guild, D. B., History of South Park Colo. (abstract): Geol. Soc. America Proc., 1935, pp. 107–108, 1936.

[86] Lindgren, Waldemar, and Ransome, F. L., Geology and ore deposits of the Cripple Creek district, Colo.: U. S. Geol. Survey Prof. Paper 54, pp. 23, 32, 113, 1906.

[87] Loughlin, G. F., and Koschmann, A. H., Geology and ore deposits of the Cripple Creek district, Colo.: Colorado Sci. Soc. Proc. vol. 13, no. 6, pp. 242–252, 1935.

The intrusives of the other volcanic centers in the southern Front Range have been little studied petrographically, but in the field the intrusive rocks of the Bare Hills and Signal Butte areas appear to be andesitic types; the small stock near Guffey is an augite-biotite monzonite.

STRUCTURE

PRE-CAMBRIAN STRUCTURE

Throughout the Front Range the foliation of the metamorphic rocks is nearly everywhere parallel to the original bedding of the ancient sediments and the flow structure of the interbedded lava flows. Open folds, tight isoclinal folds, and complex contortions are all common in these early metamorphic rocks. Locally, along planes of marked pre-Cambrian faulting, the foliation is parallel to the later structural feature. Most of the earlier pre-Cambrian intrusive rocks were intruded as thin sill-like masses parallel to the foliation of the metamorphic rocks. This concordant habit becomes less and less marked in the younger intrusives. In most places where the primary gneissic structure at the borders of the early orthogneisses is distinct it is parallel to the foliation of the enclosing schist, but locally it is discordant.

STRUCTURE OF THE GRANITES

The linearity of outcrop noted in the very early pre-Cambrian intrusives is not as evident in rocks belonging to the Boulder Creek granite series. Application of the Cloos method for interpreting the shapes and attitudes of intrusive bodies suggests that the individual masses of Boulder Creek granite are funnel-shaped and that the parallelism between the enclosing rock and the platy structure of the Boulder Creek granite series may therefore be due in part to the enlarging of the upward-moving body of magma and the consequent lateral thrusting that must have taken place.

The coarse-grained masses of Pikes Peak granite break across the foliation of the country rock in many places, but very commonly the contact between the two is parallel to the foliation of the metamorphic rock. Some of the smaller masses of Pikes Peak granite have the structure of compressed funnels illustrated by the stock northwest of Jamestown, whose long axis trends northward and whose sides dip steeply toward the center of the mass. Where they have been studied, the walls of the larger bodies of Pikes Peak granite are usually very steep or dip outward at angles steeper than 50°, but the northern contact of the Pikes Peak batholith a few miles south of Schaffers Crossing dips southward at a low angle.

Moderately fine-grained later pre-Cambrian granites of the Silver Plume type very commonly cut across the foliation of the schists and gneisses, but contacts parallel to the foliation of the early schists and gneisses may predominate locally. Granites of the Silver Plume type were apparently less effective in imposing foliation on the metamorphic rocks than were the older granites. Insufficient work has been done thus far to allow generalization regarding the shapes of the intrusives in the Silver Plume, but M. F. and C. M. Boos,[88] as well as the writers, have found evidence of many local centers of intrusion within batholiths of Silver Plume granite. In some places the coalescing of granite masses that were fed from relatively small scattered conduits at depth has resulted in a composite batholith. In such bodies of granite, some areas apparently rich in roof pendants or schist inclusions prove to be underlain by a continuous mass of schist forming the country rock of the narrowing granite conduit.

Pegmatites and aplites related to each of the intrusive granites are especially common along their borders, both on the under and upper sides of the intrusive masses. The structural relations of pegmatites containing such unusual minerals as beryl and the rare-earth minerals have not yet been worked out in detail, though it is evident that they occur close to the borders of the related granite masses (see pp. 21, 65).

The distribution of the various granites in the Front Range so far as known is shown on plate 1.

STRUCTURE OF THE METAMORPHIC ROCKS

Although it is difficult not to describe certain areas in too much detail and to deal too hurriedly with others, the writers have tried in the following description to present a balanced picture of the region and to give only the general structure of the metamorphic rocks.

In the southern part of the Front Range, north of Parkdale, the regional trend of the schist is from N. 30° to 40° E., but insufficient work has been done to establish the details of the structure. Near Guffey, just southeast of its contact with a stock of Boulder Creek granite, the schist dips southeastward at approximately 65°. It contains quartz and sillimanite, is of sedimentary origin, and apparently belongs to the Idaho Springs formation. A few miles southeast of Guffey this schist abuts against a small batholith of Cripple Creek granite. Farther southeast, about 7 miles northwest of Canon City, a triangular mass of schist containing interbedded quartzite extends in an easterly direction along the southern border of this batholith; farther east, beyond Oil Creek, it continues eastward along the south edge of the main Pikes Peak batholith. (See plate 1.) Along the Phantom Canyon road south of Cripple Creek clearly defined anticlines and synclines in this schist are well exposed. The oldest rocks noted here are quartzite beds, which

[88] Boos, M. F., and Boos, C. M., Granites of the Front Range: Geol. Soc. America Bull., vol. 45, p. 331, 1934.

form the cores of anticlines spaced approximately one mile apart. The axes of the anticlines plunge steeply to the east, and the general strike of the schists and the axes of the folds is N. 80° W. The foliation of the overlying schists is parallel to the bedding of the quartzite and is a good example of the close parallelism between foliation and original structure common throughout the Front Range. Mapping of the quartzite has been somewhat generalized in the Pikes Peak folio,[89] and the associated schists are not shown, but apparently the quartzite member extends west-northwest from Phantom Canyon, where they are 4,000 feet thick, to the edge of the Paleozoic beds in the valley of Oil Creek, beneath which they are hidden for a short distance, reappearing again in the region northwest of Canon City.

A similar bed of quartzite has been mapped by Cross in the northern part of the Pikes Peak quadrangle.[90] It extends north-northwest through Blue Ridge southwest of Florissant and farther north appears again west of Lake George, where it swings sharply to the west. The regional strike of the associated schist northwest of Lake George is N. 60° W., and the dip is approximately 60° N.; however, as the western side of the Pikes Peak batholith is followed northward from Lake George a marked change in the regional foliation is apparent. A few miles northwest of Tarryall, schist typical of the Idaho Springs formation is exposed along Tarryall Creek for 12 miles. The schist is closely folded, and many anticlines and synclines can be observed along the Tarryall Creek road. Here the general strike of the schist is N. 45° E., but in Lost Park, 8 miles to the northeast, the regional trend is N. 60° W., and the prevailing dip is almost invariably 25° to 50° NE. A few miles northwest, the strike swings sharply west and then southwest, and the schist dips approximately 35° NW. At the extreme eastern edge of Lost Park, between Pikes Peak granite and a small body of granite gneiss, a mass of schist dips east at about 45°. As shown on plate 1, the regional structure suggests a broad northeastward-plunging anticline, whose nose is nearly 5 miles across. On the crest of the ridge between Lost Park and Tarryall Creek the uniform northwesterly trend of the schists suddenly changes to a series of tight northeastward-trending folds. Their structure is parallel to and in harmony with that previously mentioned for Tarryall Creek a few miles farther southwest.

Northeast of Lost Park the northeastward-dipping structure continues for many miles and is prominent in the valleys of the North Fork of the South Platte between Bailey and Shawnee. To the northeast, the broad nose of the Lost Park anticline widens until in the region immediately north of the North Fork of the South Platte it has passed into a crumpled monocline, which trends at right angles to the axis of the anticline to the southwest. This is not an uncommon type of structure in the Front Range.

In the region between Bailey and Georgetown the regional trend of the schist in most places conforms rather definitely to the outlines of the irregular northwestward-trending mass of Pikes Peak granite and associated Boulder Creek granite. Ball[91] notes that on the western and southern sides of the batholith of "Archean quartz monzonite" (Boulder Creek granite) in the Georgetown quadrangle the encompassing schist, as well as the schistosity developed in the monzonite, in general dips steeply away from the batholith, although locally the dip is toward it. The general southerly dip on the south side of the batholith indicates the presence of a syncline between the "Archean quartz monzonite" mass and the North Fork of the South Platte 8 miles to the south. An eastward-trending area of hornblende gneiss appears on the map of the Georgetown quadrangle approximately where the axis of the syncline should lie and probably marks the continuation of a syncline northwest of Cassells which also trends northeastward and has hornblende gneiss in the middle. From the eastern border of the Pikes Peak granite batholith where the main stream of the South Platte River joins the North Fork of the South Platte to where the South Platte River leaves the pre-Cambrian area, the regional dip of the schists is northeast at angles ranging from 20° to 75°.

Along the western edge of the Front Range east of Breckenridge the sedimentary schists of the Idaho Springs formation dip east-northeast at a low angle and underlie an extensive mass of isoclinally folded hornblende gneiss about 4 miles in width. Where the Idaho Springs formation reappears at the eastern side of the gneiss its dip is nearly vertical. North of the latitude of Breckenridge this synclinal body of hornblende gneiss has a general north-northwesterly trend, but to the south it swings sharply to the south-southwest, disappearing under the Mesozoic and Tertiary sedimentary rocks at the northern edge of South Park. This crenulated syncline rises gradually toward the north, and only a few minor troughs of hornblende gneiss remain where the metamorphic rocks are cut off by the southern edge of the batholith of Silver Plume granite about 10 miles northeast of Breckenridge.

Along the northern edge of this batholith, about 15 miles farther north, the regional dip of the schists and gneisses is 45° to 60° SE. The structure reverses a few miles from the border of the granite, and a belt of hornblende gneiss is exposed in the center of this anticline;

[89] Cross, W., U. S. Geol. Survey Geol. Atlas, Pikes Peak folio (no. 7), 1894.

[90] Idem., p. 1.

[91] Spurr, J. E., Garrey, G. H., and Ball, S. H., Economic geology of the Georgetown quadrangle, Colo.: U. S. Geol. Survey Prof. Paper 62, pp. 51–52. 1908.

it apparently underlies schists of sedimentary origin, which seem equivalent to the Idaho Springs formation. The schists lying just southeast of the hornblende gneiss extend northeastward across the Fraser River, where they swing to the north and finally to the northwest, dipping 60° NE., where they disappear under Tertiary beds east of Fraser. This sharp swing marks the nose of the anticline that has the hornblende gneiss at its center southwest of the Fraser River. On the northern side of the Tertiary cover, a few miles north of Tabernash, the regional dip of the schist is about 60° NW. In the Williams Range, nearly due west of the hornblende gneiss area, the regional dip of the schists is also about 60° NW., suggesting that the hornblende gneiss is near the center of an unusually persistent anticline.

In the eastern part of the Montezuma quadrangle, about 15 miles east of Breckenridge, detailed studies show that the sedimentary formations of the Idaho Springs formation are closely folded and that the local structures are strongly influenced by the stocks and batholiths of Boulder Creek granite nearby. The regional trend of this folding is nearly due north in the southern part of the quadrangle, but it swings to the northeast near the latitude of Montezuma. Two zones of quartzitic schist, ranging from siliceous quartz biotite schist to schistose quartzite, can be traced from the southern part of the quadrangle north-northeast to the vicinity of Silver Plume and Georgetown, where they swing east and are cut off by the western edge of a batholith of Boulder Creek granite. Beds of quartzite appear on the eastern side of the batholith several miles to the east and have been traced for some distance east-southeast of Squaw Mountain. It is uncertain whether these zones are the same and mark the repetition of one bed or whether they are separate members.

In the region east and northeast of Georgetown and Idaho Springs a few large regional folds have been noted. About one mile north of Idaho Springs a marked syncline can be traced N. 60° E. for several miles. East of the North Fork of Clear Creek the trough of the syncline is cut by a mylonitic zone striking N. 45° E., and the southern limb of the fold is cut out. A parallel syncline appears just southeast of the mylonitized zone, but its northwest limb is greatly thinned along the shear zone that separates them. This second syncline, which is occupied in part by hornblende gneiss, extends northeastward nearly 5 miles, then swings south-southeast for a short distance before assuming the nearly due-east trend that it shows just before it disappears under the Pennsylvanian sedimentary rocks 3½ miles north of Golden.

Between the North Fork of Clear Creek and the eastern foothills the mylonitized zone that marks the northern edge of this syncline is one of the most conspicuous pre-Cambrian faults in the Front Range. Although much of the movement along it took place before the intrusion of the Boulder Creek granite, movement continued after the granite had solidified. The northern side of the fault is downthrown and is marked by the truncated northeastward-trending syncline of quarzite at Coal Creek. (See p. 23).

About 5 miles north of Idaho Springs there is a northeastward-trending anticline whose axis passes through Central City. This anticline is conspicuous for several miles to the northeast, but to the southwest it passes into a northward-dipping monocline and has not been observed south of Fall River, about 2 miles west of Idaho Springs. About 6 miles northwest of Central City a northeastward-plunging syncline is present and becomes very marked as it is followed south-southwest. It cannot be traced far to the northeast, for it broadens in this direction, and in a comparatively short distance the trend of the schist in what was the trough of the fold has become the regional direction of a crumpled monocline. On Boulder Creek, about 8 miles north of Central City, the regional structure of the schist is north to N. 30° W., and its dip is 50° to 80° E., from the western edge of the batholith of Boulder Creek granite to the east of the Moffat tunnel, a distance of approximately 8 miles; just west of the portal the foliation swings to the northwest and west around the nose of a marked regional anticline that plunges toward the north. On the western side of this anticline the schist dips approximately 65° NW. This anticline can be traced north-northeast from near Empire to the western part of the Caribou mining district 12 miles away. Only the south portion of the syncline that lies to the west is visible; it may be seen at the head of Jim Creek a few miles southeast of West Portal. As the trough is followed northward it is cut off by the Moffat tunnel shear zone, which brings the steeply dipping western and eastern limbs into immediate contact with each other by eliminating the transitional trough—the inverse of the relation existing along the Coal Creek shear zone (pls. 1 and 2). Along the tunnel line the westerly and northwesterly dip of the beds is evident on the surface as far west as Rifle Sight notch, where the shear zone that caused a large part of the heavy ground found in driving the Moffat tunnel crops out. As noted previously, the prevailing dip of the beds on the western side of the shear zone is east-southeast at 60° to 65°.

About 3 miles north of Nederland the strike of the eastward-dipping schists that border the batholith of Boulder Creek granite swings east-northeast, and the dip changes to 60° N. This structure prevails as far north as Ward, where the schist gives way to granite. In the band of northward-dipping schist crumpling is very evident, but no well-marked anticlines and synclines have been noted. As this band of schist is followed eastward it swings sharply northeastward within a few miles, following the northwestern side of the Boulder Creek granite batholith. The northerly dips change abruptly north of Gold Hill, and from here to the foothills the Boulder Creek granite is bordered by southeastward-dipping schist. Several anticlines and synclines have been recognized in this area by Goddard.

A small stock of gneissic granite lying between Monarch Lake and the Lake Albion porphyry stock has been unroofed along the valleys of East Fork and Cascade Creek, and the concordance of the schist with the top of the stock is well shown (pl. 2). Along the Continental Divide to the east of the stock, quartz-biotite schist and the overlying hornblende gneiss dip 20° to 30° E. In the valley walls to the north of East Fork the schist dips north or northwest at 10° to 20°, and on the south side of the valley at Thunderbolt Peak it dips south-southeast at 25°. From Monarch Lake westward the metamorphic rocks dip west or northwest at 25° to 60°. Thus the granite forms the core of an anticline, which can be traced northeastward for several miles, but to the southwest it is cut off by a small batholith of Boulder Creek granite.

The region lying north of Allens Park has received less attention by the writers than that already described and has been studied chiefly by M. F. Boos.[92] As shown on plate 1, there is much granite east of the Continental Divide between the latitudes of Jamestown and the northern edge of the Rocky Mountain National Park quadrangle. On the western side of the Continental Divide the prevailing trend of the schist is east to northeast, and the prevailing dips are to the north or northwest at from 45° to 70°. On the eastern side of the divide the prevailing strike of the schist is north, and the dips are from 20° to 70° E. This foliation suggests that, like the East Fork stock, the other granite stocks near the Continental Divide were intruded along the middle of a northward-trending anticline or that they domed the metamorphic rocks.

The schists at the edge of the Front Range just north of the Little Thompson River are clearly of sedimentary origin and dip about 65° E. A quartzitic zone in these schists can be followed northward and northeastward for several miles to where the Big Thompson River leaves the pre-Cambrian terrain. Two miles south of the river the schists dip south-southeast at 65°, but the quartzitic layers are folded sharply back on themselves, and the Big Thompson River follows the trough of a syncline that plunges east-southeast. On the south side of the river the schists dip north or northeast at 60°, but a short distance north of the river they dip south or south-southwest at 50° to 70°. About 4 miles to the north of the Big Thompson, quartz schists again appear in the middle of an eastward-trending syncline and probably mark the repetition of the same zone. Quartz schists lying in an eastward-trending syncline are again found 10 miles farther north, about 6 miles northwest of Fort Collins. Here, too, they mark an eastward-plunging syncline. The repetition of these quartz schists in synclines in many localities strongly suggests that the large area of schist between the Big Thompson and the Cache la Poudre Rivers is an isoclinorium. As shown on the map, plate 1, the general trend of the foliation is eastward, although near the eastern border of the range it swings sharply to the southeast. Northerly dips prevail, but southerly dips also occur.

Just west of the Front Range, in the region west of Cameron Pass, there is a considerable area of hornblende gneiss that may be regarded as the extreme southern end of the Medicine Bow Range. The regional westerly dips of the sedimentary schists to the east suggest that the hornblende gneiss has a synclinal position, but little detailed work has been done on the structure of this part of the mountains. Where the range leaves Colorado, just north of North Park, interbedded hornblende gneiss and quartz-biotite schist form the bulk of the crystalline rocks. The regional strike of the foliation is east, and nearly everywhere the dip is steeply northward. About 10 miles north of the State boundary, the trend of the foliation swings toward the northeast, and this regional trend has been observed over a wide area. The presence of closely folded anticlines and synclines in the schist has been noted by the writers, but the structure of what seems to be a later series of pre-Cambrian sedimentary rocks described by both King[93] and Blackwelder[94] has not been studied in sufficient detail to allow a satisfactory discussion here. These later rocks form a thick series of interbedded quartzites, phyllites, conglomerates, slates, and graywackes and bear a marked resemblance to the quartzite at Coal Creek and to the Needle Mountains group of the San Juan area. The regional trend is to the northeast, and the dips are steep.

ORIGIN OF THE METAMORPHIC STRUCTURE

The extremely complex structure of the pre-Cambrian terrain of the Front Range can be reduced to a few comparatively simple elements. The regional distribution of the pre-Cambrian sediments is significant. The metamorphic rocks in the central part of the range from Canon City to Wyoming are almost exclusively

[92] Boos, M. F., and Boos, C. M., op. cit., pp. 303–332. Fuller, M. B. (Mrs. M. F. Boos), General features of pre-Cambrian structure along the Big Thompson Valley, Colo.: Jour. Geology, vol. 32, p. 52, 1924; Contact metamorphism in the Big Thompson schist of north-central Colorado; Am. Jour. Sci., 5th ser. vol. 11, pp. 194–200, 1926.

[93] King, Clarence, United States geological exploration of the fortieth parallel, vol. 1, pp. 28–29, Washington, 1878.

[94] Blackwelder, Eliot, Pre-Cambrian geology of the Medicine Bow Mountains: Geol. Soc. America Bull., vol. 37, pp. 615–658, 1926.

members of the Idaho Springs formation, and the deepest parts of this formation are exposed in this narrow northward-trending zone. The Swandyke hornblende gneiss is abundant along the flanks of the range, to the east and west of the central zone, and the youngest pre-Cambrian sediments crop out only at the easternmost edge of the mountains. This distribution suggests that the complexities of structure so characteristic of the metamorphic rocks have been imposed on a comparatively simple regional pre-Cambrian anticline, which trends almost due north. The major folds in the western flank of this anticline are both parallel and transverse to the axis, but the eastern flank is crumpled into dominantly transverse folds plunging east-northeast.

The Pikes Peak and Sherman granite batholiths, by far the largest in the Front Range, follow the axis of the regional anticline. The Boulder Creek granite batholith also trends northward, but the many irregular stocks and batholiths of Silver Plume granite that are present between the Sherman and Pikes Peak granite batholiths in general trend northeastward. The smaller masses of Boulder Creek granite and the granite gneiss and quartz monzonite gneiss bodies commonly are elongated parallel to the part of the major structure in which they were emplaced.

The grade of metamorphism and the intricacy of the minor folding tend to increase with depth in the metamorphic series and with proximity to some of the intrusive bodies. Granitization that involved both fusion and replacement of schist has been observed northeast of Monarch Lake and northwest of the mouth of Geneva Creek. In both localities the granitized rocks are in the lower part of the Idaho Springs formation. The ubiquitous complex minor folding in large part is due to small intrusions, and the general structure of the foliates, as well as the primary structure of the intrusives themselves, tends to parallel the edges of the stocks and batholiths.

The pervasive metamorphism of the Idaho Springs formation and the Swandyke hornblende gneiss seems linked with the widespread introduction of thin seams of aplite and pegmatite, but there is nothing in the composition of these seams to suggest the presence of powerful metamorphosing agents; their simple mineralogy suggests that they accompanied rather than caused the metamorphism. It is possible, however, that the temperature gradient due to the great age of the sediments would make the beds susceptible to metamorphism with only minor magmatic contributions from the numerous granite masses.

The age of the earth is commonly adjudged to be approximately 2,000,000,000 years. The youngest metamorphic formation in the Front Range, the quartzite at Coal Creek, is older than the Boulder Creek granite, which in turn is older than the billion-year-old Pikes Peak granite. The regional structure and the striking similarity of the metamorphic rocks in the northern Front Range, the Hartville uplift, and the Black Hills, has led the writers to correlate the Idaho Springs formation with the ancient schists of the Harney Peak region, which are cut by the Harney Peak granite. This granite has been the subject of much careful study, and its age is approximately 1,465,000,000 years. The evidence within the Front Range, supported by that in the Black Hills, indicates a great antiquity for the Idaho Springs formation and its deposition during the first quarter of our planet's existence.

Theories of the origin of the earth are still diverse, but most of them that now have credence agree that the earth was molten at an early stage in its existence. Many factors, such as radioactive heating, condensation, endothermic and exothermic reactions, and atomic disintegration under cosmic rays, would affect the cooling of the earth and are difficult to appraise. It is clear, however, that from an extremely steep initial slope the geothermal gradient has fallen to one of very moderate slope. Spicer [95] has calculated the gradient that would exist at certain time intervals in a homogeneous nonradioactive earth for a variety of assumptions as to initial gradient and thermal constants. The results show that in a general way the present gradient is about 70 to 75 percent of the gradient at the end of the first 500,000,000 years (Harney Peak granite time) and approximately half of that which probably existed at the end of the first 350,000,000 years (Idaho Springs formation time?). Thus the temperature gradient in early pre-Cambrian sediments may well have been twice that which exists today in comparable beds. Spicer [96] has also summarized known data for temperature gradients in the United States. The average gradient in Louisiana, a region of thick sediments probably comparable to the ancestral unconsolidated Idaho Springs formation, should lead to a temperature of 100° C. at 7,000 feet. In the original sedimentary basin containing the Idaho Springs formation, the Swandyke gneiss, and the quartzite at Coal Creek, the data available (see pp. 20, 23) indicate a thickness in excess of 35,000 feet. A gradient of twice that found in Louisiana would lead to a temperature of 1,000° C. at this depth, probably sufficient to cause incipient fusion, even under the load existing there. At half this temperature the beds would still be extremely susceptible to metamorphism and would require little tectonic disturbance and magmatic addition to transform them into schists and gneisses.

[95] Spicer, H. C., Tables of temperature, temperature gradient, and age for a nonradioactive earth: Geol. Soc. America Bull., vol. 48, pp. 75–92, 1937.

[96] Spicer, H. C., Rock temperatures and depths to normal boiling points of water in the United States: Am. Assoc. Petroleum Geologists Bull., vol. 26, pp. 270–279, 1936.

The chief factors in the development of the pre-Cambrian structure may be summarized as follows: (1) A thick series of dominantly clastic sediments with some intercalated volcanic rocks accumulated; (2) the sediments became highly heated because of a steep normal temperature gradient and thus were very susceptible to metamorphic processes; (3) a great northward-trending anticline began to form while magmatic emanations from a deep-lying widespread granite magma rose into the sediments and metamorphism commenced; and (4) the anticline was invaded by a series of salic plutonic rocks. The earlier ones were guided by the local structure to a large extent and were contemporaneous with the late stages of regional metamorphism; the intermediate and largest bodies followed only the major structure of the region and modified the local structure to one concordant with themselves; and the latest granite bodies broke through with much less effect on the metamorphic structure and tended to follow transverse northeasterly local folds but were quite irregular in outline.

LARAMIDE STRUCTURE

The pre-Tertiary topography and structure of the Front Range region strongly influenced the localization of folding and faulting during the Laramide revolution. The persistent positive areas and the basins of deposition that separated them during Paleozoic and Cretaceous time can be outlined with a fair degree of certainty in Colorado (fig. 14). The Front Range highland and Wet Mountains highland may be regarded as a compound positive unit trending north-northwest. A northwest trend is very marked on the western edge of the wedge-shaped Front Range highland, but its eastern edge extended almost due north. The narrow Wet Mountains highland trended northwestward, and during the interval when it was not directly connected with the Front Range highland its northern end was only a short distance south of the Front Range highland. The central Colorado basin, which lies chiefly between the Uncompahgre highland and the Front Range highland, splits in the southeastern part and passes on both sides of the Wet Mountains highland. It was developed in large part during Carboniferous time and is one of the deepest basins in Colorado. During the Paleozoic era this trough was filled with sediment to a thickness of as much as 15,000 feet, and later during Cretaceous time several thousand feet more of sediment accumulated in it. The Denver basin, which lies just east of the central part of the

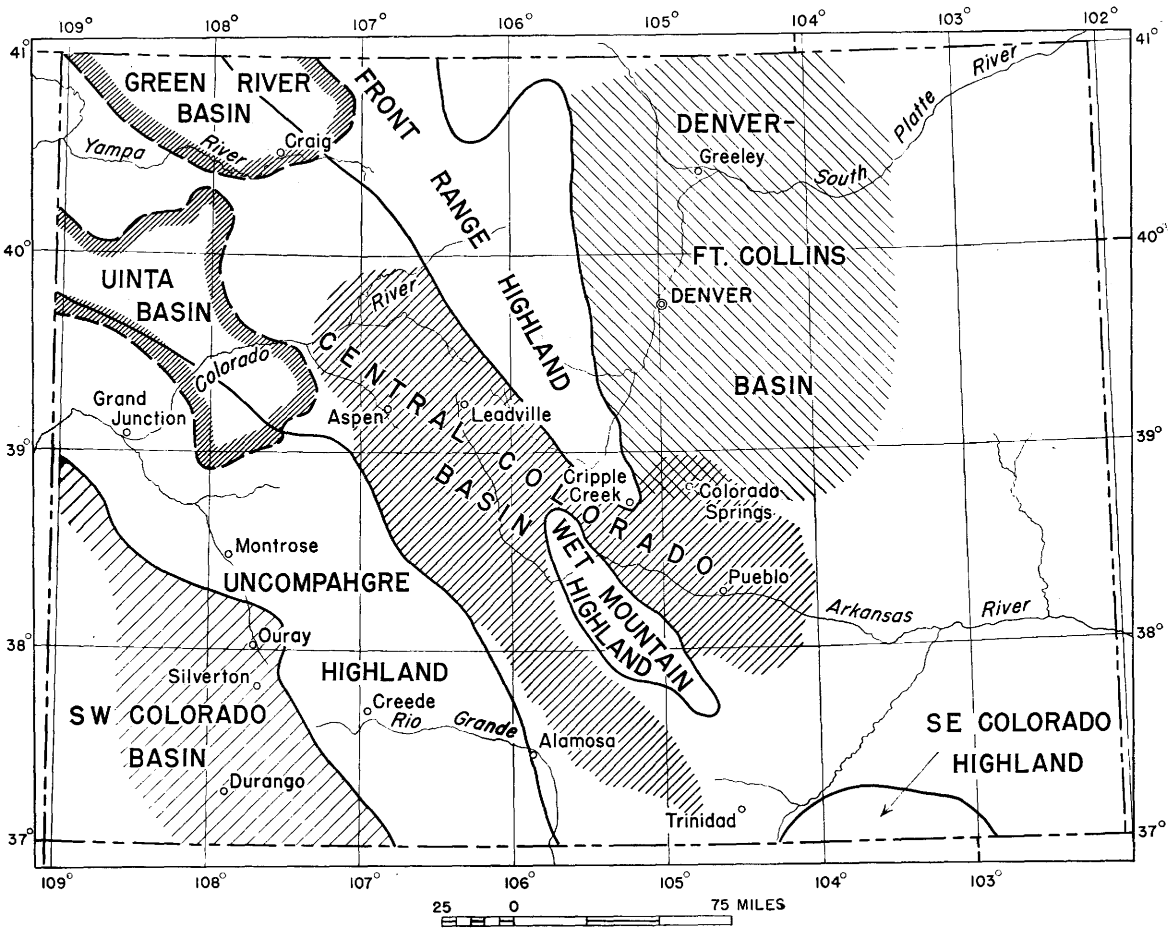


FIGURE 14.—Paleotectonic map of Colorado, showing ancient positive and negative areas.

Front Range, is comparable in depth to the central Colorado basin. Although the Paleozoic section is only a few thousand feet thick in the foothills belt, it thickens eastward, becoming more than 10,000 feet thick a few miles east of Denver. The Cretaceous rocks are also about 10,000 feet thick in this part of the basin but thin to the east.

During the latter half of the Paleozoic era, the central Colorado basin was broken by an uplift, which joined the north end of the Wet Mountains highland with the Front Range highland. The thick accumulation of sediments in the trough to the west involved the downwarping of the basin while uplift was occurring in the adjacent highlands. The dominant trend of the minor folds that were formed during this differential movement was northwest. During much of the Upper Cretaceous epoch all the Front Range was submerged, and by far the thickest sediments accumulated in the basin just east of the present Front Range between Denver and Greeley.

The uplift of the Front Range probably began in middle Pierre time while the Denver basin was still being downwarped. The central part of the Front Range, however, probably moved upward at an ever-increasing rate, and as early as Fox Hills time parts of the old positive area were contributing pre-Cambrian debris to the sediments that were forming a short distance to the east. The peak of the accelerating uplift did not occur until after the late Cretaceous and Paleocene sediments in the Denver basin were deposited. It is probable that most of the pronounced structural features of the Front Range had their origin shortly afterward, in the latter half of Fort Union time. The most intense folding occurred at the edges of the basins of deposition in the zone where the troughs gave way to the old positive elements of the old Front Range and Wet Mountains highlands.

During the Laramide revolution orogenic movements of the same types occurred in similar order over wide areas. There is reason to believe that igneous activity began earlier in the west than in the east, but corresponding members of the early magmatic series show the effect of more orogenic movements on the western slope than on the eastern slope. This difference suggests that the orogenic movements were more nearly synchronous on both sides of the Front Range than the intrusions of correlative igneous series. The general order of structural events during the Laramide revolution is essentially as follows:

1. Noticeable arching of the Front Range highland began shortly before Denver time.

2. Northwesterly folding and faulting and some east-northeasterly fissuring began in early Denver time in the border zone of the Front Range on both the eastern and western slopes.

3. Thrust faulting and overfolding occurred at the end of Denver time in this border zone and outlined the Front Range as it now is. The folds and most of the faults of this group trend northwestward, but on the western border several north-northeasterly faults are present in the region between Empire and Granby.

4. As the regional northwesterly faulting and folding died out, fracturing became localized in narrow transverse zones marked by intrusive activity. Northeasterly and east-northeasterly faulting took place on a large scale throughout the mineral belt and was followed by the deposition of lead-silver ore in many localities.

5. As shown in figure 12, movement recurred along the northwesterly and east-northeasterly faults during the intrusion of the alkalic rocks in the northeast part of the mineral belt just prior to a pyritic gold mineralization.

6. Further movement along both the northwesterly and northeasterly faults preceded the deposition of gold tellurides in the northeast part of the mineral belt.

7. The final convulsion of the dying Laramide orogeny resulted in a slight westward movement of a wedge-shaped block whose base is just west of Boulder and whose apex is near Nederland, resulting in renewed movement along east-northeasterly and associated northeasterly fractures. This movement was followed by tungsten mineralization.

The most prominent structural feature on the west side of the present Front Range is the early series of great northwestward-trending and northward-trending faults. In all the major faults the downthrown side lies on the west. Some of them are normal faults, some are steeply dipping reverse faults, and a few are gently dipping thrust faults. South of the Colorado River the belt of northwestward-trending and northward-trending faults coincides with the northeastern edge of the central Colorado basin. Farther south, beyond the Arkansas River, this tectonic belt splits around the north side of the Wet Mountains, the eastern branch dying out gradually to the southeast and the western branch passing into the central part of the old sedimentary trough, now marked by the Sangre de Cristo Mountains.

Between Breckenridge and Fraser the Front Range splits into several northwest-trending minor ranges, such as the Williams River Mountains and the Vasquez Mountains. These spur ranges mark folds and faults of the Laramide revolution that trend northwest to west-northwest and have their depressed side on the southwest. The largest of the thrust faults is the Williams Range thrust fault, which forms the western limit of the Front Range in the Williams River Mountains for more than 50 miles. Its northernmost limit is represented by klippen or outliers of pre-Cambrian rocks resting on Cretaceous shale (fig. 11, *C*). This fault has a horizontal displacement of more than 4½ miles. It has been described as an underthrust,[97] but the validity of distinguishing between overthrusting and underthrusting has been questioned by sceptical geologic disciples of relativity. The two terms are of no consequence unless some point of reference is established; they remain meaninglessly relative if only the hanging walls and footwalls of the thrust fault are considered, but the terms acquire significance if an adjacent area of less intense deformation is present, which can be used as the necessary reference point.

A marked swing of formations toward or away from the axis of the parent overturned fold as the thrust fault is approached suggests underthrusting or overthrusting, respectively, with reference to the area of less intense deformation. Similarly, the movement of the walls of tear faults shows the direction of movement of the adjacent thrust block and indicates whether overthrusting or underthrusting has occurred.

East of Breckenridge the displacement on the Williams Range thrust fault rapidly lessens, and it passes into an overturned fold, which is well exposed at Georgia Pass. This transition zone is marked by the northeastward-trending belt of mineralized shear faults that coincides with the main part of the mineral belt in this area. Movement on the shear faults here and in the mineral belt to the northeast shows that the northwest walls moved northeastward; this would be the apparent direction of movement of the footwall of the thrust fault and would indicate underthrusting in reference to the less-deformed Georgia Pass area to the south. The overturned formations in that area swing from northwest to north as they are followed northward into the transition zone and thus bend toward the axis of the overturned fold as they approach the shear zone, where they disappear under the hanging wall of the thrust fault. Such a bend also suggests underthrusting, and both criteria for distinguishing underthrusting from overthrusting are present; it would seem that the Williams Range thrust fault may be called an underthrust with some confidence.

A belt of complexly broken thrust faults trends northward along the east flank of the Vasquez Mountains from the vicinity of Byers Peak to the latitude of Tabernash, where it turns northwestward and continues to Hot Sulphur Springs.[98] These faults bring pre-Cambrian rocks, chiefly hornblende gneiss westward over marine Cretaceous strata and the late Cretaceous and Paleocene Middle Park formation as far north as Tabernash; northwest of this locality the structure is somewhat simpler than to the south, but Pierre shale has been thrust westward over the Middle Park formation.

For many miles to the north of Fraser the structures of the Laramide revolution have a northerly trend in contrast to the region to the southwest.

A short distance south of Fraser the Berthoud Pass fault breaks through schist and granite in a north-northeast direction for many miles. The wide shear zone along the fault was first discovered in the construction of the Moffat tunnel and was largely responsible for increasing the cost of the bore from an estimated $6,000,000 to $18,000,000.[99] The position of Berthoud Pass is probably determined by the presence of this strong shear zone (fig. 15).

Westerly thrusting occurs at the edge of the crystalline rocks in some places and is well shown a few miles north of Granby, where the contact between the pre-Cambrian and the overlying Jurassic rocks is offset several miles to the west by a thrust fault. From this locality to the Middle Fork of Michigan Creek, nearly 25 miles to the north, the contact between the sediments and crystalline rocks trends nearly due north and coincides with the outcrop of this fault.[1]

Near the locality where the contact between crystalline and Jurassic rocks swings northwestward across the Colorado River, a few miles northeast of Granby, there is a marked bend in the course of the river, which flows nearly due south from its headwaters to this place and nearly west from here to Kremmling. North of this bend the wide, deep, southward-trending valley contains Tertiary beds older than lower Miocene. This marked topographic trough is directly in line with a similar depression along which the Laramie River flows north from the divide that separates it from the headwaters of the Colorado River. The complex structure of this area has been admirably worked out by Gorton. Immediately south of Cameron Pass the Middle Fork of Michigan Creek follows a strong tear fault that separates two tectonic units. To the south a single great thrust sheet underlies the Never Summer Range, and to the north two thrust sheets are present; the earlier of these two Gorton named the Cameron Pass thrust. Where it is exposed along the highway just south of Cameron Pass it has brought Pierre shale up from a syncline that lies under the pre-Cambrian rocks east of Joe Wright Creek (the name by which the Laramie River is known between Cameron Pass and Chambers Lake). This thrust was preceded and followed by strong folding; later the steep Montgomery Pass fault broke through this area north-northwest for 17 miles (pl. 1). Minor thrusting later than both faults formed the North Fork thrust, whose horizontal dis-

[97] Lovering, T. S., Field evidence to distinguish overthrusting from underthrusting: Jour. Geology, vol. 40, pp. 651–663, 1932.

[98] Tweto, O. L., Pre-Cambrian and Laramide geology of the Vasquez Mountains, Colo. Thesis, University of Michigan, 1947.

[99] Lovering, T. S., Geology of the Moffat tunnel, Colorado: Am. Inst. Min. Met. Eng. Trans., vol. 76, pp. 337–346, 1928.

[1] Gorton, K. A., Geology of the Cameron Pass area, Grand, Jackson, and Larimer Counties, Colo. Unpublished doctoral thesis, University of Michigan, 1941.

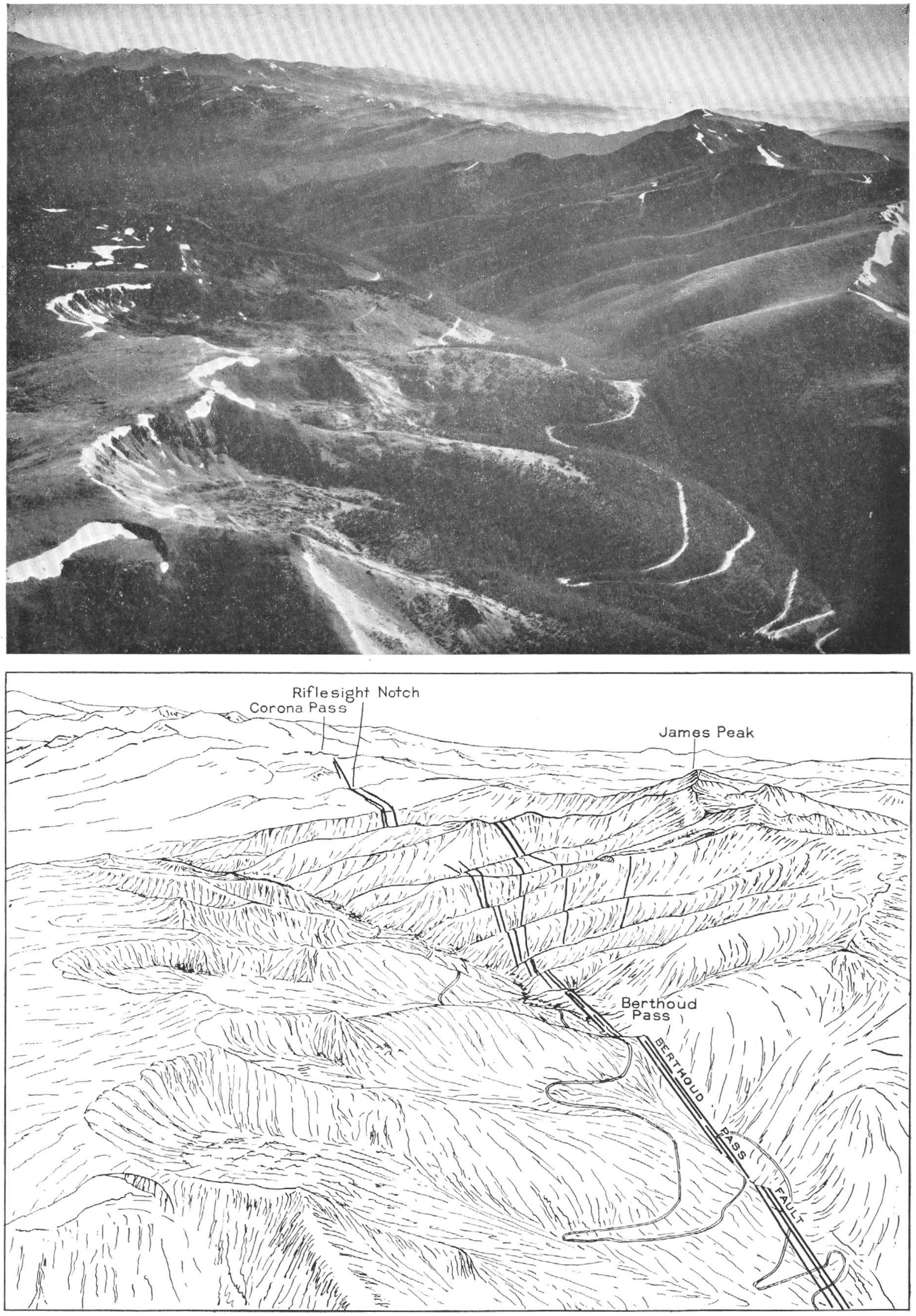


FIGURE 15.—Aerial view looking northeast across Berthoud Pass from an altitude of 16,200 feet. The position of the Berthoud Pass fault, which is responsible for the heavy ground in the Moffat tunnel 6 miles to the north, is shown. Two cirques of Wisconsin age, which are cut into the Flattop peneplain at an altitude of slightly more than 12,000 feet, appear in the foreground and middle distance. Courtesy of Geological Society of America.

placement is only about 1 mile. Alluvium conceals the structure near Chambers Lake, and the Cameron Pass fault cannot be traced more than a few miles. Pre-Cambrian rocks crop out on both sides of the Laramie Valley for several miles, but 12 miles north of the pass Cretaceous beds appear, apparently in sedimentary contact with pre-Cambrian rocks on the west side of the valley and in thrust-fault contact on the east side. From here to the Wyoming line the valley follows a broken syncline of Mesozoic sediments locally concealed by unconformable Tertiary beds. The structure has been little studied, but eastward-dipping thrust faults are known both north and south of Sand Creek, which enters the Laramie River 10 miles south of the Wyoming line. It is apparent that the course of the Laramie River is controlled by structure formed during the Laramide revolution and that it follows a zone of faulting that trends from north to northwest. The writers believe the course of the Colorado River as far south as its junction with Arapahoe Creek a few miles northeast of Granby is also determined by a southerly continuation of the Laramie River fault zone.

The Medicine Bow Range branches north-northwest from the Front Range at Cameron Pass, where it is bordered by thrust faults on both sides. (See pl. 1.)

The deep Cretaceous basin on the east side of the Front Range is bordered by an echelon arrangement of the early northwesterly folds and faults, oblique to the mountain front, whose general trend is northerly. Many of the folds are broken at trough or crest by faults whose western sides have dropped. Near the Colorado-Wyoming line the echelon folds are broad and open, but as the mountain front is followed to the south the folds become more compressed, and faulting becomes more and more prominent. South of Boulder the echelon folds are not evident, but echelon faults with downthrow on the west are prominent structural features of the mountain front (fig. 11, *D*). Several of these strong northwesterly faults have been traced for many miles, from the foothills region, where they displace Carboniferous rocks, into the pre-Cambrian terrain (pl. 2). In the region west of Boulder persistent faults of this system have had a marked control on the localization of ores [2] (see pp. 237, 259). South of Golden the mountain front trends slightly east of south and in many places is paralleled by strong faults in the bordering sedimentary rocks. Locally the contact between pre-Cambrian and sedimentary rocks is a fault.

The faults in Perry Park, west of Larkspur, and in Woodland Park, northwest of Colorado Springs, have a more northerly trend than the persistent northwesterly faults of the eastern part of the mineral belt and in the region north of it, but like them the downthrown side is on the east. The Ute Pass fault, which marks the western side of the Woodland Park trough, strikes N. 20° W. and can be traced for more than 30 miles along a downthrown block of Paleozoic sediments in the pre-Cambrian terrain. Just west of Colorado Springs the Ute Pass fault passes into a thrust fault, which terminates against a tear fault south of Cheyenne Mountain where Little Fountain Creek leaves the range. (See fig. 16). The abundant sandstone dikes in the pre-Cambrian rocks near the Ute Pass fault are believed to be derived from the Sawatch quartzite in the footwall of the thrust.

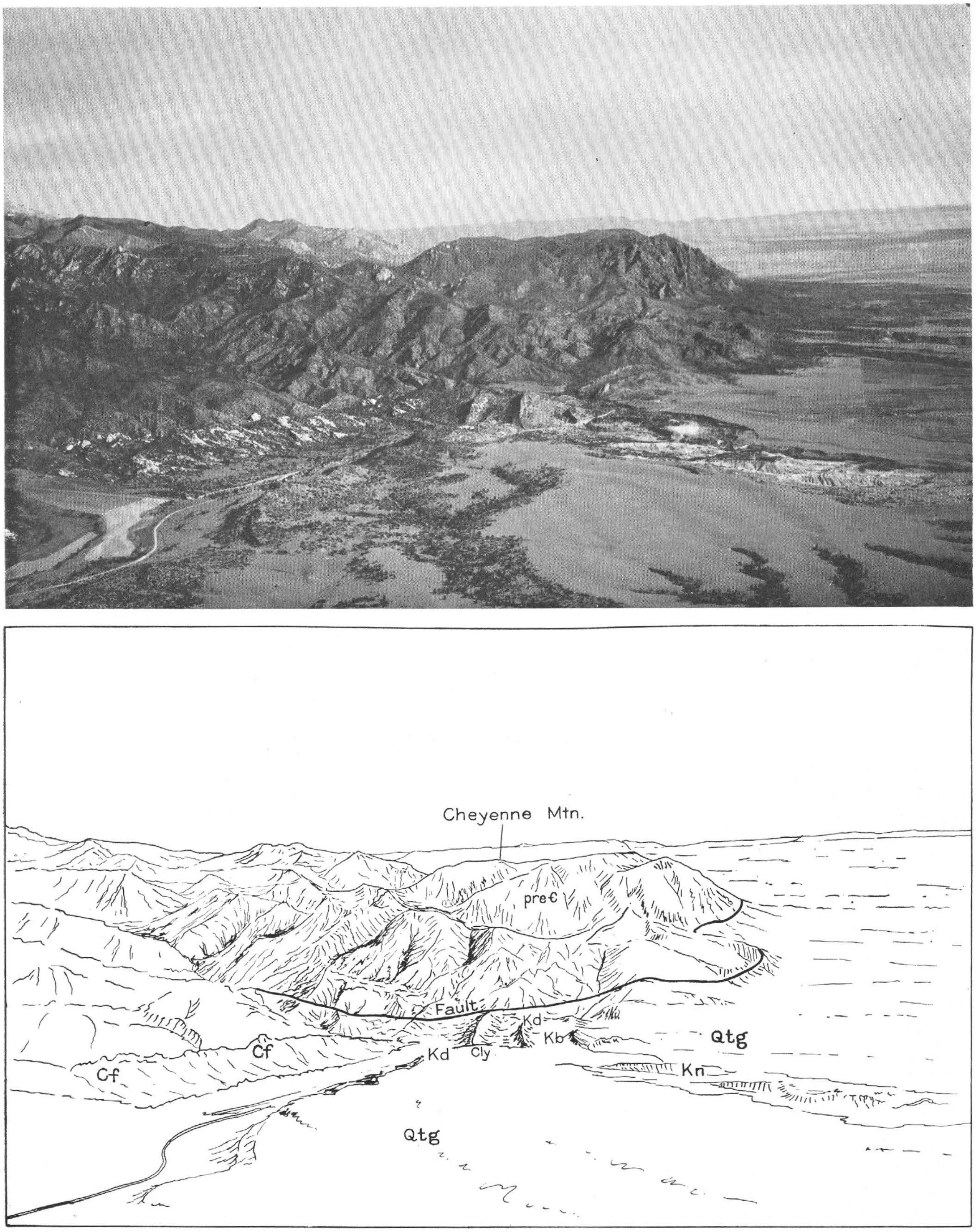
South of the latitude of the Little Fountain Creek tear fault the Front Range is a gently folded, slightly faulted, flat arch, which plunges southward at a low angle and carries the crystalline rocks under Paleozoic formations along the scalloped northern side of the Canon City embayment. The most pronounced syncline in this area is also the zone of strongest faults; it lies just north of Canon City and coincides with the topographic trough excavated by Oil Creek. A line of persistent northward-trending faults follows the eastern side of the valley; their downthrown sides are on the west.

The northward-trending belt of Tertiary sediments that extends to Lake George was in part deposited in northward-trending fault basins alined with the Oil Creek structure.

North-northwest of Canon City many erosion remnants of Cretaceous sediments lie on the crystalline rocks in a narrow belt that is structually lower than the terrain northeast or southwest of it. Between Micanite and the site of Howbert (now flooded by the Elevenmile Canyon Reservoir) the pre-Tertiary rocks are concealed beneath volcanic rocks, but it seems probable that the great South Park syncline so conspicuous to the northwest continues under the lava and that the belt north-northwest of Canon City is synclinal and structurally continuous with it.

The structure of the Front Range formed during the Laramide revolution is most clearly shown along its edges where the Paleozoic or Mesozoic beds have been deformed. It is probable that much of the Laramide structure existing in the pre-Cambrian core of the range has not been recognized, but certain features of early Tertiary orogeny have been distinguished from those of pre-Cambrian origin. As shown on plate 1, the porphyry belt is one of the most striking geologic features of the Front Range. It is a northeastward-trending zone of early Eocene porphyry stocks extending from Breckenridge to Jamestown, with a marked concentration of sills and metalliferous deposits on its southeastern side. The abundance of strong northwesterly faults in the crystalline rocks of Boulder and Jefferson Counties, where mapped by the writers, suggests that they are common eleswhere in the Front

[2] Lovering, T. S., Preliminary map showing the relations of ore deposits to geologic structure in Boulder County, Colo.: Colorado Sci. Soc. Proc., vol. 13, pp. 77–88, 1932.



Qtg, Terrace gravel; Kn, Niobrara formation; Kb, Benton shale; Kd, Dakota sandstone; Cly, Lyons sandstone; Cf, Fountain formation; pre €, Pikes Peak granite

FIGURE 16.—Aerial view looking north at Cheyenne Mountain from an altitude of 10,000 feet above Lytle. Cheyenne Mountain, type locality of the Cheyenne Mountain erosion surface, is a mass of pre-Cambrian rock that has been thrust eastward onto Cretaceous strata at the south end of the Ute Pass fault. The fault line is marked by the abrupt termination of the foothills. Courtesy of Geological Society of America.

Range, but they have not yet been recognized (fig. 21). North of Golden, in the foothills belt, almost all these faults have downthrows on the southwest. In the region south of the porphyry belt the faults have a more northerly trend, and many of them dip steeply; those on the eastern side of the range commonly have downthrows to the east, but most of those on the western side have downthrows to the west. Still farther south in the latitude of the Wet Mountains, northwestward-trending thrust faults become prominent, and in this region the downthrow side is consistently to the east, indicating thrusting from the west. Thus, just north of the latitude of Colorado Springs there is a tectonic transition zone between regions marked by overthrusting in opposite directions.

The distribution of the northwestward-trending faults and asymmetric folds in the region northwest of the tectonic transitional zone indicates regional compression that was greatest just northwest of the present porphyry belt. Although local doming of the sedimentary rocks occurs around some of the stocks, such as that north of Montezuma, in most places the stocks broke through with little or no doming; there is no evidence of any northeastward-trending anticlinal structure of regional character where the porphyry belt crosses the northwestward-trending syncline in the sedimentary formations just west of the Front Range. As the axis of tension is always perpendicular to the axis of compression and the porphyry belt lies perpendicular to the direction of the Laramide compression, it is possible that tensional forces of some magnitude were present here during the folding of the region. The belt of porphyry stocks occupies a position on the northwestern side of a tectonic transition zone between two different types of regional deformation. Fault movements in the porphyry belt suggest that the northern part of the transition zone was one of shearing with nearly horizontal movement as well as one of tension. It is believed that these two stresses—shearing and tension—were in part responsible for the rise of the magma that formed the porphyry stocks and almost wholly responsible for the regional pattern of the porphyries and fractures. The relations of the northeastward-trending and northwestward-trending faults and veins in the porphyry belt are discussed on pages 78–84.

The slightly mineralized region between Cameron Pass and Manhattan is also marked by a northeastward-trending zone of cross-breaking porphyry masses that are of pre-Miocene age and are tentatively correlated with the early Eocene intrusives. This region, however, has been little studied.

POST-LARAMIDE STRUCTURE

In the region southwest of Fraser, strong north-northeasterly faults postdate Miocene strata locally but predate them elsewhere. Faults of parallel trend of the Laramide revolution, notably the Berthoud Pass fault, occur in the pre-Cambrian region to the east. A few miles northwest, in the Blue Ridge and Never Summer Mountains on the western side of the Colorado River, the distribution of the Miocene volcanic rocks suggests their relationship to a northward-trending structure. It is probable that movement recurred along some of the early faults during Oligocene and Miocene time and caused minor warping of the Tertiary beds. In South Park no faulting of importance has been found in the Oligocene, Miocene, and Pliocene beds, but local warping is evident. To the southeast, in the Oil Creek drainage basin west of Cripple Creek, several small Pliocene faults[3] have been found near Mitre Peak and at the edge of High Park. They are apparently related to local rather than regional warping.

Study of the many erosion surfaces found in the Front Range indicates several periods of rejuvenation after the Laramide revolution. Some of them resulted from broad regional uplift, but in places the warping was accompanied by movement along old planes of weakness and locally by new fracturing. The most pronounced post-Laramide movement apparently occurred at the close of Eocene time and resulted in the interruption of the Green Ridge peneplain. The differential movement between the crystalline and the surrounding sedimentary rocks apparently ranges from 500 to 1,500 feet. It is probable that renewed movement at this time on the northerly and north-northeasterly faults near Fraser contributed largely to the formation of the Oligocene and Miocene basin here. A study of the benching of the various peneplains indicates that few of the post-Eocene uplifts of the Front Range caused a movement of more than a few hundred feet at the eastern margin of the range, and it seems probable that the early Pleistocene uplift was much greater at the crest of the range than it was at the edge. Each of the successive uplifts of the Front Range in late Eocene, early Miocene, late Miocene, early Pliocene, and early Pleistocene time was accompanied locally by renewed movement along pre-existing faults.

ORE DEPOSITS

For many years the ore deposits of the Front Range have been classified according to geologic age into three main groups: Pre-Cambrian, Tertiary, and those of the Laramide revolution. This classification is followed by the writers, although they admit that the age of some of the deposits walled by pre-Cambrian rocks is uncertain.

The age of the ore deposits classed as pre-Cambrian in the following pages can be determined unequivo-

[3] Cross, Whitman, General geology of the Cripple Creek area: U. S. Geol. Survey 16th Ann. Rept., pt. 2, pp. 54, 55, 1895. Loughlin, G. F., and Koschmann, A. H., Geology and ore deposits of the Cripple Creek district: Colorado Sci. Soc. Proc., vol. 13, no. 6, pp. 239–242, 1935.

cally in very few places. At Sillsville, southeast of Gunnison, Mesozoic beds truncate ore deposits whose mineral composition and bedrock environment are identical with those of a group of deposits in the Front Range classed as pre-Cambrian. Here, according to Boyd,[4] the Morrison formation truncates the Maple Leaf vein, a quartz-chalcopyrite-gold vein that cuts hornblende gneiss. In the Copper King nickel mine, near Gold Hill, in Boulder County, nickeliferous pyrrhotite ore is cut by an early diabase dike (group 2, p. 47) of Paleocene (?) age. At several localities ores are apparently contemporaneous with basic pre-Cambrian rocks, and some deposits are cut by pegmatitic dikes whose pre-Cambrian age seems unquestionable. As noted in the description of the deposits, pages 67–68, Lindgren believed that the ores of the F. M. D., Malachite, and Sedalia mines are almost contemporaneous with hornblende-augite gneiss; a pegmatite dike cuts the ore at the Sedalia mine near Salida. Veins in the Masonville district are also cut by pegmatite dikes. Pegmatitic gold-quartz veins, such as that in the Masonville mine, occur remote from Tertiary igneous rocks, and their pre-Cambrian age seems established. The distribution of the ores in relation to the pre-Cambrian rocks and their group characteristics are further evidence of pre-Cambrian age.

The ores of the Laramide revolution in the Front Range have been chiefly valuable for gold, silver, lead, and zinc, but the pre-Cambrian ores are chiefly valuable for copper, zinc, and gold. The primary mineral assemblages of pre-Cambrian deposits are distinctive in most places. The ore minerals that are most common include free gold, chalcopyrite with subordinate bornite, pyrrhotite locally containing nickel and cobalt, pyrite, marmatite and gehlinite, and subordinate galena and magnetite. The usual gangue minerals are tremolite, garnet, feldspar, and other high-temperature silicates, quartz, and coarse calcite. The pre-Cambrian deposits occur chiefly in areas of hornblende gneiss and at the borders of stocks of pre-Cambrian granite, never more than 2 miles within a batholith, and show little relation to rocks or structure of the Laramide revolution. In contrast to the pre-Cambrian ores, the Laramide ores seem complex; many sulfantimonides and sulfarsenides, such as polybasite, stephenite, freibergite, tetrahedrite, and famantinite, are common, as are the gold tellurides and the rich galena and silver ores. The Laramide deposits are found in areas where porphyries occur and are related to structure formed during the Laramide revolution rather than to pre-Cambrian rocks.

[4] Boyd, James, Pre-Cambrian ore of Colorado. Thesis, Colorado School of Mines, 1933.

PRE-CAMBRIAN DEPOSITS

The great age of the youngest pre-Cambrian rocks, approximately 940,000,000 years, and the evidence of a long period of erosion prior to the deposition of the first Cambrian rocks preclude the possibility that ore deposits formed at shallow depths in pre-Cambrian time still exist. In contrast to the dominantly mesothermal appearance of the Laramide ores, only a few of the pre-Cambrian ore bodies show any features characteristic of mesothermal veins; the majority are unquestionably hypothermal deposits or magmatic segregations.

Although numerous occurrences of ore minerals in associations that stamp them as pre-Cambrian in age are known throughout the Front Range, there are few productive mines in pre-Cambrian deposits. Intermittent development work has been carried on at many prospects and small properties, but no shipments have been made for several years from mines exploiting deposits of this group. However, chalcopyrite and sphalerite ores containing some gold and silver have been mined in moderate amounts at several localities, and a small tonnage of lead-zinc ore and nickel ore has also been shipped.

The pre-Cambrian ore deposits fall into four general classes: (1) Magmatic segregations, disseminations, and related ores; (2) hypothermal replacement bodies; (3) pegmatitic quartz veins; and (4) pegmatites.

The ores assigned to group 1 by Lindgren are commonly chalcopyrite-marmatite-pyrrhotite-magnetite ores associated with an intrusive hornblende gneiss representing metamorphosed gabbroic dike rocks. The supposed syngenetic origin of these ores does not seem thoroughly established, and it may be that they are more properly classed as replacement ores. (See fig. 17, *C*.) Such ore bodies have not been found within granite terranes. The ore bodies occur as lenticular masses of moderately high-grade ore and as disseminations that are locally rich enough to work. The erratic distribution of the ore within a dike does not encourage extensive development and prospecting. Work by Boyd[5] suggests that it may be possible to detect the presence of hidden ore bodies by the use of the magnetometer, as the higher-grade ores are associated with sufficient magnetite and pyrrhotite to cause a magnetic anomaly over a workable ore body. Deposits of this group have been the most productive of the pre-Cambrian ore deposits, and the chief representatives are the zinc mine at Cotopaxi, the chalcopyrite ores in Jefferson County, and the gold-copper deposit near Empire.

The hypothermal replacement deposits are perhaps the most widespread of the pre-Cambrian ore deposits

[5] Idem.

but are nearly everywhere noncommercial. The ores commonly occur near the edge of large granite masses in actinolite schist or other limy beds of the Idaho Springs formation. The ore bodies usually consist of coarsely crystallized aggregates of amphibole and calcite with minor amounts of the sulfide minerals, the most abundant of which are chalcopyrite and pyrrhotite (fig. 17, *D*, *E*, *F*). In some places nickel and cobalt minerals are associated with the pyrrhotite and chalcopyrite, and in a few localities sphalerite with minor amounts of galena is more abundant than chalcopyrite. It would be impracticable to list all the known deposits of this type, but some of the better-known deposits are those along the south and west side of the Tarryall Mountains just west of the Pikes Peak granite batholith, the Isabel mine on Currant Creek, the oxidized copper deposits in the Platte River Mountains a few miles southwest of Shawnee, the Copper King nickel mine at Gold Hill, the deposits of the Monarch Lake district, the Vasquez Peak lead-zinc mines, and the Hosa Lodge zinc prospect.

In many places pegmatite dikes related to the granite batholiths contain metallic minerals in sufficient quantities to encourage prospecting. Commonly the ore-bearing dikes consist chiefly of milky quartz and orthoclase with minor vugs and stringers of chalcopyrite associated with coarse-grained calcite and fluorite. In some of the pegmatitic quartz veins galena and sphalerite are common and are associated with fluorite and barite. The gold content is usually less than an ounce per ton and the silver content less than 10 ounces per ton, although in some veins, notably those of Lost Park, the silver content has been greatly increased by secondary enrichment. Mineral occurrences and deposits of this group are common, but only in a few localities are they abundant enough to encourage development, and relatively few have been productive. Some of the better known properties of this group include the Nisley mine near Shawnee, the Happy Dream and Molly Grove mines near Kremmling, and the Masonville gold mine.

Pre-Cambrian pegmatites in the Front Range have been a commercial source of feldspar for several decades, and during World War II they also supplied beryl, mica, tantalite, and some rare-earth minerals to the war industries. Nearly two hundred of these deposits were examined by the United States Geological Survey, and open-file reports are available on most of them. As a result of these detailed studies certain generalizations of value to the prospector can be made. The writers are indebted to Mr. J. B. Handley, who made nearly all the examinations in the Front Range, for the information given below.

Pegmatites of economic importance are concentrated at the edges of granite batholiths and are much more common in the metamorphic rocks than within the granite. A few commercial spar pegmatites have been found well inside of a batholith, as much as 12 miles from the border, but such dikes are rare. Nearly all the beryl, tantalite, and mica deposits have been discovered in the metamorphic terrain adjacent to the granite. No one type of granite is parent to these deposits; in different localities commercially important pegmatites seem related to each of the three major types of pre-Cambrian granite—the Boulder Creek, Pikes Peak, and Silver Plume.

The minimum width for a pegmatite dike that has minable concentrations of the pegmatite ores seems to be about 15 inches, and the wider the dike the greater is the probability of finding substantial ore shoots. The strike length of a shoot very rarely measures half the total length of the dike, and dikes carrying commercial concentrations of beryl, tantalite, or the rare-earth minerals through 10 percent of their length are uncommon. The average length of the commercial deposits is probably about 5 percent of the total length of the pegmatite dike. The ore may occur in one shoot or in several completely unconnected bodies within a single dike.

All the commercial pegmatites in the Front Range seem to be minor variants of a distinctive type of banded pegmatite. Ideally this pegmatite consists of a central core of quartz or microcline, or both, surrounded by a casing of coarse muscovite and albite, which in turn is bordered by an envelope of much less coarse quartz, muscovite, and microcline. The beryl, tantalite, and sheet mica are almost completely limited to the muscovite-albite casing. However, the symmetry and continuity of layers suggested above is rarely found. Quite commonly the "central core" is crowded against one wall of the pegmatite in a very irregular band, and the important muscovite-albite casing is present only locally as lenticular masses between the core and the envelope which forms a single irregular band.

The best deposits seem to occur in dikes that were intruded into walls that were already hot. A gradational contact, a marked coarsening in texture of the walls next to the pegmatite, migmatitization of the walls, or the presence of a selvage of some coarsely recrystallized minerals characteristic of the wall rock suggest wall-rock temperatures well above normal when the pegmatite formed.

The most productive pegmatite localities in the Front Range include the Eight Mile Park or Royal Gorge area a few miles west of Canon City; the Micanite district, 20 miles northwest of Canon City; the Lake George district, 5 miles west of Florissant; the Jefferson County pegmatite district, a belt extending from Conifer to Clear Creek just west of Golden; Jamestown (cerite deposits); and the Crystal Mountain district, southwest of Fort Collins, comprising most of T. 6 N., R. 72 W., and T. 7 N., R. 72 W.

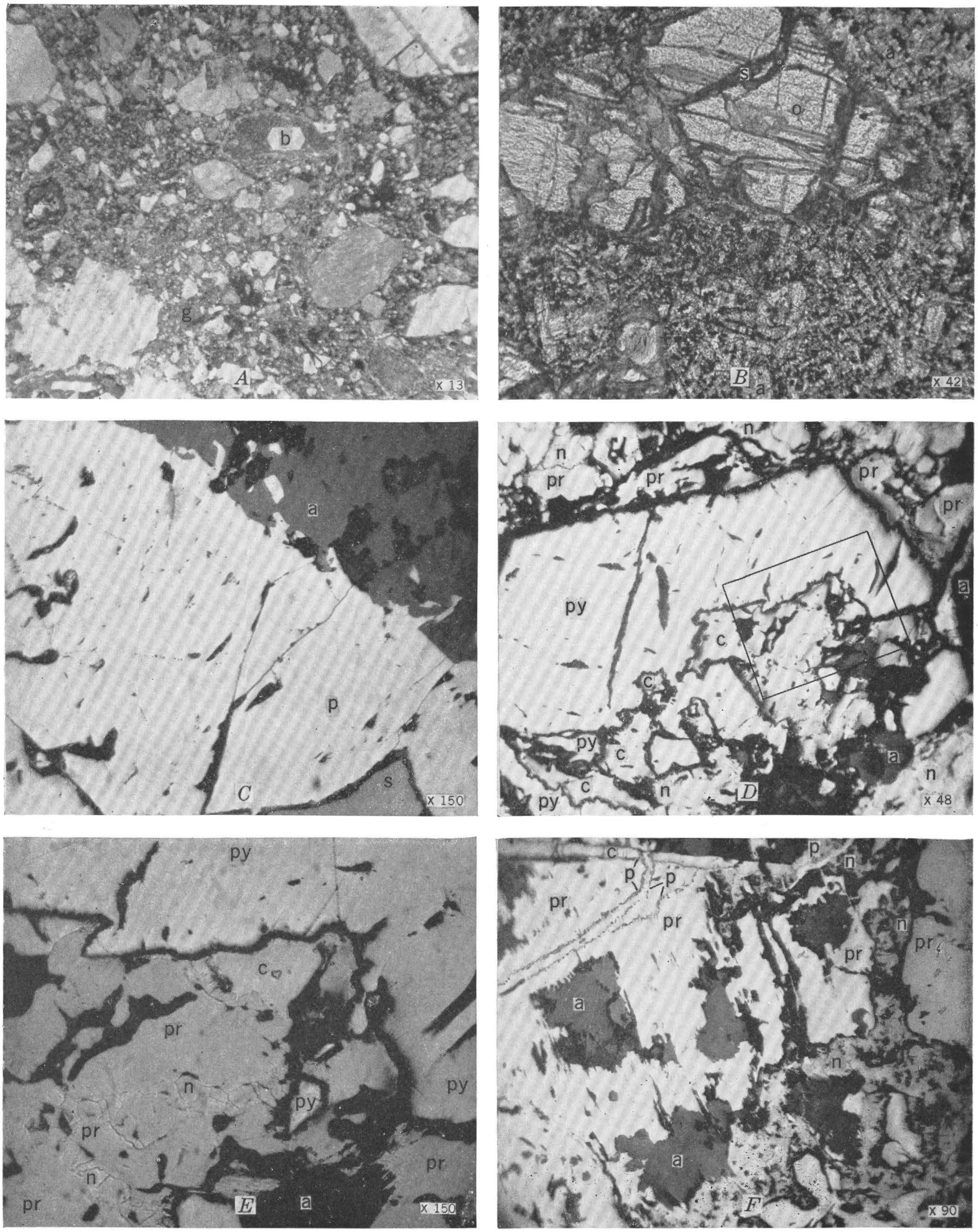

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FIGURE 17.

MINE DESCRIPTIONS

MAGMATIC SEGREGATIONS AND DISSEMINATIONS

COTOPAXI MINE

Cotopaxi, at an altitude of 6,373 feet, is on the Denver & Rio Grande Western Railroad, 26 miles west of Canon City. The Cotopaxi mine, credited with a substantial output of copper ore prior to 1907, is in a small gulch half a mile northwest of the railroad station. The three adits that open the mine, at altitudes of about 6,650, 6,700, and 6,730 feet, were inaccessible in 1932 and 1933 when the property was visited by Survey geologists. The prevailing rock of the area is reddish gneissoid granite cut by irregular pegmatite dikes. Fifteen hundred feet above the river Cambrian strata rest upon the granite. The country rock of the mine is a granite gneiss whose irregular foliation has a general northeasterly strike and a dip of about 45° NW. Lindgren [6] states that the deposit is a lenticular ore-bearing basic igneous rock greatly metamorphosed and conformable to the schistosity of the granite gneiss. According to Boyd [7] the granite gneiss is cut by lenticular schistose masses of amphibolite, which strike approximately N. 30° W., and dip steeply to the northeast, but the foliation of the amphibolite is not reflected in the trend of the ore body. The open stopes mined near the shaft since Lindgren's visit confirm his view of the lenticular shape of the ore bodies. The lenses apparently dip about 20° N. and strike approximately N. 60° W., thus differing from the trend of the foliation of the country rock.

The ore is an intimate intergrowth of chalcopyrite and dark-brown zinc blende containing a few scattered crystals of galena; the quartzose gangue contains a large percentage of biotite, reddish garnet, and dark-green amphibole. According to Butler and Goddard,[8] some of the rocks are pegmatitic and consist of quartz, labradorite, and dark-green zinc spinel (gahnite) with a little chalcopyrite and galena. In 1883 [9] the ore was reported to consist largely of zinc blende and chalcopyrite free from lead; after sorting it contained 58 percent of zinc, 4.6 percent of copper, and 10 ounces of silver to the ton.

[6] Lindgren, Waldemar, Notes on copper deposits of Chaffee, Fremont, and Jefferson Counties, Colo.: U. S. Geol. Survey Bull. 340, pp. 169–170, 1908.

[7] Boyd, James, op. cit.

[8] Butler, B. S., and Goddard, E. N., unpublished report, U. S. Geol. Survey, 1932.

[9] Corregan, R. D., and Lingane, D. F., Colorado Mining Directory for 1883, Denver. Colorado Mining Directory Co.

Across the river from Cotopaxi a 600-foot tunnel was driven in 1883 to develop magnetic iron ore containing approximately 59 percent of iron and 7 percent of silica.

COPPER DEPOSITS IN JEFFERSON COUNTY

Copper has been mined from the pre-Cambrian rocks west of Denver, between Clear Creek and Bear Creek as far west as Evergreen. In that area the widespread schists and gneisses of the Idaho Springs formation are cut by granite, granite gneiss, and metamorphosed metalized diorites and gabbros represented in large part by hornblende schist and gneiss. Belts of the hornblende gneiss and schist occur in the Idaho Springs formation a few miles east of Evergreen and like the schists have a northwesterly trend. The hornblendic schists and gneisses at the F. M. D. prospect are apparently younger than the Idaho Springs formation but older than pegmatite dikes which cut it. The copper deposits are in or very close to the amphibolite schists and gneisses.

F. M. D. property.—The F. M. D. property is on a tributary to Bear Creek, about 2 miles northeast of Evergreen, at an altitude of 6,800 feet. A vertical shaft 350 feet deep has been sunk, and three veins of copper-bearing ore are reported cut by the shaft. The country rock is a dark-green amphibolite schist, which contains pyrite, chalcopyrite, and magnetite, and is probably a metamorphosed diabase. It consists of green hornblende and biotite intimately intergrown and embedded in a mosaic of labradorite with accessory magnetite, apatite, pyrite, and chalcopyrite. Coarse-grained masses of quartz, biotite, and pale-green labradorite, which occur in the schist and probably represent a dike, also contain pyrite and chalcopyrite. Fractures in this dike rock contain secondary pyrite andånzinciferous siderite. This pyritic dikelike deposit trends eastward toward the Malachite mine and is oblique to the foliation of the schist. Lindgren [10] believes that it probably represents a dike somewhat younger than the

[10] Lindgren, Waldemar, op. cit., pp. 168–169.

EXPLANATION OF FIGURE 17

A, Photomicrograph of intrusion breccia of group 11 (fig. 12) from Logan mine, 5 miles west of Boulder. Highly fragmented granite and some porphyry and early vein material lie in a biotite-flecked glassy groundmass which is partly silicified and sericitized. *b*, Fragment of biotite latite; *g*, glassy groundmass. Crossed nicols.

B, Photomicrograph of limburgite of group 12 (fig. 12) from dike near Sugarloaf post office. Corroded serpentinized olivine phenocryst in mosaic of small augite crystals lying in a glassy groundmass. *a*, Augite; *o*, olivine; *s*, serpentine. Crossed nicols.

C, Photomicrograph of pre-Cambrian replacement ore from Malachite mine. Pyrrhotite (*p*) and sphalerite (*s*) replaced amphibole (*a*).

D, Photomicrograph of pre-Cambrian ore from nickel mine a mile west of Gold Hill. Amphibole (*a*) and early pyrite (*py*) replaced by pyrrhotite (*pr*), chalcopyrite (*c*), and niccolite (*n*). Area included in *E* shown by rectangle.

E, Photomicrograph of ore from nickel mine, a mile west of Gold Hill, showing part of area included in *D*. Pyrite (*py*) and pyrrhotite (*pr*) replaced by chalcopyrite (*c*). Niccolite (*n*) replaces pyrrhotite, which replaces amphibole (*a*).

F, Photomicrograph of pre-Cambrian replacement ore from nickel mine, a mile west of Gold Hill. Schistose amphibole (*a*) is replaced by pyrrhotite (*pr*), which imperfectly preserves the metamorphic structure. Later replacement veinlets of niccolite (*n*), pentlandite (*p*), and chalcopyrite (*c*) are well shown. The fuzzy outline of the pentlandite veinlets in the pyrrhotite is caused by minute borders of niccolite.

amphibolite mass. The continuity of the pyritic ore between the two deposits is not proved.

Malachite mine.—The Malachite mine is on a high ridge near the northerly divide of Bear Creek, 1¼ miles east of the F. M. D. property. Prior to 1907 oxidized ore to the value of approximately $35,000 had been shipped from workings connected with a shaft 150 feet deep. A tunnel 300 feet long was driven through contorted biotite-amphibolite schist to the lower level in 1907, where a sulfide ore body 10 feet wide was found in metagabbro. A winze 45 feet deep was later sunk in the ore, and at the bottom the ore body was about 4 feet wide. The sulfide in this body showed no direct connection with the oxidized ore first worked, and as the ore pinched laterally as well as with depth and was parallel to the foliation of the enclosing rock it is thought to be one of several lenticular segregations in the metagabbro. The ore consisted of coarse-grained masses of chalcopyrite, zinc blende, and pyrrhotite said to contain some nickel, but it contained very little gold or silver. Some pyrite is embedded in the pyrrhotite. According to Lindgren the ore minerals are intergrown with augite and feldspar of the metagabbro and are apparently contemporaneous with them, but in specimens of ore examined by the writers the ore minerals apparently replace the silicate minerals (fig. 17, *C*). Accessory apatite and titanite are present. Lindgren believed that the ore was a magmatic differentiate in a metamorphosed gabbro dike.

A small prospect a quarter of a mile west of the Malachite mine and between it and the F. M. D. property shows amphibolite schist containing garnet and epidote with streaks of chalcopyrite and pyrite. Barren pegmatite dikes cut this amphibolite. One of the most noticeable differences between the ores of the Malachite and the F. M. D. properties is the abundance of pyrrhotite in the Malachite ore and the abundance of magnetite in that of the F. M. D.

Empire mine.—The Empire mine is a short distance west of the center of sec. 11, T. 7 N., R. 70 W., 6½ miles due west of Fort Collins. In 1933 the mine had been idle for two decades, and water stood within 20 feet of the collar of the shaft, but in 1901, according to Lee,[11] the mine was developed to a depth of 250 feet. The ore occurred chiefly between narrow bands of greatly altered country rock, which was locally mined and treated as ore. The vein appears to be a mineralized shear zone in a metamorphosed basic intrusive and is easily traced by float and the numerous prospect holes, which follow its outcrop for more than a mile west of the main shaft. The shear zone strikes N. 80° W. and closely parallels the foliation of the country rock. The outcrop is marked by gossan and copper stains, and quartz stringers are common in the adjacent schists. The belt of hornblende gneiss, near the center of which the mine is situated, is about a mile wide and trends westward for approximately 4 miles from the eastern edge of the Front Range. To the north and south the gneiss is in contact with quartzose schist of the Idaho Springs formation, and to the west it is in fault contact with granite.

An open stope immediately west of the main shaft extends for about 30 feet along the vein, which is here 3 feet wide. Some malachite is present on the back of the stope, but no ore remains. A moderate tonnage of copper-gold ore is reported to have been shipped from this stope in the late nineties. A large mass of pre-Cambrian pegmatite apparently crosses the vein in this region, but the intersection is not exposed; another pegmatite dike cuts a similar vein about 300 feet to the north of the Empire vein and parallel to it. In 1932 no ore was exposed in the vein, but sufficient ore had been left on the dump to show its general character. The weathered fragments of sulfide ore are rich in residual masses of pyrrhotite and are similar in appearance to the pyrrhotite ore of the Malachite property described above.

HYPOTHERMAL REPLACEMENT VEINS

ISABEL MINE[12]

The Isabel mine, which has produced some high-grade zinc ore containing a little lead and copper, is situated in Fremont County near the center of the north boundary of sec. 31, T. 16 S., R. 72 W. It is on the north bank of Smith Gulch, 2 miles west of its junction with Currant Creek and about 12 miles north of Parkdale, a station on the Denver & Rio Grande Western Railroad.

According to ranchers in the vicinity, the mine has been idle a number of years, but at one time a substantial quantity of high-grade lead-zinc ore was shipped from it; several tons of lead-zinc ore were still on the dump in 1932. The deposit was worked through a shaft 100 feet or more deep, which was not accessible in 1932, but the size of the dump indicated several hundred feet of workings.

The country rock is chiefly biotite and hornblende schist, but many quartz seams and a few pegmatite dikes are present. The foliation of the schist trends northeastward and is nearly vertical. The deposit is a vertical vein that follows a pegmatitic quartz seam in the schist and parallels the foliation. From the north bank of Smith Gulch the vein has a course of N. 60° E. for about 75 feet and then changes to N. 20° E. It appears to pinch out within a distance of 100 feet. To the southwest it is covered by the alluvium of Smith Gulch and does not reappear on the other side, several hundred feet distant. It is 2 to 4 feet wide and is composed

[11] Lee, H. A., Report of the State Bureau of Mines, Colorado, 1901–2.

[12] From manuscript report of E. B. Eckel, U. S. Geological Survey, 1932.

largely of brecciated and shattered pegmatitic quartz. Much of the schist near the vein consists of fibrous actinolite. The ore minerals form blebs and streaks in shattered quartz or blebs in altered schist near the vein walls. They include dark-brown sphalerite, fine-grained to steel galena, and small amounts of massive chalcopyrite. Stains of malachite, chrysocolla, and iron and manganese oxides appear on the surface, but oxidation has been very slight. Occasional small veins of calcite cut the sulfide minerals.

The age of the deposit is in doubt. No intrusive igneous rocks occur in the immediate vicinity of the deposit, and it lies about midway between batholiths of Pikes Peak and Silver Plume granites, which are about 10 miles apart in this region. A small basic dike cuts the schist near Smith Gulch, about a mile east of the Isabel mine, but no other post-Cambrian intrusives have been noted. The deposit is probably pre-Cambrian, but the ore does not share the brecciation of the pegmatitic vein quartz and was deposited after the shattering had ceased.

LONE CHIMNEY, MILL GULCH, AND COPPER KING MINES

The Lone Chimney mine is in sec. 16, T. 15 S., R. 73 W., about a quarter of a mile south of the road between Guffey and Black Mountain, 2½ miles west-southwest of Guffey. The Mill Gulch and Copper King mines are 3 to 4 miles S. 22° W. of the Lone Chimney, in sec. 5 or 6, T. 16 S., R. 73 W. Copper ore containing some silver and gold has been shipped from the three properties, which are on the same vein. The Lone Chimney mine was examined by E. B. Eckel of the Geological Survey in 1932, but the workings of the Mill Gulch and Copper King mines were said to be inaccessible and were not visited.

The old Howell shaft on the Lone Chimney claim was sunk 300 feet, but no drifting was done in 1932. In that year A. B. Dell had sunk a new shaft 30 feet deep and had drifted northeastward on the vein for about 30 feet and had made one short crosscut, which did not penetrate the hanging wall of the vein. No ore had been shipped. The Copper King mine was developed by a rather long drift adit on the vein, and the Mill Gulch mine was worked through a shaft, but no data are available as to the extent of the workings. Both mines yielded some native copper ore, and the dump of the Mill Gulch mine is said by Mr. Dell to have assayed about 8 percent in native copper. The ore shipped from these mines, according to Mr. Dell, contained 3 to 50 ounces of silver to the ton. The ores contained no gold or lead, in contrast to that from the Lone Chimney mine.

The Lone Chimney vein is in a quartz-muscovite schist along the hanging wall of an unmineralized dike of rhyolitic or latitic intrusion breccia about 100 feet thick, striking N. 42° E. and dipping about 65° SE. The dike where not brecciated is pink and is locally dense and fine-grained, but most of it is a typical intrusion breccia. No phenocrysts were observed. The encompassing schist strikes N. 22° E. and dips 55° to 65° E. About 200 feet northeast of the mine a large irregular body of comparatively fine-grained aplitic granite, probably of pre-Cambrian age, cuts the schist.

The dike does not penetrate the aplitic granite to the northeast but can be traced southwestward for a distance of about 4 miles to the Mill Gulch mine. It is resistant to erosion and forms a well-defined ridge. A small dike of dense dark-green diabase striking N. 6° W. and dipping 67° W. cuts both the breccia dike and the Lone Chimney vein just north of the mine workings. The rhyolite breccia dike, which is almost certainly of Tertiary age, was apparently intruded along the plane of weakness made by the Lone Chimney vein. About 150 feet southeast of the vein and roughly parallel to it the schist contains a hornfels zone 5 to 20 feet wide composed of garnet, vesuvianite, dark-green hornblende, and quartz. It transects the regional foliation and thus differs from the ordinary lime-silicate zones so characteristic of some pre-Cambrian schists.

The ore-bearing zone of the Lone Chimney vein is 10 to 12 feet wide, is entirely in schist, and is composed largely of a light-green actinolite, but calcite, light-colored to dark-colored quartz, muscovite, and white fibrous sillimanite are common, and a little cordierite (?) is present. The ore minerals are chiefly malachite and azurite, with small amounts of galena and chalcopyrite. They are rather uniformly distributed through the deposit but locally are concentrated into spots of high-grade ore. In many places the chalcopyrite seems to be intimately intergrown with actinolite but may have replaced an early calcite that was similarly intergrown. Mr. A. B. Dell reported that titanium, molybdenum, and arsenic occur in the ore from his new shaft, but minerals containing these elements were not observed by Eckel. The rhyolite-breccia dike underlying the ore shows no sign of alteration near the vein and contains no disseminated sulfide minerals.

The best grade of ore is unquestionably due to oxidation and enrichment of a low-grade chalcopyrite-galena body. No data were obtained on the tenor of the ore at the bottom of the 300-foot Howell shaft, but most of the unaltered sulfide minerals found on the dump probably came from this shaft and suggest a depth of oxidation of less than 300 feet.

The apparent intergrowth of the ore minerals with actinolite and sillimanite is suggestive of pre-Cambrian age, and the fact that the vein does not penetrate the aplitic granite nor the breccia dike is also suggestive. The relation between the vein and the garnet-idocrase (vesuvianite) zone is not clear, but the zone may be a product of contact metamorphism during pre-Cambrian time and directly related to the formation of the ore deposit.

NISLEY MINE

The Nisley mine lies 1 mile northwest of Shawnee, in section 17, T. 7 S., R. 73 W. The mine is opened by an adit, whose portal is on the eastern side of a small tributary stream on the north side of the Platte River about half a mile above its junction. The country rock comprises hornblende gneiss and granite gneiss trending nearly due eastward. The primary ore forms masses of chalcopyrite in a brecciated zone 1 to 4 feet wide in granite gneiss. The ore exposed in 1929 was much brecciated and replaced by such secondary copper minerals as cuprite, malachite, azurite, and the black oxide of copper. A vein of much-fractured fluorite follows the main copper-bearing zone, and both it and the copper ores are cut by veins of coarsely crystalline calcite. This deposit is doubtfully referred to the pre-Cambrian group but may have been formed when the early "breccia reef" mineralization of the Laramide revolution took place.

HOSA LODGE MINE

In sec. 10, T. 4 S., R. 71 W., in Jefferson County, about a mile northwest of Hosa Lodge, a tunnel 50 feet long has opened up a small deposit of chalcopyrite, dark-brown sphalerite, and well-crystallized galena. The ore minerals form masses and small grains throughout a layer of light-green hornblende-actinolite-tremolite schist enclosed by a quartzitic gneiss of the Idaho Springs formation. A mass of lime silicates trends across the foliation of the amphibole schist. The schist itself contains lenses of quartz parallel to the foliation, and the lenses are cut and slightly displaced by a pegmatite dike. Hornblende schist forms the south wall of the tunnel but does not appear at the surface. Chalcopyrite, altered in places to malachite and chrysocolla, appears at the outcrop in the lime-silicate rock. The mineralization appears to have taken place later than the crystallization of the amphibole minerals, but sufficient work has not been done to establish the age relations.

COPPER KING NICKEL MINE

Three-quarters of a mile southwest of Gold Hill, in NW¼ sec. 14, T. 1 N., R. 72 W., in Boulder County, the three adits of the Copper King nickel mine [13] open up a deposit of nickeliferous pyrrhotite. About 3,000 tons of nickel ore was mined from this property in 1942. The ore has replaced definite beds in an amphibolitic schist of the Idaho Springs formation. As shown on the map, plate 8, the schist trends N. 10° E. to N. 15° W., and dips 60° to 80° W. All the adits crosscut the schist. The intermediate adit penetrates a bed about 35 feet thick that contains 1 to 4 percent of nickel and a small amount of cobalt and averages about 2 percent of nickel throughout. The lower adit is chiefly in hornblende diorite gneiss, but nickel ore is exposed in a raise from a point 20 feet above the lower adit to the surface, about 250 feet above.

Most of the ore is composed of pyrrhotite partly replaced by small quantities of niccolite and pentlandite, but some pyrite and chalcopyrite are also present (fig. 17, *D*, *E*, *F*). The ore-bearing beds are cut by a pegmatite dike containing no ore minerals, but this dike in turn is cut by a fault containing pyrrhotite that appears to be later than the fault. The pegmatite dike cuts an almost barren hornblende diorite gneiss that is intrusive into the schist. All these formations are cut by a northwestward-trending diabase dike 40 feet wide that dips about 70° SW. It is unmineralized, cuts the ore body sharply, and is identical with dikes known to be of Laramide age. The ore deposits are a short distance northwest of the northwestern edge of the Boulder Creek granite batholith, and it is believed that both the pegmatite and the hornblende diorite gneiss are related to the Boulder Creek granite magma.

ST. LOUIS MINE

The St. Louis mine of the Fraser quadrangle lies about 2½ miles south of Byers Peak and half a mile north of St. Louis Lake, near the headwaters of St. Louis Creek, 11 miles southwest of Fraser. The country rock of the region is Swandyke hornblende gneiss. Its regional strike is N. 60° E. and its general dip 45°SE. At the mine, however, the gneiss is bent into a sharp anticlinal fold, which plunges to the northeast. The deposit seems to have been formed by replacement of a calcic bed in the hornblende gneiss formation; its form coincides with the foliation of the enclosing gneiss. Most of the ore observed ranges from 2 to 10 feet in width and consists of galena and sphalerite with some pyrite in a gangue of diopside and quartz. The ore is exposed for at least 300 feet along the strike at an altitude of about 11,750 feet on the west slope of Gordon Creek, near the crest of the ridge between this creek and the next tributary of St. Louis Creek to the south. The deposit is easily traced through a somewhat greater distance on the south side of the ridge. In the metalized area the ridge coincides with the nose of the northeastward pitching anticline, and the ore zone here changes direction abruptly, doubling back on itself as it is followed across the ridge. Two short adits had been driven on the deposit in 1928, when it was visited by Lovering, but no openings exposed the ore for more than 10 feet below the surface, and most of the ore seen was strongly oxidized. The character of the ore and the lack of Tertiary intrusive rocks nearby suggest that it is a pre-Cambrian replacement deposit.

[13] Goddard, E. N. and Lovering, T. S., Nickel deposit near Gold Hill, Boulder County, Colo.: U. S. Geol. Survey Bull. 931–O, pp. 349–362, 1942.

According to Ogden Tweto,[14] a northward-trending zone of altered mylonite can be traced several miles through the metamorphic rocks north from St. Louis Lake; it contains molybdenite and weathered pyrite on Iron Creek, about 3 miles to the north.

HIGH LONESOME MINE

Two miles due south of Monarch Lake, in the NW.¼ sec. 1, T. 1 N., R. 75 W., is a copper deposit known as the High Lonesome mine. It is at the contact of the Idaho Springs formation and the north edge of a large mass of granite. The deposit has been opened by two tunnels, each probably more than 500 feet long, at altitudes of approximately 10,200 feet and 10,100 feet. The country rock to the southwest is a medium-grained, slightly gneissic, pinkish-gray biotite granite, which strongly resembles the typical Silver Plume granite of the Georgetown quadrangle. To the north the Idaho Springs formation strikes N. 50° W., and dips 45° to 80° NE. The most prominent rock at the contact is a coarsely recrystallized marble containing much disseminated chalcopyrite, tremolite, epidote, and a little galena. Quartz schist, quartz-biotite schist containing pink garnet, and quartz-biotite-amphibole schist are common nearby. Although the carbonate rock spotted with ore minerals might be a vein filling, the writers believe it to be an original limestone member of the Idaho Springs formation that has been metalized close to the contact of the Silver Plume granite. The limestone probably does not contain more than 5 percent of copper nor more than 1 percent of lead. No Tertiary intrusive was seen in the district nor in the glacial drift nearby, and the deposit is believed to be a pre-Cambrian contact-metamorphic deposit.

About 4 miles northeast of Monarch, near the headwaters of Roaring Fork, in sec. 6, T. 2 N., R. 74 W., there are some small prospects on a vertical brecciated zone striking N. 55° W. Fragments of schist are cemented by pegmatitic quartz, which contains a small quantity of chalcopyrite in disseminated grains and short seams. The country rock of this locality is a much-contorted schist of the Idaho Springs formation trending N. 30° E.

PROSPECTS NEAR TRAILS END

There are a number of copper-stained prospects in granite on Trail Creek, in Larimer County, about 30 miles northwest of Fort Collins and not far from Trails End, which is 18 miles west of Livermore. On Sheep Creek, 15 miles south and west of Trails End, a prospect exposes a fracture zone parallel to the foliation of the enclosing mass of hornblende gneiss. Unaltered chalcopyrite occurs in the fracture zone close to the surface, but the workings, which seem extensive, were filled with water, and nothing is known of the history of the property.

[14] Oral communication.

PEGMATITIC QUARTZ VEINS

LOST PARK CREEK

Pegmatitic lead-silver veins occur in Pikes Peak granite on the eastern side of Lost Park or "Goose" Creek east of the Tarryall Mountains. The E. M. Palmer veins are about 2½ miles northwest of the first boulder fill, known as the No. 1 Reservoir site, and were worked in a small way for many years prior to 1930. The veins are 6 to 12 inches wide and consist of brecciated pegmatite and granite cemented by coarsely crystalline quartz, green and purple fluorite, white to flesh-colored barite, and a small amount of galena. The veins are said to contain an appreciable amount of silver and, though no silver minerals were recognized by the writers, the oxidized condition of the galena suggests possible enrichment. The veins are near the edge of the Pikes Peak granite batholith, and no Tertiary intrusives or Tertiary mineralization are known in this region. The veins are believed to be genetically related to the Pikes Peak granite.

MINES NEAR COPPER CREEK

A small amount of copper mining has been carried on near the headwaters of Copper Creek, a tributary of Kinney Creek, which joins the Colorado River at Parshall, in Grand County. The Molly Grove mine is in the E½, sec. 18, T. 1 S., R. 79 W., about 6 miles west of the main Leal to Parshall road, and the Happy Dream mine is about half a mile west of the Molly Grove. The Molly Grove mine is opened by three adits averaging about 800 feet in length and in 1927 was equipped with cabins and tool shop. The Happy Dream mine is opened by a shaft about 210 feet deep, which was not accessible in 1927.

The ore occurs in the hanging-wall block of the Williams Range underthrust fault, about a mile east of the fault contact between the Pierre shale and the overlying pre-Cambrian hornblende gneiss. The country rock of the region comprises biotite and hornblende schists and gneisses much injected with pegmatite and cut by small masses of granite. Near the Molly Grove mine the rock is a chlorite-amphibole schist, which made "heavy ground" where cut by the tunnels. None of the workings were accessible at the time of the writers' visit, but several tons of ore remained on the dump. It consisted of coarse pegmatitic quartz spotted with chalcopyrite and hematite and some bornite and pyrite. The ore is said to have come from a brecciated zone 6 inches to 2 feet in width. There is some evidence that the granite and schist from this brecciated zone were replaced by the ore-bearing quartz. Ore on the dump does not contain more than 5 percent of chalcopyrite by volume. One thousand pounds of ore containing about 1 ounce of gold to the ton is reported to have been shipped about 1912.

CARTER MINE NEAR MASONVILLE

Gold ore has been mined from the Carter mine, on Carter Hill about a mile north of Masonville, near Buckhorn Creek, in sec. 10, T. 6 N., R. 70 W. Most of the country rock near the mine workings is pegmatite and the fine-grained variety of Silver Plume granite known here as Mount Olympus granite,[15] but several bands of schist ranging from a few inches to 15 feet or more in width are exposed underground. The schist bands trend northwestward and are nearly vertical. A short distance east of the mine the granite area gives way abruptly to a schist terrane, the contact striking northwestward parallel to the schist inclusions found in the mine. The granite near the contact of the main body of the schist is fine-grained and as it is followed to the west it becomes somewhat coarser-grained and also contains a higher percentage of dark minerals. As no indication of faulting was observed,[16] the contact between the granite and schist is probably intrusive. About half a mile west of the mine the granite is faulted against the Paleozoic sedimentary rocks along the northwestward-trending Buckhorn fault of late Cretaceous age.

The vein strikes N. 10° W. and dips 75° SE., following an ancient fault in the Mount Olympus granite. Minor slickensided fissures are present in some of the underground workings, but the movement along them seems to have been small. Half a mile north of the mine a diorite dike crosses the vein without displacement. Most of the ore consists of veinlets and bunches of ore "frozen" to granite or aplite walls, but some of it resembles a breccia of aplite and granite cemented by quartz and chalcopyrite. The chief minerals are quartz, chalcopyrite, violarite (?), and their oxidation products. Some ore on the dump contains hematite, limonite, and free gold in a quartz gangue.

The deposit is doubtfully assigned to the pre-Cambrian group but may prove to belong to the late Cretaceous "breccia reef" deposits, represented by the Quigley mine 10 miles southwest.

LARAMIDE (LATE CRETACEOUS-EARLY TERTIARY) DEPOSITS

Nearly all the mineral production of the Front Range outside the Cripple Creek district has come from deposits formed during the Laramide revolution. (See p. 12.) These ores are associated with porphyritic intrusive rocks, whose composition commonly ranges from diorite to granite. Unlike the later Tertiary ore deposits, these ores are nowhere associated with lavas or extrusive volcanic rocks. In the pre-Cambrian terrane the ores formed during the Laramide revolution occur as fissure fillings, but in the sedimentary rocks west of the Front Range both fissure fillings and replacement deposits are found. As noted on page 64 the common characteristic minerals of the Laramide ore deposits are those belonging to deposits formed at moderate depth, temperature, and pressure; as a group they differ markedly from those characteristic of the pre-Cambrian deposits. The gangue minerals usually found are quartz, ankerite, fluorite, and barite, and the most common ore minerals are pyrite, sphalerite, galena, chalcopyrite, the gray-copper minerals, silver sulfantimonides and sulfarsenides, gold, silver, and lead tellurides, free gold, and native silver. Most of the ores are fissure fillings. Vugs and druses are very common, and angular fragments of country rock covered by successive crusts of ore may occur in open rubblelike masses; nearly solid ore may show banding parallel to the walls or may be nearly massive and consist of medium-grained intergrown minerals. Replacement ore bodies formed during the Laramide revolution are few and small within the Front Range. Almost all the output from the ore deposits emplaced in the late stages of the Laramide revolution in the Front Range has come from the narrow zone of territory known as the mineral belt of the Front Range (pls. 1 and 2), but a few occur elsewhere and are discussed on pages 279–287.

MINERAL BELT OF THE FRONT RANGE

SOURCES OF DATA

Descriptions of nearly all the individual districts discussed in the following pages have been published, and references to them are cited in the appropriate places in the text. The description of the regional interrelation of the features found in the various districts is in part a result of the information contained in the published descriptions and in part a result of 15 years of field work in the Front Range by the writers. The statistics of output for the years preceding 1904, have been gathered from various sources, and the figures for subsequent years were obtained from Mr. C. W. Henderson and R. H. Mote of the United States Bureau of Mines.

LOCATION OF DISTRICTS

As shown on plate 2, the mineral belt as considered in this report stretches northeastward from Breckenridge across the Front Range to that portion of its eastern border lying between Boulder and Lyons. In this report, groups of organized mining districts are discussed under the headings of appropriate geographic districts. The geographic districts and the organized mining districts that each includes, from southwest to

[15] Fuller, M. B. (Mrs. M. F. Boos), General features of pre-Cambrian structure along the Big Thompson River Valley, Colo.: Jour. Geology, vol. 32, p. 52, 1924.

[16] Chapman, E. P., written communication May 12, 1932.

northeast, are as follows: Breckenridge district, including the Tiger mining district; Montezuma district, including the Swandyke, Geneva Gulch, and Hall Valley mining districts; Argentine district; Silver Plume-Georgetown district; Empire district; Lawson-Dumont district; Central City-Idaho Springs district, including the Freeland-Lamartine mining district; Alice district, including the Yankee Hill mining district; North Gilpin County district, including the Apex, Perigo, and Rollingsville mining districts; Eldora district; Caribou district; Boulder County tungsten district; Ward district; Sunset district; Magnolia district; Gold Hill district, including the Wallstreet, Salina, and Sunshine mining districts; and the Jamestown district, called the Central district in early reports. The location of the various geographic districts are shown on the map, plate 4. The approximate geographic limits of the organized mining districts are indicated in the discussion of the individual districts. The topography, physiography, and drainage of the mineral belt and its means of transportation have been discussed briefly on pages 8–12 and are well shown on plate 3.

GEOLOGIC FORMATIONS

The marked northeasterly trend of the belt of porphyry stocks and the associated ore deposits reflects both the direction of the Laramide mountain-building forces and the regional and local distribution of the earlier rocks. The Front Range mineral belt is largely in the area of pre-Cambrian formations, but in the southwestern part Mesozoic and Paleozoic sediments are also present. The sinuous northeasterly course of the mineral belt corresponds rather closely with the irregular area of relatively weak schists and gneisses that lie between large masses of granite. The granite batholiths probably acted as buttresses that withstood the stresses of Tertiary mountain building better than the less competent schists and gneisses. The chief rocks, in the order of their abundance, include pre-Cambrian metamorphic rocks, pre-Cambrian intrusive rocks, Laramide porphyritic intrusive rocks, and Mesozoic and Paleozoic sedimentary rocks. Their general distribution is shown on plates 1 and 2. The lithologic features and general relations of the formations are described briefly on pages 19–50, where the geology of the Front Range as a whole is considered, but additional information regarding the distribution of some facies is given below. Additional details are also given in the description of the individual districts.

PRE-CAMBRIAN ROCKS

Idaho Springs formation.—The much-metamorphosed sedimentary rocks of the Idaho Springs formation are widely distributed and constitute the chief country rock in the mineral belt from the Geneva Gulch district northward through Idaho Springs to Ward. The most common lithologic types are quartz-biotite schist, quartz-biotite-sillimanite schist, biotite-sillimanite schist, and injection gneiss. Quartz schist and gneiss and occasional masses of lime silicates intergrown with magnetite and garnet are prominent in the upper part of the formation. These rocks are especially common in an arcuate belt extending north and northeast through the head of Hall Valley to the region east of Argentine Pass and on eastward through Chief Mountain a few miles south of Idaho Springs. Where the schist has not been strengthened by the addition of lit-par-lit injections it is much weaker than most of the pre-Cambrian rocks, and in it veins and other planes of structural weakness are much less persistent and continuous than in harder formations.

Swandyke hornblende gneiss.—In the southwestern part of the mineral belt, in the Montezuma, Swandyke, and Hall Valley districts, the Swandyke hornblende gneiss is abundant. Hornblende gneiss occurs also locally in the mineral belt on the eastern side of the Continental Divide but is nowhere as abundant as it is to the west. Biotite schist and quartz-biotite gneiss, and in the Hall Valley district quartz schists and gneisses of considerable thickness, are interlayered with the hornblende gneiss. In the Montezuma and Como quadrangles and southwest of Idaho Springs the hornblende gneiss is associated with many narrow lenticular masses of biotite-quartz monzonite gneiss and gneissic pegmatite. Its metamorphism is fully as great as that characterizing the Idaho Springs formation, but it is a much more competent formation and is therefore more likely to contain productive veins.

Quartzite at Coal Creek.—As shown on plate 2, the conglomerate, quartzite, and phyllitic schist of Coal Creek occur in a trough that pitches east-northeast under the Pennsylvanian rocks between Coal Creek and South Boulder Creek. From the eastern edge of the mountains the quartzite extends west-southwest for 7 miles. It is bordered by aplite or granite, except on the east, but the Swandyke hornblende gneiss and Idaho Springs formations crop out extensively a short distance to the south.

Granite gneiss group.—The granite gneiss group includes the quartz monzonite gneiss and the granite gneiss of the central and southwestern parts of the mineral belt and the gneissic aplite of the northeastern part. The quartz monzonite gneiss is somewhat earlier than the granite gneiss and the gneissic aplite. Although each may be recognized and separated from the others in certain localities, all three types have many features in common, and, as many exposures show no diagnostic features, they are grouped together on plate 2. All are later than the Idaho Springs formation and Swandyke hornblende gneiss but were intruded early in the batholithic cycle that gave rise to most of the pre-Cambrian intrusives of the mineral belt.

Quartz monzonite gneiss occurs at many places, but the only large areas in the mineral belt are on Green Mountain, a few miles south of Georgetown, and on Sante Fe and Saddleback Mountains, southeast of Idaho Springs.

As shown on plate 2, these stocks each cover several square miles, but elsewhere in the mineral belt the exposures are mostly restricted to lenticular areas a mile or more long and only a few hundred yards wide. The gneiss is largely localized near the borders of stocks or batholiths of Boulder Creek granite. In some places it forms irregular sheetlike masses in the Idaho Springs formation and the Swandyke hornblende gneiss, its boundaries as well as its gneissic structure being essentially parallel to the foliation of the older rocks; at other localities, as in the region south of Corona, it lies at the edge of the granite. Small bodies of quartz monzonite gneiss are intimately associated with hornblende gneiss at many places, but only the more conspicuous of them have been separated from the Swandyke hornblende gneiss on the map (pl. 2).

The granite gneiss and the somewhat less foliated gneissic aplite occur in small or medium-sized concordant bodies commonly measuring a few feet to several hundred yards in width and a quarter of a mile to several miles in length. They are especially abundant in the central part of the mineral belt, where they form strong ribs in the Idaho Springs formation that make especially favorable walls for veins. Within the schist the granite gneiss and gneissic aplite are more strongly foliated than within the stocks of quartz monzonite gneiss and Boulder Creek granite. Only the more prominent bodies of gneissic aplite have been mapped within the stocks, as it is impossible to show the innumerable small dikes and irregular bodies that are present.

Boulder Creek granite.—The Boulder Creek granite occupies moderately large areas in the northern half of the mineral belt. One batholith lies between Boulder and Nederland in the southern part of the Boulder quadrangle and the northern part of the Blackhawk quadrangle. Another mass occurs in the Georgetown quadrangle south of Georgetown and Idaho Springs, where it was named the "Archean quartz monzonite" by Ball. There its areal relations suggest that it is a border facies of the later Pikes Peak granite. Several smaller stocks occur in the high country along the western side of the Central City quadrangle and in the extreme southeastern part of the Rocky Mountain National Park quadrangle. The Boulder Creek granite is more susceptible to hydrothermal alteration than the granite gneiss, gneissic aplite, and Silver Plume granite, but where it was not badly altered prior to ore deposition it is moderately strong and makes good walls for ore deposits.

Pikes Peak granite.—The Pikes Peak granite forms a large batholith to the south of the mineral belt but is represented by only a few small stocks within the belt. It has been recognized only in the western part of the Montezuma quadrangle and in the southern part of the Georgetown quadrangle.

Silver Plume granite.—The Silver Plume granite includes a number of slightly different types found in small batholiths, stocks, and dikelike masses, all of which are later than the pre-Cambrian rocks described above.

Two large masses of Silver Plume granite occur in the mineral belt, one occupying the northern part of the Montezuma quadrangle and the other extending into the Jamestown district from the north. In addition to these two batholiths some smaller stocks and innumerable dikelike masses of Silver Plume granite occur irregularly throughout the mineral belt. The fine-grained Mount Olympus type of granite, which is later than the main mass of the Silver Plume, occurs chiefly in the Boulder and Loveland quadrangles north of the mineral belt, but small masses are also found in the Argentine Pass district, where they have been included with the Silver Plume granite on plate 2.

Pegmatites.—Granite pegmatites and associated bodies of aplite and granite porphyry occur abundantly but in small bodies throughout the mineral belt. Because of their strong lithological similarity, the pegmatites related to the Boulder Creek granite, the Pikes Peak granite, and the Silver Plume granite have all been grouped as one cartographic unit on plate 2. The largest bodies of pegmatites are found close to the edges of the batholiths already described, but probably nowhere in the mineral belt can a 50-foot section of the Idaho Springs formation or Swandyke hornblende gneiss be found that is free from seams of pegmatite or aplite. The structural relations of the pegmatites to one another and to other rocks indicate that intrusion took place over a long period of time.

PALEOZOIC AND MESOZOIC SEDIMENTARY ROCKS

At the eastern edge of the Front Range the pre-Cambrian rocks are bordered by the Paleozoic red sandstones, shales, and grits of the Pennsylvanian Fountain formation. On the western slope Cretaceous beds border the pre-Cambrian rocks of the mineral belt at the edge of the range, but earlier sedimentary rocks crop out a short distance farther west. The relations and distribution of the Paleozoic and Mesozoic systems are shown on plate 1, and a description of their lithologic features is given on pages 29–40. Ore deposits do not occur in the sedimentary rocks to the east of the range, but to the west, in the Breckenridge district, veins of the southwestern part of the mineral belt are walled by

Pennsylvanian, Permian, Jurassic, and Cretaceous formations.

In addition to the broad areas covered by Cretaceous rocks on the eastern and western borders of the Front Range two small areas are exposed by "windows" in the Williams Range thrust fault. They are in the Snake River Valley in the Montezuma quadrangle, about 4 miles east of the western border of the Front Range. These areas are described on pages 125–126.

With the exception of small areas of Tertiary (?) gravel in the Idaho Springs-Central City district and in the Nederland district, no Tertiary sediments have been recognized in the Front Range mineral belt. Early and late glacial deposits are widespread in the higher mountains but have not been shown separately on plate 2; furthermore, as the bedrock geology is of greater economic importance in most places, glacial deposits are indicated only in areas where they are comparatively deep. As noted earlier, the thickness of the present gravel downstream from the terminal moraines is less than 30 feet in most places in the Front Range, but in the Valley of the Blue, on the western slope, the gravels have an average thickness of about 60 feet near Breckenridge and are 100 feet thick at the junction of the Snake River with the Blue River. The glacial moraines reach a maximum thickness of 150 feet near Breckenridge, but other large moraines are much thinner. The relation of placer deposits to the glacial deposits is discussed on pages 110–111.

LARAMIDE INTRUSIVES

The general features of the porphyries of the Laramide revolution have already been described on pages 44–47.

Named in the approximate order of decreasing abundance, the Laramide intrusives of the porphyry belt formed during the Laramide revolution fall in the following rock families: Quartz monzonite, diorite, monzonite, granodiorite, bostonite, syenite, felsite, rhyolite, gabbro, syntectic ultramafic rocks of the Caribou stock, volatile-rich biotite latite, and limburgite. The first four make up the bulk of the intrusives and include all the stocks except that of bostonite at Sunset. The mineralogic composition and texture of the Laramide igneous rocks is shown diagrammatically in the tabular summary (p. 47) and their chemical composition on plate 7, and photomicrographs of typical porphyries are shown in figures 10, *D*, *E*, *F*, 13, and 17, *A*, *B*. For detailed petrographic descriptions the reader is referred to the earlier reports dealing with the individual mining districts of the mineral belt. The age relations of the igneous rocks of the Laramide revolution have been worked out at many places in the porphyry belt[17] and, as shown in figure 12, establish a remarkable similarity in the general sequence of porphyries throughout the mineral belt. If the folding and various systems of faulting are regarded as essentially contemporaneous throughout the Front Range, it is apparent that in the porphyry belt there was a general progression of intrusions from southwest to northeast, corresponding lithologic types appearing earlier in the southwestern part than in the northeastern. The general succession southwest of Silver Plume began with the aluminous silicic andesite, regarded as equivalent to the White (granodiorite) porphyry of Leadville; this rock was succeeded by more and more mafic rocks until porphyries having the composition of an augite diorite were intruded. The intrusions occurring subsequently were of magma that became progressively more and more silicic and alkalic; they are represented by monzonite, quartz monzonite, and rhyolite porphyry. In each of the major mining districts these intrusions were followed by widespread lead-zinc-silver mineralization.

Northeast of Silver Plume the earliest rocks intruded in the mineral belt were highly aluminous felsites; they were followed by more mafic rocks, a trend that ended with gabbros and olivine basalts. At Caribou gabbroic magma probably reacted with calcareous pre-Cambrian rocks to produce peculiar ultramafic syntectic masses and later differentiated into monzonite and quartz monzonite. At other places the gabbros were followed by monzonites and hornblende or augite diorites, similar to the more mafic rocks in the southwestern part of the porphyry belt. The monzonites were followed in turn by quartz monzonite, alaskite or rhyolite, alkalic syenite, bostonite, and pyritic gold-silver-lead ores. In a few districts a later telluride mineralization was preceded by biotite monzonite or biotite latite containing an unusual concentration of volatiles and by intrusion breccia of similar composition. In the region east of Caribou the deposition of the telluride ores was followed by tungsten mineralization. The early ferromagnesian rocks are most abundant in the northeastern part of the mineral belt where gabbro occurs in long northwest dikes. Shorter dikes and stocklike bodies of gabbro and augite diorite are scattered sparsely throughout the mineral belt and for some distance to the north and south of it.

The rocks of the diorite-quartz monzonite-rhyolite series dominate the entire porphyry belt. Although somewhat more sodic in the northern half of the belt, the similarity in appearance persists from Boulder to Breckenridge, and some distinct lithologic types, such as the coarsely porphyritic quartz monzonite known as the Lincoln porphyry, are recognized as equivalent to formation units. In the northeastern half of the mineral belt an alkalic group of rocks including bostonite and "alkali syenite" are well represented, but southwest

[17] Lovering, T. S. and Goddard, E. N., Laramide igneous sequence and differentiation in the Front Range, Colorado: Geol. Soc. America Bull., vol. 49, pp. 35–68, 1938.

of Georgetown they are entirely lacking. In the Cretaceous shales of the Breckenridge district the early members of the diorite-quartz monzonite series commonly form sills in the sedimentary rocks, and the later members including the Lincoln porphyry are cross-breaking or dikelike. Diorite, monzonite, and quartz monzonite are the chief rocks of the large cross-breaking masses of porphyry found in the belt of stocks but are also very common as dike rocks throughout the mineral belt. Later rocks of the quartz monzonite series occur almost exclusively as dikes, though two small stocklike bodies of granite porphyry occur in the Georgetown district. A small plug of "alkali syenite" occurs near Idaho Springs, and related sodic granite and syenite occur in small stocks north of Jamestown and southeast of Ward (pl. 2). An irregular stock of bostonite may be seen near Sunset, southeast of Ward, but elsewhere this rock is found only in dikes. All exposures of biotite latite are small, and the rock occurs only in short dikes and as the matrix to explosion breccia. It is found south of Idaho Springs and in the Gold Hill and Jamestown districts.

There is a noteworthy difference in the structural habit of the porphyries in the southwestern half of the mineral belt and those in the northeastern half. The dikes southwest of the Silver Plume district are comparatively short or discontinuous, very few of them extending more than a mile and the majority much less than half a mile. To the northeast of Silver Plume the persistence of the dikes is much greater. Some of the bostonite porphyries of the Central City district have been traced for 5 miles, and the early gabbro dikes of the Gold Hill district have been traced almost continuously for as much as 15 miles. The persistence of the dikes along the strike in the northeastern part of the mineral belt suggests a corresponding persistence in depth. It thus seems probable that the fissures in the northeastern part of the district tapped magmatic reservoirs at greater depth than did those in the southwestern part.

In many places in the mineral belt dikes have been found underground that do not appear at the surface. At other places short discontinuous dikelike masses of the same type of rock occur in line with one another, suggesting that erosion has just reached the uneven top of a continuous dike. In some places the top of a dike is marked by brecciated rock, but at most places there is little evidence of a fissure above the dike, and one is forced to conclude that the dikes made way for themselves by crowding the walls apart and forming a fissure as they were driven up like a liquid wedge from beneath.

MAGMATIC DIFFERENTIATION

The genesis of the porphyries has been attributed by the writers [18] to the initial melting down of a dioritic substratum in the western part of the mineral belt and of a gabbroic substratum in the eastern half, and to its subsequent slow consolidation and differentiation during a period of orogeny. Parts of the deep changing magma were withdrawn from time to time to shallower chambers, where more rapid cooling resulted in changes of a different type from that occurring in the deep hearth. The slow cooling of the deep-source magma allowed time for nearly complete reaction; apparently neither crystal settling nor the growing of zoned crystals greatly affected its composition. Instead, the changes in composition of liquid and crystals during solidification were almost exactly the reverse of the changes during liquefaction, except where filter-pressing strained off some magma and caused a local change in the composition of the slowly crystallizing substratum. Withdrawal of the changing residuum to shallow reservoirs and further differentiation there occurred several times in the eastern part of the range but only once in the western part. The change from diorite through quartz monzonite to granite represents subtractive differentiation of material withdrawn from the deep magma during its dioritic stage into comparatively shallow hearths. The bulk of this differentiation was accomplished by crystal settling, zoning, and filter-pressing. Desilication caused by silica-rich volatiles moving into reactive roofs resulted in a change of composition that may explain some of the late dikes and the corrosion of the early quartz phenocrysts. The successive pulses of intrusion on the eastern side of the range gave rise to distinct differentiation series, for example, diorite, monzonite, quartz monzonite, granite, alaskite, and lead-silver-zinc ores; alkalic syenite, bostonite, and pyritic gold ores; biotite monzonite, biotite latite, latite intrusion breccia, and gold-telluride ores.

[18] Lovering, T. S. and Goddard, E. N., op. cit., pp. 66–68.

METAMORPHISM AND WALL-ROCK ALTERATION

In general, rock alteration is much more common in the late intrusives than in the early (figs. 10, *D*, *E*, *F*, 13, and 17, *A*, *B*). In areas where hydrothermal alteration is not related to mineralizing channels and seems to be a rather direct igneous effect there is a marked difference in the degree of rock alteration in the dikes of the different groups. In the ferromagnesian intrusives of the early group almost no rock alteration occurs except where the rock is crossed by later channels of mineralization. Mild propylitic effects, characterized by chlorite, epidote, and calcite, are noticeable in many of the diorites and monzonites, but these rocks are generally fresh and have exerted no contact metamorphism on the wall rocks. Many of the stocks of quartz monzonite porphyry, on the other hand, produced marked contact-metamorphic effects on their wall rocks. In the southwestern part of the mineral belt the shales close to the quartz monzonites are commonly intensely silicified and contain garnet, epidote, hematite, magnetite, and disseminated pyrite. Even the schists and gneisses adjacent to the larger quartz monzonite stocks are marked by haloes of silicification and contain disseminated pyrite. The bulk of the quartz monzonite itself is fresh, but some of it has undergone endomorphic alteration, which produced epidote, sericite, and secondary quartz. The plugs and dikes of bostonite and the stocks of alkalic syenite are remarkably fresh and free from alteration, except where they are crossed by later channels of mineralization. In contrast to these rocks, the granite and rhyolite porphyries are nearly everywhere much altered to sericite and quartz. The wall rocks commonly show similar alteration effects close to the dikes.

The abundance and large size of diorite and quartz monzonite stocks in contrast to the small masses of alkalic syenite and bostonite suggest that the difference in alteration is due simply to the difference in the quantity of magma consolidating in the shallow hearths during the two different epochs of intrusion, not to a difference in content of volatiles in the original source magmas of the two series.

The alteration minerals have a consistent order of paragenesis, but a progressive change in the type of alteration is found as the mineral belt is followed from the southwest to the northeast. The effects of hydrothermal alteration characteristic of the mineral belt southwest of the Argentine district are well illustrated in the Montezuma district.[19] Sericite and chlorite were apparently formed in the cooler parts of the contact (pyrometasomatic) zone of the Montezuma quartz monzonite stock at nearly the same time that typical contact minerals, such as garnet, tremolite, hematite, magnetite, and epidote formed close to the intrusive. In the contact zone these high-temperature minerals are the earliest products of alteration induced by the quartz monzonite magma. Sericitization was active from this time until the period of ore deposition. During the early stages of ore deposition, and at later stages in places where alteration was not intense, chlorite actively replaced ferromagnesian minerals. During the latter part of the period of sericitization, and locally at an earlier stage in regions where alteration was intense, fine-grained quartz partly or completely replaced ferromagnesian minerals and feldspar. Locally siderite or ankerite was introduced near the end of the period of sericitization. Some sulfur went into the country rock during the solidification of the stock and reacted with magnetite to form pyrite, but sulfur was not given off in large quantities until the end of the period of sericitization, when most of the pyrite in the veins was deposited.

Silicification was the dominant type of wall-rock alteration accompanying the deposition of pyrite, but in some places the wall rocks were replaced to a minor degree by ankerite and siderite. In most of these places the carbonates were formed later, near the close of the period of mineralization. The latest effect of hydrothermal processes in veins was the introduction of calcite and fine-grained quartz; locally, the wall rocks also were replaced by these minerals. In many porphyries, the calcic feldspars were replaced by calcite and fine-grained quartz, both of which were formed after sericitization of the rock. The absence of clay minerals and iron stains indicates that this alteration was not due to weathering and suggests that it occurred late in the period of waning hydrothermal activity.

In the Argentine district and northeast to the Silver Plume district wall-rock alteration was similar to that just described, but some slightly different effects are worthy of note. The dominant effect of alteration was the replacement of the rock by quartz, sericite, and pyrite. Locally, however, fluorite, roscoelite, and adularia also replaced the wall rock. In the hornblendic wall rocks of this part of the mineral belt the ferromagnesian minerals were much replaced by magnetite or hematite. Clay and calcite, which are common but not abundant alteration products of the wall rock, were clearly formed at a late stage when hydrothermal alteration was waning. In the Idaho Springs district the effects of alteration are very similar to those just described, but fluorite is said to be more abundant than in the Silver Plume district. In the northeastern part of the mineral belt hypogene clay minerals became more and more prominent members of the alteration suite. In the Nederland tungsten district the most widespread product of wall-rock alteration is clay, but sericite, quartz, and adularia are abundant in the granite walls adjacent to the veins and are especially prominent next to ore shoots. In this district the alteration to clay minerals preceded the silicification and sericitization that accompanied the introduction of the tungsten ores.[20]

STRUCTURE

PRE-CAMBRIAN STRUCTURE

The regional features of pre-Cambrian structure in the mineral belt have already been discussed in the description of the pre-Cambrian of the Front Range on pages 53–56. South of the Central City and Fraser quadrangles, the mineral belt is almost entirely limited to a northeastward-trending group of metamorphic rocks bordered on the northwest by a batholith of Silver Plume granite and on the southeast by a batholith of Boulder Creek granite and smaller masses of Silver Plume granite and granite gneiss (pl. 1). North of

[19] Lovering, T. S., Geology and ore deposits of the Montezuma quadrangle, Colo.: U. S. Geol. Survey Prof. Paper 179, 1934.

[20] Lovering, T. S., The origin of the tungsten ores of Boulder County, Colo.: Econ. Geology, vol. 36, pp. 234–240, 1941.

FIGURE 18.—Ditchlike trough caused by a strong fault zone crossing the crest of Keystone Mountain at the east side of sec. 31, T. 5 S., R. 76 W. This is the common topographic expression of strong unsolicified fault zones formed during the Laramide revolution in the pre-Cambrian terrain.

Central City the mineral belt follows the metamorphic rocks along the western and northwestern border of a Boulder Creek granite batholith through Nederland, Ward, Gold Hill, and Jamestown. At Nederland however, an eastward-trending zone of mineralization branches to the east and crosses the Boulder Creek granite batholith. The regional trend of foliation in the metamorphic rocks is parallel to the borders of the large granite masses nearby, but as the schists and gneisses are folded into both isoclinal and open anticlines and synclines the foliation shows some marked local variations from the regional trend (pls. 1 and 2).

In the Montezuma district, the regional northward-trending syncline whose trough is occupied by the Swandyke hornblende gneiss has already been mentioned. In the northeast part of the Montezuma quadrangle the schist swings from north to northeast and is closely compressed into tight narrow isoclinal folds. In the Silver Plume and Georgetown districts the foliation swings from northeast to nearly east-west with a regional dip toward the north. This is the prevailing strike and dip as far east as the Idaho Springs and Central City districts where the foliation swings again to the northeast. As shown on the map, the most prominent structures in this region are the monoclinal dip toward the north in the Idaho Springs district and the upward flexing of the beds to form a strong anticline passing through the heart of the Central City district. North of Central City the foliation of the schist trends nearly north and south parallel to the edge of the Boulder Creek granite as far as a locality about 3 miles north of Nederland. Here the foliation swings sharply to the east with a regional dip to the north. This attitude is prevalent in the Ward district and continues as far east as the Gold Hill district. Between Gold Hill and Jamestown the schists trend northeastward and are closely folded into a number of minor synclines and anticlines. The structure of the metamorphic rocks in the mining districts is of much importance, as it exercises a distinct control in the localization of ore deposits in the cross-breaking and parallel fissures. As shown on plate 2, most of the small masses of pre-Cambrian intrusive rocks are elongate parallel to the regional trend of the metamorphic rocks.

LARAMIDE STRUCTURE

Folds.—Except close to the borders of the Front Range there is little evidence that folding occurred during the Laramide revolution in the mineral belt, although faulting is prominent (pl. 2). It is probable that early in the period of orogeny many of the localities now marked by northwestward-trending faults were the sites of northwestward-trending folds similar to those found along the eastern margin of the mountain front farther north. The structure at the northeastern end of the mineral belt is in general that of the steeply dipping eastern limb of a regional anticline broken by strike faults that dip steeply to the west.[21] To the southwest the mineral belt crosses the western edge of the pre-Cambrian terrain of the Front Range at the place where the Williams Range thrust fault breaks from the somewhat sliced overturned fold that extends southward through Georgia Pass into South Park. In the region northwest of Tiger and west of the Williams Range thrust fault the Cretaceous strata have a monoclinal dip of approximately 30° toward the east or northeast. South of Tiger the structure is one of a sheared overturned asymmetric syncline whose axial

[21] Ziegler, Victor, Foothills structure in northern Colorado: Colorado School of Mines Quart., vol. 12, no. 2, 1917, and Jour. Geology, vol. 25, pp. 715–740, 1917.

plane dips steeply eastward. Within the pre-Cambrian terrain, about 4 miles east of the Williams Range thrust fault, erosion along an east-west anticlinal fold has exposed the Cretaceous rocks underlying the thrust plate. This "window" in the pre-Cambrian terrane shows the Cretaceous rocks to be dipping steeply away from the western edge of a large stock of porphyritic quartz monzonite. The linear structure and the orientation of aplites in the porphyritic quartz monzonite indicate that the stock rose along the westward-pitching anticlinal fold that exposes the thrust plane in this region, but it is difficult to say whether the intruding magma followed a pre-existing anticlinal axis or domed the rocks by intrusive pressure.

Faults.—Although nearly all the recognizable faults record movement in early Tertiary time, some of them may follow zones of weakness that developed much earlier. Many northwesterly fractures are marked by the so-called breccia dikes,[22] more properly called breccia reefs. In many places the breccia reefs follow persistent dikes of pegmatite and gneissic aplite related to the Boulder Creek granite. Similarly the Williams Range thrust fault occurs at the edge of the old Paleozoic basin in what was probably the zone of weakness between the downwarped basin and the upwarped highland to the east.

The breccia-reef fault system and a few persistent north-northeast faults on the west side of the range, such as the Berthoud Pass fault shown in figure 15, represent the first marked effects of the Laramide revolution in this region. Except where reopened later, these early faults are poorly mineralized and for the most part have received little attention. The unmineralized fault zones are marked by depressions or troughs in some places, especially where erosion has not been too rapid, as on the crests of broad divides (fig. 18), but where strongly silicified the fault zone may stand out as a prominent wall-like outcrop (fig. 19); even where but slightly silicified the zones commonly weather in relief (fig. 20, *A*). The persistence and frequency of the north-northwesterly faults in the areas that have been studied in detail suggest that they may be common in the more competent pre-Cambrian rocks far beyond the narrow confines of the mineral belt (fig. 21). In the region south of the belt of intrusive stocks the direction of displacement of the walls of the large northerly or northwesterly faults is nearly everywhere the same, the western side having dropped relative to the eastern side. (See fig. 20, *B*.) In the Jamestown district, north of the main axis of the mineral belt, the displacement along the northwesterly faults is in the opposite direction, the eastern side being downthrown. These northwesterly faults apparently played an important part in localizing mineralization in the later east-northeasterly veins that cross or join them.

A glance at plate 3 or the claim maps of Summit, Clear Creek, Gilpin, and Boulder Counties brings out the fact that the majority of the mineralized fissures trend northeastward. In general, these mineralized fissures correspond to steeply dipping shear faults that developed after the northwesterly faults; in most places

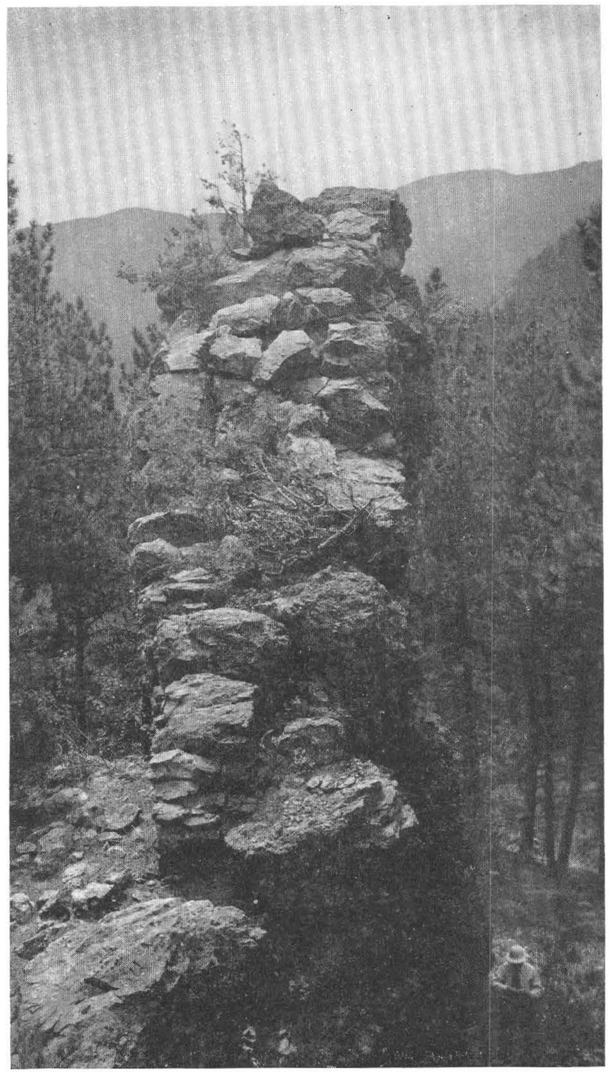

FIGURE 19.—Differential erosion of the Hoosier breccia reef near the head of Black Tiger Gulch, 6 miles west of Boulder. The country rock of this silicified northwest fault zone is Boulder Creek granite. Wall-like outcrops of this kind have given rise to the local use of the term "dikes" in naming these faults.

the movement along them is nearly horizontal. These shear faults probably represent a regional movement, for, as pointed out on pages 62 and 63, all the overthrusting northwest of the mineral belt was from the east towards the west, whereas the southern part of the Front Range and the region to the south and southwest are characterized by large overthrust faults in which the movement is from the west towards the east; thus, the direction of overthrusting is diametrically opposed on the north and south sides of a tectonic transition zone (fig. 21). It seems probable that much of the

[22] Lovering, T. S., Preliminary map showing the relations of ore deposits to geologic structure in Boulder County, Colo.: Colorado Sci. Soc. Proc., vol. 13, pp. 77–78, 1932.

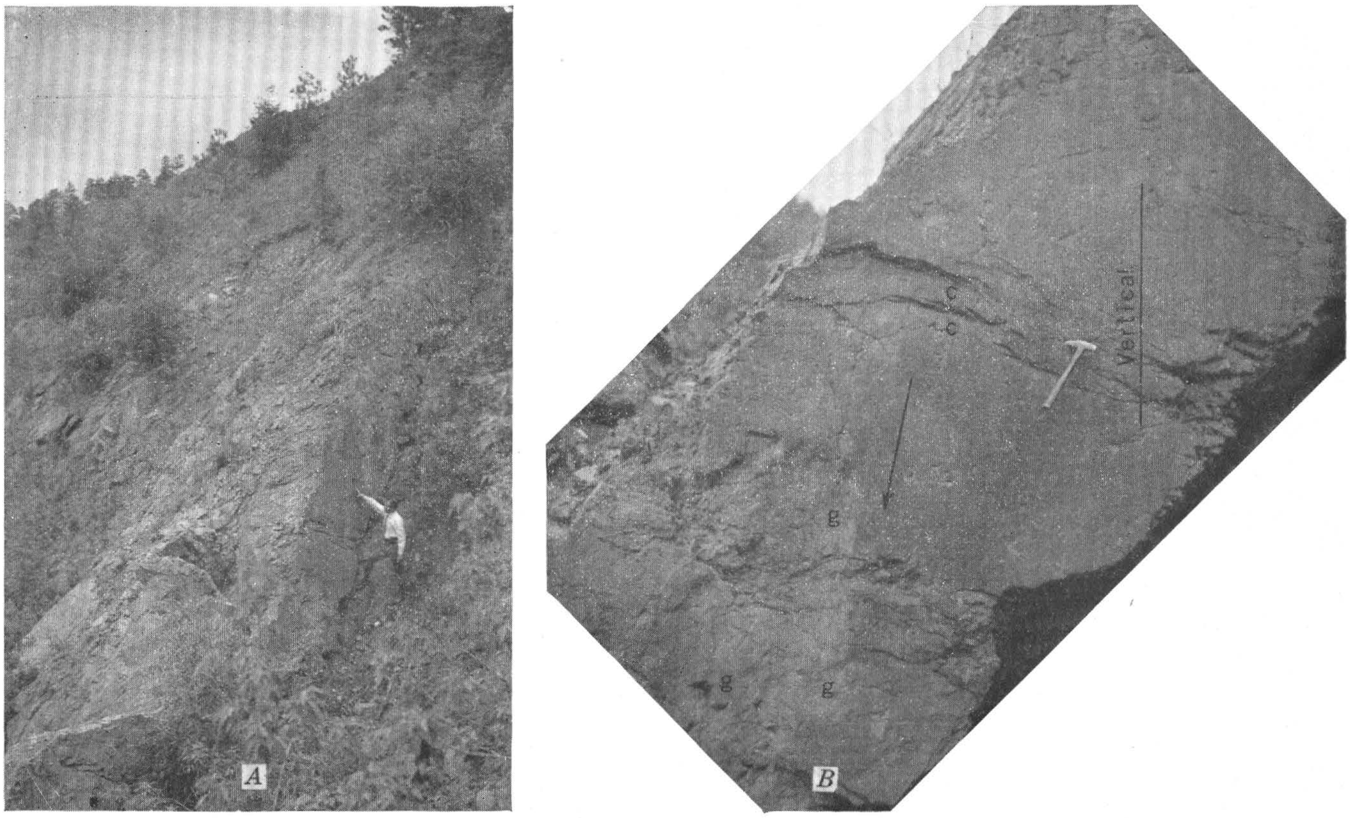

FIGURE 20.—*A*, Looking east at the Maxwell breccia reef near the junction of Fourmile Creek and North Boulder Creek. At this exposure the reef consists of brecciated Boulder Creek granite moderately silicified and stained with hematite. The breccia reef has been mapped previously as a pegmatite dike cutting the granite; *B*, Part of reef illustrated in *A*, showing the polished and grooved face of the Maxwell breccia reef. The direction of the grooves (*g*) is indicated by the arrow. The large-scale chatter mark (*c*) or "pressed in" structure shows that the west wall (toward the observer) has moved down with respect to the one pictured.

horizontal movement recorded in the northeastward-trending and eastward-trending faults of the mineral belt is due to the movement of the more active region to the northwest past the relatively stationary and stable mass to the southeast of the mineral belt. In most of the faults that have strong horizontal components of movement in the region between Tiger and Central City the northerly wall moved eastward relative to the southerly wall; in other words, this zone of horizontal movement is one of tear faults. This kind of movement and its distribution suggest that the Williams Range thrust fault is an underthrust.[23]

In addition to the shear faults just described, which are only slightly younger than the northwesterly faults, there are many other faults trending from east through northeast to north whose walls moved almost parallel to their dip. Most of them seem related to the intrusion of the porphyry stocks. In general, the porphyry stocks themselves are little fractured, and it is clear that most of the faulting and fissuring in the mineral belt was over before the quartz monzonite stocks solidified. In some places, as in the Jamestown district[24] and near Sunset, zones of brecciation and complex fissuring of the country rocks are clearly related to the emplacement of the porphyry stock. In the stockworks of the Breckenridge and Tiger districts the porphyries that lie in the marked zone of weakness directly in line with the tear fault zone of the Williams Range thrust fault were complexly shattered by slight movements that continued along this weak zone long after appreciable thrust faulting had ceased. Later mineralization of the shattered porphyry produced stockworks. In general, faults and fractures in the porphyry masses are short and discontinuous and record only minor movements.

In the northeastern part of the mineral belt horizontal movement of the fault walls is prominent. Along the northwestern edge of the mineral belt the left-hand wall moved ahead along most of the northeasterly faults, or, put somewhat differently, the horizontal component of movement in the southeastern wall was southwestward relative to the other wall. A few miles to the south, also, in the region just west and southwest of Boulder, horizontal fault movements were prominent, but the direction of movement was the opposite to that described above, and the northern walls of the eastward-trending faults moved west. These relations as well as those of the ore deposits themselves suggest a gradual focusing of compression on a wedge-shaped area near Boulder and possibly a change from a northeast-south-

[23] Lovering, T. S., Field evidence to distinguish overthrusting from underthrusting: Jour. Geology, vol. 40, no. 7, pp. 651–664, 1932.

[24] Goddard, E. N., Relation of Tertiary intrusive structural features to mineral deposits at Jamestown, Colo.: Econ. Geology, vol. 30, no. 4, pp. 374–376, 1935.

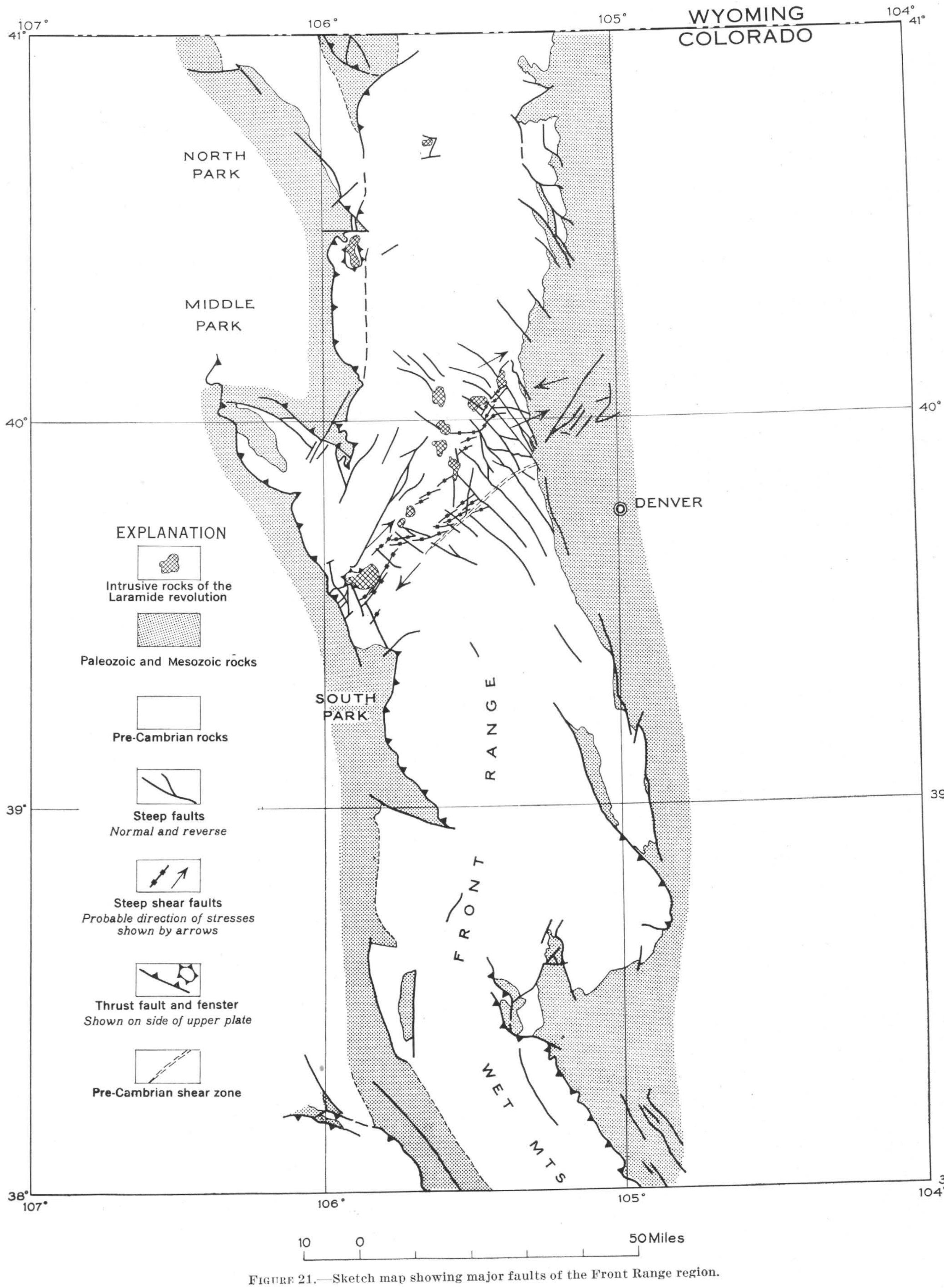

FIGURE 21.—Sketch map showing major faults of the Front Range region.

west compression to a more nearly east-west compression. The final movement of this wedge-shaped mass was almost due west and had its most intense effect in the southern part of the block (fig. 21). These late fractures were followed by the tungsten mineralization.

Stocks.—As shown on plates 1 and 2, the cross-breaking masses of porphyry intruded after the early Denver volcanism occupy a relatively narrow zone trending about N. 40° E. across the Front Range from Breckenridge to Jamestown. This zone of intrusion is nearly at right angles to the numerous northwesterly folds and suggests a transverse uplift; indeed, as already noted, there is a marked local doming around the Montezuma quartz monzonite stock, and at many other places fracturing close to stocks seems related to upthrust of the porphyry masses. This type of structure, however, is limited to the immediate vicinity of the porphyry stocks and presents no evidence of a regional northeasterly anticlinal fold coinciding with the belt of stocks. The porphyry belt, and especially the line of stocks, is substantially perpendicular to the direction of nearly horizontal compression indicated by the Laramide folding. As the direction of least compression or tension always lies perpendicular to the direction of maximum compression, tensional forces if present would be directed toward the northwest and southeast and would tend to pull the area apart along a northeastward-directed rip.

The belt of porphyry stocks follows a zone of northeasterly faulting, occupies a position nearly at right angles to the regional compression, and lies just northwest of the tectonic transition zone between two regions of oppositely directed thrusting. The relative movement of fault walls shows that the northwestern edge of the transition zone was one of nearly horizontal shearing as well as one of mild tension. It is believed that these conditions were largely responsible for the rise of deep magma into the upper part of the lithosphere and almost wholly responsible for the regional pattern of the porphyry stocks. The occurrence of the stocks in the schist areas and at the contacts of schist and granite masses suggests that the final localization of the stocks themselves was largely determined by zones of weakness in the pre-Cambrian rocks.

In the Jamestown district, the only one in which detailed work has been done on the direction of emplacement of the stocks, both the granodiorite and the younger quartz monzonite rose in smooth-sided columnar conduits that pitch steeply to the southwest.[25] At the western edge of the Montezuma quartz monzonite stock the primary structural features of the porphyry indicate that its roof slopes west-southwest at about 25°. On the northeastern side of the mass the roof slopes 45° NE. The northern and southern sides of the stock, however, are practically vertical. These structural features suggest that with further unroofing the long axis of the intrusive will coincide even more definitely with the general direction of the belt of stocks. This stock probably represents the high point on an underlying batholith of quartz monzonite. The monzonite stock west of Empire has pronounced primary flow lines, and a brief study of its southern edge indicates that here it had an irregular roof sloping steeply south-southeast.

Dikes.—Nearly all the dikes in the mineral belt are found within a zone a few miles wide bordering the belt of stocks on the southeast side. Most of the dikes in the southwestern half of the porphyry belt are relatively short, but some of those in the northeastern half attain lengths of many miles. Southwest of the Idaho Springs district the majority of the dikes have easterly strikes. From the latitude of the Idaho Springs district northward to Jamestown the most persistent dikes trend northwestward, and many follow fissures that pass into breccia reefs to the southeast. As dikes are intruded along fissures that offer least resistance, one might infer that these were tension fissures formed in the direction of a northwest-southeast compression; however, there is no evidence of northwest-southeast compression in the mountain front nearby, and the writers ascribe this northwesterly trend to preexisting planes of weakness opened by tensional forces developed in a nearly vertical upward movement of this part of the mineral belt. In this area between Idaho Springs and Nederland the northwesterly dikes are nearly all bostonites, one of the latest porphyries in the mineral belt. In the area east of Nederland, the northwesterly dikes belong to the very early ferromagnesian group and were intruded before marked folding and faulting took place. In this area the writers believe that the northwesterly dikes followed the lines of weakness developed during an early upward movement corresponding to the incipient northwesterly echelon folds of the type so evident to the north. Most of the dikes of the quartz monzonite series in the Nederland, Jamestown, and Ward districts trend from due east to northeast, suggesting that the direction of maximum compression at the time of their formation was from the east and northeast.

The scarcity of dikes and sills northwest of the belt of stocks and their relative abundance just southeast indicate the presence of subjacent magmatic chambers a relatively short distance below the surface southeast of the zone of stocks and suggest the lack of such bodies at shallow depths to the northwest. It is in the region just southeast of the belt of stocks, marked by the abundant dikes, that nearly all the ore deposits of the mineral belt occur, but important deposits at Ward and Ballarat lie just to the north of the main belt of stocks.

[25] Goddard, E. N., op. cit., pp. 370–386.

Porphyry stocks of early Denver age occur in a northward-trending zone extending from Caribou as far north as Mount Audubon, and the early low-grade pyritic gold ores in breccia reefs of the Ward district are more closely related to the epoch of igneous activity in which these stocks were emplaced than to the subsequent epoch in which stocks along the northeasterly belt were emplaced. From Caribou to Jamestown post-gabbro dikes are not uncommon just north of the main belt of stocks, and some of the mineral deposits that formed during the later periods of ore deposition are also found in this region.

Veins.—In a few places in the mineral belt, notably in the Ward district, ore deposits follow persistent northwesterly fissures, but more commonly the veins occur along the much less persistent northeasterly and east-northeasterly premineral faults related to the shearing stresses that accompanied the later stages of the Laramide revolution (pl. 3). Nevertheless, the northwesterly faults exercised a profound influence on the localization of the ore deposits. The faults of this system that break the batholith of Boulder Creek granite and the southern part of the batholith of Silver Plume granite at Jamestown are apparently contemporaneous with or slightly later than several moderately persistent easterly faults of undetermined but slight displacement. Both sets of faults are marked by silicified fault breccias and contain small amounts of hematite (fig. 23, *A*) and locally contain low-grade gold ore. These faults are evident in the schist areas only in a few places. At Ward the persistent west-northwesterly faults contain an early quartz that assays less than 0.05 ounce of gold to the ton. The appearance and tenor of this quartz are similar to those of the fault breccia just described; however, slightly later base-metal ores have supplied most of the district's output. In a few other localities these northwesterly faults were reopened and later mineralized, as at the Livingston mine of the Sugarloaf district.

The cross-breaking porphyry masses of the northeasterly belt of stocks are distinctly later than the northwesterly faults and the early barren silicified fault breccia. The discontinuous, nonpersistent, northeastward-trending fissures and faults that are common in the northern half of the granite mass west of Boulder and in the southern part of the Silver Plume granite near Jamestown are also later than the northwesterly faults, and in part they are later than the porphyry stocks.

Nearly all the productive gold and gold-telluride veins of Boulder County have been found in northeasterly fissures close to their intersections with the persistent early faults. Of later age than the northeasterly fissures is the zone of east-northeasterly fractures to the south, extending from Boulder westward to Nederland. Most of the tungsten mined in Boulder County comes from easterly fractures in this zone. Like the gold-telluride ores, most of the tungsten has come from later fissures close to their junctions with the earlier persistent northwesterly zones of weakness. The persistence of the vein material in these cross fractures differs greatly among the veins. Commonly extensive parts of a "vein" are found to be completely barren and unmineralized (fig. 22) or filled with a nearly barren

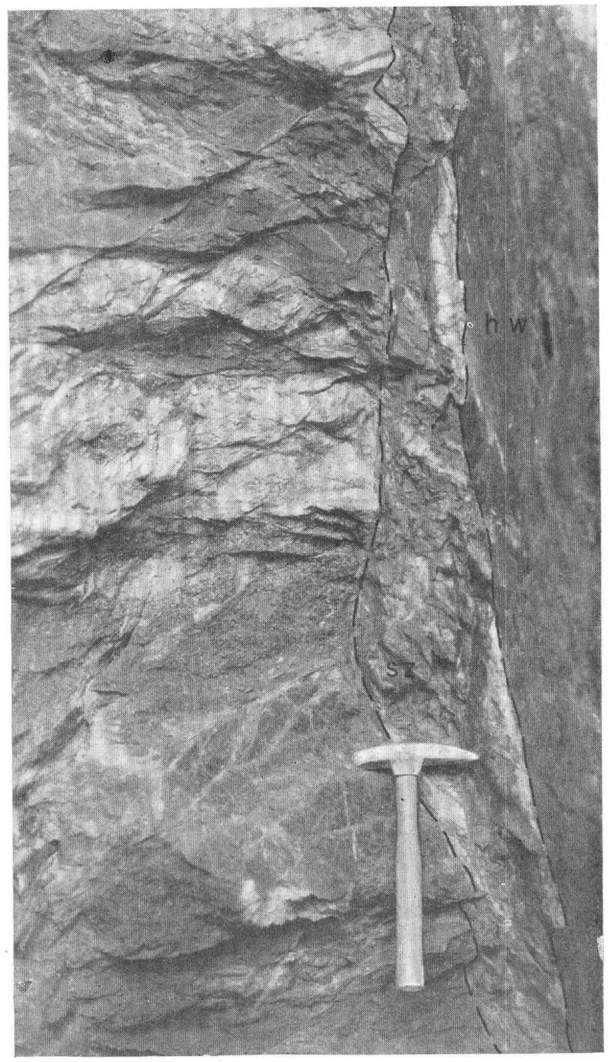

FIGURE 22.—Unmineralized part of tungsten vein 200 feet west of large ore shoot, 100-foot level of Tungsten Vein mine. Note interior faulting and drag in barren sheeted zone (*sz*), showing that the hanging wall (*hw*) has dropped.

quartz gangue (fig. 23, *B*); most of them contain commercial ore only locally (fig. 23, *C*). It would seem that the early faults extended to greater depth than the later fractures and acted as master fissures guiding the regional movement of ore-forming solutions. As these deep-reaching fractures were apparently in large part clogged during the early barren stage of mineralization, the later ore-forming solutions found conditions suitable for deposition only where these trunk channels had been refractured by later shearing movement or where access was gained to the later but less persistent cross fractures.

The northeast edge of the mineralized area of the Idaho Springs-Central City district is sharply limited by the northwesterly Blackhawk fault, and the southeastern boundary coincides closely with the pre-Cambrian shear zone extending from Chicago Creek northeastward through Junction Ranch (pls. 3 and 9). The mineralized area ends less abruptly to the southwest, but the last ore-bearing veins fall in a well-defined west-northwesterly zone along Cascade Creek, in line with the strong west-northwesterly faults and veins of Democrat Mountain and Saxon Mountain a few miles to the west. These faults apparently die out west of Cascade Creek, however. Most of the mineralization in the Central City area is related to a center of mineralization east of The Patch—a neck of explosion breccia. The nearby veins, from which much of the district's ore has come, trend slightly north of east and are localized in an anticline of granite gneiss between the northeastward-dipping Gem vein and the Blackhawk fault. Southwest of Idaho Springs the output has come chiefly from northeasterly veins (pl. 3).

In the region between the Idaho Springs-Central City district and Silver Plume the predominant trend of the veins is east to east-northeast, and the veins occur chiefly in relatively competent masses of gneiss and granite interlayered in the Idaho Springs formation. The easterly trend of the veins coincides with the easterly swing in the main mineral belt between Silver Plume and Central City. Southwest of Silver Plume nearly all the important veins trend northward.

In the Breckenridge district most of the productive veins strike from east to northeast, and the long dimensions of the stockworks also trend in that direction. Just as the mineral belt has a short prong extending northward from Caribou in the northeastern part, so near the southwestern edge of the Front Range there is a short southerly prong extending southward into Hall Valley. Nearly all the veins in this southern prong trend northeastward and are close to a north-northwesterly premineral fault.

ORE DEPOSITS

The Front Range mineral belt is characterized throughout by base-metal ores containing appreciable amounts of silver and gold. Except for the eastward-trending tungsten belt between Nederland and Boulder, the ores in the mineral belt northeast of Idaho Springs have been chiefly valuable for their gold content. To the southwest the ores are chiefly valuable for their base-metal and silver contents, except in part of the Breckenridge and Tiger districts where gold is the most important metal.

The great majority of the ore deposits are veins deposited as simple fissure fillings in the open parts of premineral faults. (See fig. 23, *C*.) Their wall rocks may be greatly altered and replaced by sericite, ankerite, or the clay minerals beidellite and dickite, and locally by silica and pyrite, but replacement veins or other replacement deposits containing valuable ores are found in only a few places. Most of the replacement ore is found in the wall rocks next to veins (see fig. 23, *D*) and does not extend more than a few feet from the vein fissure; replacement ores of the blanket type are rare, but both gold and lead-silver ores occur in replaceable beds of the upper part of the Dakota quartzite in the Breckenridge district. Stockworks and chimneylike shoots of ore are found in several places and have yielded substantial quantities of gold, especially from their superficially enriched zones near the surface.

The local intrusive centers are commonly centers of mineralization, and each may contain ores that are as characteristic of it as is the intrusive porphyry itself. The intrusive centers are marked by an unusual abundance of dikes, and many of the small porphyry masses are associated with more extensively mineralized ground than are the centers where large intrusive stocks are exposed. Thus, the Central City and Silver Plume districts have proved to be more extensively mineralized than the Montezuma or Empire districts. This relation accords with Butler's generalization that ore deposits are most abundant near intrusive centers where erosion has not been too deep.[26]

There are many local centers of mineralization in the mineral belt, and solutions emanating from different centers at corresponding periods in their magmatic history were similar. As shown in figure 12, the various porphyry differentiation series were followed by somewhat different types of mineralization. At many of the different centers of mineralization in which two or more intrusions of porphyry occurred, successive periods of ore deposition also took place. In some districts the deposits represent a fairly complete succession of these waves of mineralization, and in other localities only a single type is present. A zonal arrangement of the ores can usually be found around local centers of mineralization, and in many places the outer zones of separate centers overlap. In each locality the general features of the zoning and the age relations of the different types are in harmony with those found elsewhere in the mineral belt.

In the Jamestown district (fig. 77) the quartz monzonite stocks seem closely related to the centers of mineralization. Close to the stock is a zone of brecciation

[26] Butler, B. S., Relation of ore deposits to different types of intrusive bodies in Utah: Econ. Geology, vol. 10, pp. 101–122, 1915. Lovering, T. S., Localization of ore in the mineral belt of the Front Range, Colorado: Colorado Sci. Soc. Proc., vol. 12, no. 7, p. 241, 1930.

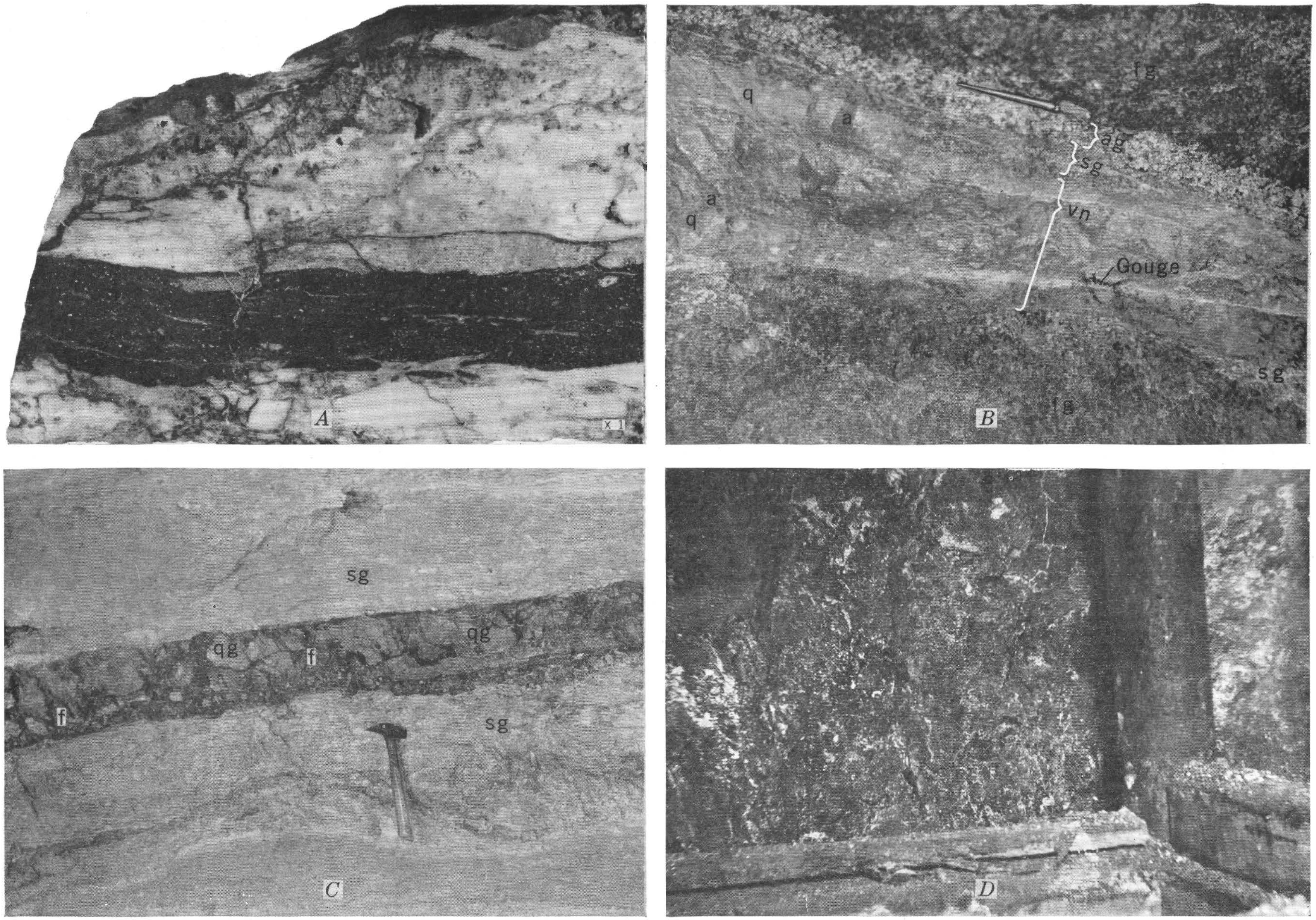

FIGURE 23.—*A*, Coarse vuggy quartz (white) cut by intergrown hematite and fine-grained quartz (black). From Rogers breccia reef west of Pewink Mountain. *B*, Characteristic appearance of the horn quartz in a barren part of a tungsten vein. Looking directly up at the Cold Spring vein in the roof of the 5th level, 600 feet east of New shaft. *fg*, Fresh granite; *ag*, argillized granite; *sg*, sericitized granite; *vn*, vein; *q*, horn quartz; and *a*, ankerite. *C*, Characteristic appearance of productive part of an average-size tungsten vein. Looking directly up at the Cold Spring vein in roof of stope on 1930 ore shoot 100 feet above level 4, west of Old shaft. *sg*, Sericitized granite; *qg* silicified and sericitized fragments of granite; *f*, intergrown ferberite and horn quartz. *D*, Main vein of Wellington mine on 3d level of Oro shaft, Breckenridge district. Massive sphalerite cut by seams of late white ankerite partly replaces the shale wall on the left side of picture.

related to the emplacement of the stock itself, and in this zone early silver-bearing base-metal veins and fluorspar veins are prominent. Pyritic gold veins locally cut the early base-metal ores but are more common at a slightly greater distance from the stock. Gold-telluride veins occupy nearly the same area as the pyritic gold deposits but are of later age.

In the Gold Hill district rich silver ores are earlier than gold-telluride ores, and they in turn are earlier than the pyritic gold veins that contain galena and sphalerite. In the silver ores the rich silver sulfantimonides are later than galena.

In the Nederland tungsten district the ores occur in a narrow eastward-trending belt whose western end seems closest to the source of mineralization. Silver ores in this belt are earlier than high-grade gold ores, and the high-grade gold and gold-telluride ores are both earlier than the tungsten ores. (See figs. 74, *A*, *B*.)

A zonal arrangement of the ore deposits in the Central City district was recognized by Collins long ago.[27] The most striking feature of this district is the central area of enargite-fluorite veins bordered by a broad zone of pyritic gold veins. In the outer part of this pyritic zone the veins carry appreciable amounts of lead and zinc; just beyond them is an intermediate zone of gold-bearing and silver-bearing pyritic galena-sphalerite veins that is fringed by an outer surrounding zone of lead-silver veins (pl. 9). The ores of the intermediate zone contain abundant lead and zinc, but these metals are rarely conspicuous constituents of the ores in the inner pyritic zone. The pyrite in the intermediate zone was the first sulfide to be deposited and was followed in turn by auriferous chalcopyrite, sphalerite, argentiferous gray copper, galena, and a minor amount of silver sulfantimonides (fig. 60, *F*).

When Bastin[28] studied this district he divided the ores into three groups: Pyritic ores, sphalerite-galena ores, and ores of uncertain character. Enargite ores and the uraninite ores of the district were regarded by him as local variants of the pyritic group. The galena-sphalerite ores are much less abundant and are later than the pyritic ores. They are always richer in silver and may or may not be poorer in gold. Telluride ores are rare and later than the pyritic ores, but their relationship to the sphalerite-galena ores was not discovered.[29] In the Empire district and near Georgetown, gold-bearing pyrite and quartz veins are definitely younger than the argentiferous base-metal veins, and for this reason Spurr,[30] in contrast to Bastin, regarded the pyritic gold ores of the Idaho Springs and Central City district as younger than the base-metal ores at Georgetown and Silver Plume and as contemporaneous with the late pyritic gold veins of these silver camps. In the Empire, Georgetown, Argentine, and Silver Plume districts, as in the Jamestown district, it seems probable that the silver-bearing veins characterized by galena and blende are older than the gold-bearing veins that are characterized especially by pyrite and chalcopyrite. In the silver-bearing veins of these districts the galena and blende are by far the most abundant constituents and, with pyrite, are earlier than the rich silver sulfides and sulfantimonides and the rather common but not abundant gangue minerals, quartz, kaolinite, calcite, and barite (fig. 60, *F*). In many of the silver veins the deposition of early quartz and pyrite preceded that of sphalerite-galena ore, and in some veins barite and hematite are present as presulfide minerals. In the pyritic gold ores of this region the succession of deposition was as follows: (1) Pyrite, ankerite, and quartz; (2) chalcopyrite, quartz, and galena, with blende in minor amounts; and (3) barite and kaolinite. The characteristic and essential constituent of these deposits is the auriferous pyrite in the quartz gangue. Galena and sphalerite may be absent but are usually present in small amounts.

In the Montezuma district there is evidence of zoning around the southern part of the large quartz monzonite stock. Veins in the southern part of the stock contain more pyrite and sphalerite than the veins outside the stock. Nearly all the rich silver ores of the Montezuma district are scattered irregularly through a belt about a mile wide, which borders the stock on the south from Glacier Mountain to Revenue Mountain, where it swings north and west into the stock, extending through Cooper Mountain and on into Lenawe Mountain. South of the rich silver veins barite and gray copper are abundant in the lead-zinc veins of Glacier Mountain and Revenue Mountain. Bismuth ores rich in silver occur in the veins farther south and are apparently somewhat later than most of the base-metal ores. In many of the mines in the Montezuma quadrangle a very appreciable amount of gold occurs in the base-metal ores. In these ores the gold content is directly related to the chalcopyrite, which is associated with early pyrite and quartz and is earlier than most of the galena and the sphalerite.

In the Breckenridge district there are probably several centers of mineralization, but for only one of them has a zonal arrangement been described.[31] Close to a

[27] Collins, G. E., The relative distribution of gold and silver values in the ores of Gilpin County: Am. Inst. Min. Met. Eng. Trans., vol. 12, pp. 480–499, 1903.

[28] Bastin, E. S., and Hill, J. M., Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colo.: U. S. Geol. Survey Prof. Paper 94, pp. 132, 133, 1917.

[29] Idem, p. 114.

[30] Spurr, J. E., Garrey, G. H., and Ball, S. H., Economic geology of the Georgetown quadrangle (together with the Empire district), Colo.: U. S. Geol. Survey Prof. Paper 63, pp. 99, 100 and 391, 1908.

[31] Lovering, T. S., Ore deposits of the Breckenridge mining district, Colo.: U. S. Geol. Survey Prof. Paper 176, 1934.

quartz monzonite stock just north of Breckenridge there is a border zone of high-temperature contact-metamorphic minerals with which low-grade copper ores are associated. Extensive silicification of shale accompanied the intrusion of the quartz monzonite stock, and nearly all this jaspery shale contains 0.005 to 0.04 ounce of gold to the ton. Later than the contact-metamorphic ores there formed successively pyrite, sphalerite, galena, and gold ores. The relation of the primary gold ores to the base-metal ores is not definitely known elsewhere in the district, but by analogy the gold is inferred to be later than the base-metal ores.

The general sequence of mineralization throughout the Front Range, indicated by the zonal arrangement of the ores, the age relation of the veins, and the paragenesis of the ore minerals is as follows: (1) Pyrite; (2) sphalerite; (3) chalcopyrite; (4) galena and chalcopyrite; (5) silver-bearing sulfantimonides, sulfarsenides, and bismuthinides; (6) pyrite and subordinate chalcopyrite; (7) free gold; (8) minor amounts of sphalerite, galena, and silver minerals; (9) gold tellurides; (10) sparse pyrite, gold, sphalerite, and galena; and (11) ferberite followed by sparse sulfides showing the usual order of deposition. Most of the ores from the region between the Idaho Springs district and the Breckenridge district belong in groups 1 to 5. To the north the bulk of the output from the mineral belt has come from groups 6 to 11.

RELATON OF ORES TO DEPTH

The depth to which the primary ore deposits extend is probably greatly in excess of that observed in any district, but the depth to which the ore of profitable tenor occurs may not be far below the present deepest openings in each district. The fact that most of the mines in the northeastern part of the mineral belt are comparatively shallow probably reflects the pockety nature of the ore deposits rather than the presence of a barren zone below a given depth. One of the deepest mines in this part of the mineral belt is the Slide mine at Gold Hill, where gold-telluride ore was mined from a continuous ore shoot extending from the surface to a depth of 1,000 feet. Five miles to the south, in the Magnolia district, the average depth of mine workings is only 200 feet, but in the adjacent canyon of Boulder Creek gold and tungsten ores of similar character are mined at an elevation 1,500 feet below that of the ore shoots exploited near Magnolia. Tungsten ore of shipping grade was found to a depth of 700 feet in the Conger mine near Nederland. In the Ward region to the north some of the gold mines have attained a vertical depth of 1,100 feet. In the Caribou and Eldora districts to the south silver and gold ores have been mined to a depth of 800 to 1,000 feet from the surface. In the pyritic gold veins of the Central City-Idaho Springs district the greatest depth reached is approximately 2,200 feet. In the Silver Plume district silver-lead-zinc ores were mined at a depth of 1,800 feet from the surface. In the Montezuma quadrangle the greatest vertical depth of any single ore shoot is approximately 800 feet. Near the western edge of the Montezuma quartz monzonite stock, however, galena-sphalerite ore has been taken from the Pilot vein in the valley of the Snake River 2,000 feet lower than similar ore in the Ida Bell mine on Independence Mountain about a mile to the south. In the Breckenridge district ore has been mined through a vertical range of about 1,750 feet between altitudes of 11,000 and 9,250 feet, although few individual ore shoots attain a vertical extent of more than 500 feet. The deepest continuous ore shoot in the Front Range is found on the Bismarck vein at Silver Plume, where silver-bearing lead-zinc ores extend from the surface to a depth of 1,800 feet. In most of the deep mines, as in the California-Hidden Treasure mine at Central City, several ore shoots connected by barren or low-grade vein matter were found at successively greater depths.

Because of the mountainous topography of the mineral belt, a somewhat clearer picture of the depth to which ore has been mined in the various districts may be given by expressing the level of the lowest workings in altitude above sea level. In the Boulder-Gold Hill-Jamestown region the vertical range of the ores mined roughly corresponds to that of the topographic relief. Thus, in the Poorman mine, a few miles west of Boulder, ore cropping out at 6,300 feet has been followed downward to an altitude of approximately 6,000 feet, about the level of the nearby Four-mile Creek. A few miles to the northwest, near Gold Hill, the Horsefal vein contained good ore at its outcrop at an altitude of approximately 8,400 feet. In the Jamestown district the altitude of the bottom of the lowest mine is approximately 7,000 feet, corresponding roughly with the altitude of James Creek at Jamestown. Good ore has also been worked at the outcrops of the veins at the tops of the nearby hills at altitudes of a little more than 8,000 feet. In the Ward district the lowest workings are at an altitude of approximately 8,000 feet, about 500 feet below the level of the nearby creek bottom. Near Nederland tungsten mining has been carried down from an altitude of 8,800 feet to one of 7,700 feet. In the Central City-Idaho Springs district the lowest altitudes reached by mine workings are between 7,000 and 7,100 feet. In the Georgetown-Silver Plume district little ore has been found below an altitude of 8,700 feet. In the Argentine Pass district ore has not been found below an altitude of 11,500 feet. At Montezuma the lowest ore is at an altitude of 10,000 feet. A few miles farther east, in the Pilot vein, ore has been mined at an altitude of 9,350 feet, approximately the level of the Snake River Valley in this locality. In the Breckenridge district ore has been mined at an altitude of 9,250 feet. Ore undoubtedly exists in the districts below the altitudes mentioned, but nearly all the ore has been produced well above them.

In almost all the districts ore has been found from the valley bottoms to the mountain tops, but the ore never has been followed for more than a short distance below the level of the master drainage of a district. Thus the vertical range of ore in individual mining districts may be as much as 3,500 feet, but most of this vertical distance is above the bottoms of the present valleys. The relation of known ore shoots to topography is accidental; it reflects the greater difficulty and expense of finding new ore shoots not directly connected by pay ore with shoots that crop out at the surface. There is no question, however, that in individual districts there are fewer fissures and veins at low altitudes than at high altitudes. The long premineral faults that later became veins were open at greater depths than the less persistent ones and thus would in general be filled by correspondingly deeper-reaching ore shoots, but all fissures must eventually disappear along both the dip and strike. In many places, however, a zone of movement is marked in plan by overlapping faults and such overlapping occurs along the dip as well as along the strike of the premineral faults. Blind ore shoots may exist in fractures that do not reach the surface but are parallel to and not far from known veins.

The lowest limit of exploration in any district may mark the bottom of a deep ore shoot or simply a transition to lower-grade material; in few places does it coincide with the end of the vein itself. In some veins, as in the Concrete-Gunnell vein of the Central City district, the lowest workings on the vein suggest that the vein itself is feathering out with depth (fig. 30). Such "horsetailing" in depth, however, may indicate the presence of an overlapping fissure a short distance away which continues to greater depth. (See p. 96 for a discussion of the pattern habits of such fissures.) The expense of deep exploration is so high that comparatively little work is done in searching for deep blind ore shoots. Where such exploration has been carried on the search for new ore bodies has been successful in only a few places. Unfavorable structural conditions rather than depth may account for the high percentage of failures in deep exploration, but the high percentage itself should discourage exploration except where structural conditions are especially encouraging.

SUPERGENE ENRICHMENT

Both residual enrichment and supergene sulfide enrichment are common in the ores of the mineral belt. A zone of residual enrichment in which the relatively insoluble minerals lingered while the more soluble ones were leached out coincides with the oxidized zone of the sulfide deposits and with the soil zone of other types of deposits. Residual enrichment of the tungsten ores was prominent and resulted in rich accumulations of "float ore" at the surface along the outcrops of ore shoots. In many places the oxidized zone of sulfide veins does not extend downward to the present water level, and in few places does it extend far below it. Within the pre-Cambrian terrain the oxidized zone ranges from a few feet from the present surface to a maximum of approximately 100 feet. In the Breckenridge and Tiger districts, however, oxidized ores have been found as deep as 300 feet in certain localities. The oxidized ores are commonly richer in gold, silver, and lead than the primary ores but contain less zinc and copper. At very few places in the mineral belt are barren leached zones found above the oxidized zones, and these leached zones are not more than 20 feet deep. Below the oxidized zone, and commonly below the present level of ground water, there is a marked increase in the silver content of many veins. This is due to the reprecipitation of secondary silver minerals from solutions that have dissolved some of the silver of the oxidized zone. Secondary copper minerals are also common in this sulfide zone but are of far less interest for their copper content than for the silver minerals with which they are commonly associated.

Both residual enrichment and supergene sulfide enrichment are determined by the composition of the veins, the former upward extent of the ore deposit above the erosion surface, the rate of erosion since the tops of the veins came within the zone of vadose circulation, and the past and present position of the ground-water table. The physiographic history of the Front Range indicates that the Flattop peneplain has not been cut much below the level of the surface that existed when most of the veins in the Front Range were formed. In harmony with this history, veins that crop out on the Flattop peneplain have a very shallow enriched zone. Thus in the pyritic gold veins that crop out on Wise Mountain in the Montezuma quadrangle rich gold ore was limited to a depth of 25 feet from the surface; below this level the ore turned abruptly into low-grade pyrite. Where the present erosion surface corresponds to the Green Ridge peneplain or to the Rocky Mountain peneplain both residual and secondarily enriched sulfide ores are much more important. In the Breckenridge district the relation of supergene enrichment to the Tertiary peneplain is a very striking feature of the ore deposits. (See p. 108.) A similar relationship is well illustrated in the Caribou district a few miles south of Ward. The peneplains are of two-fold importance; they indicate approximately the amount of material that has been removed by erosion, and they also indicate a temporary base level towards which the region was progressing over a long period of time, and consequently a level below which the water table did not sink far. The effect of these two factors on enrichment is evident.

By far the most important factors in the secondary enrichment of the ores is the relative solubility in the reducing environment below the water table of the various constituents dissolved in the oxidizing environment above the water table. With those compounds that are sensitive to a change from the oxidizing to the reducing environment, the speed with which precipitation takes place and consequently the depth and richness of the secondary sulfide zones depend on the rate of change in the acidity of the solution. Thus, in veins containing large proportions of primary minerals that readily react with acid solutions and therefore rapidly neutralize them, the change from oxidizing to reducing conditions is relatively rapid, and a marked zone of secondary sulfide enrichment would be expected. The attack of an acid sulfate solution on copper, lead, zinc, and silver sulfides decreases the acidity of the solution in proportion to the amount of these minerals it dissolves. As the rate of decrease varies with the rate of attack, the easily soluble minerals are much more effective in quickly changing the acidity than are the others. Common minerals, arranged in their order of effectiveness in decreasing the acidity of acid sulfate solutions are: Calcite, pyrrhotite, siderite, tetrahedrite, chalcocite, sphalerite, galena, bornite, chalcopyrite, marcasite, and pyrite.[32] Those sufides that are soluble in acid sulfate solutions but insoluble in neutral or alkaline solutions are of course precipitated where the solutions act on minerals that reduce the acidity; such a process commonly results in the replacement of early minerals by late supergene sulfides. As carbonate gangues, pyrrhotite, tetrahedrite, galena, and sphalerite all react rapidly with acid sulfate solutions, veins containing noteworthy amounts of these minerals would be the ones most likely to have a marked zone of secondary sulfide enrichment. In the heavy pyritic ores the effect would be the opposite. Both Spurr[33] and Bastin[34] have noted the difference between secondary enrichment of the pyritic gold veins and that of the base-metal veins.

Copper sulfides are easily soluble in acid sulfate waters but precipitate when the solutions become neutral or alkaline. Thus the change of pH concentration that corresponds to a change from ferric sulfate to ferrous sulfate causes almost complete precipitation of the copper. All of the primary copper minerals of the Front Range ores are attacked by the ferric sulfate solutions generated during the oxidation of pyrite. Some of the primary copper in veins may be changed to carbonates and oxides which linger in the oxidized zone, but much of it is leached and carried down to the sulfide zone, where it is precipitated. In the mineral belt most of the supergene copper occurs in the form of malachite, azurite, basic sulfates, chalcocite, covellite, and bornite. The zone of secondary enrichment is marked by a decided increase in the copper content of the ore throughout the mineral belt, but it is chiefly important for the increase in gold and silver associated with the secondary copper minerals.

Silver is readily soluble in acid sulfate solutions but is easily precipitated by many substances. Neutralization of the acidity is sufficient to precipitate native silver, and hydrogen sulfide instantly precipitates silver sulfide. Chloride solutions will cause the deposition of horn silver (cerargerite), a common reaction in the upper part of the oxidized zone in arid regions but of little importance in the mineral belt. Weak silver solutions in places react with silicates, such as the clay minerals and orthoclase, and precipitate silver that often is not evident without assay. In well-drained slightly arid localities silver and iron sulfates commonly react to form the basic sulfate argentojarosite, which has been observed at several outcrops in the mineral belt. Where silver-bearing sulfate solutions attack such sulfantimonides or sulfarsenides as gray copper below the zone of oxidation, the silver generally reacts to form one of the complex silver sulfantimonides or sulfarsenides of the ruby-silver group. In the mineral belt nearly all the freibergite and dark ruby silver are primary, whereas most of the proustite, pearcite, stephanite, and argentite are supergene; much of the native silver and stromeyerite have been ascribed to supergene processes, but in most of the occurrences studied by the writers these minerals are primary. Supergene silver was abundant in the Caribou district, however (fig. 68, *A*).

Almost the only primary zinc minerals in the Front Range are varieties of sphalerite. This sulfide is easily oxidized by meteoric sulfate water and not only dissolves readily but remains in solution even though the water changes from acid to neutral or alkaline. Smithsonite may be precipitated from zinc sulfate solutions by limestone, and secondary sulfide may form rarely where the solutions are alkaline and free hydrogen sulfide is present. Such conditions have not been found in the mineral belt, and secondary zinc minerals are confined to commercially unimportant occurrences of hemimorphite, smithsonite, and hydrozincite in the oxidized zone.

Although lead occurs in many primary minerals, the sulfide galena is the one that constitutes almost all the lead ore. The behavior of galena in the vadose zone is strikingly different from that of sphalerite. Although galena exposed at the surface is quickly filmed over

[32] Emmons, W. H., Enrichment of ore deposits: U. S. Geol. Survey Bull. 625, pp. 124–137, 1917.

[33] Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., pp. 143–144.

[34] Bastin, E. S., and Hill, J. M., op. cit., pp. 137–152.

with a thin coating of sulfate or carbonate, both of these compounds are so insoluble that they protect the galena from further rapid change. The carbonate, sulfate, and sulfide are all practically insoluble in meteoric water unless the water contains unusually large proportions of organic acid or is brinelike in character. Under the semihumid conditions that have prevailed in the Front Range since Eocene time a continual vegetative covering has probably been a source of humic acids. Lead carbonate is readily soluble in humic acids [35] but is easily precipitated by hydrogen sulfide, sulfate solutions, or by neutralization of the acid. This behavior accords with the fact that cerussite, the carbonate of lead, is very common in the oxidized zone, whereas anglesite, the sulfate, is relatively rare, and secondary galena is unknown either in the oxidized or sulfide zone. The oxidized lead ores generally contain residual masses of galena that are much richer in gold and silver than the primary ore (fig. 60, *A*).

Gold, though noted for its general resistance to solution, is soluble in the upper part of a vein under certain conditions that are not well understood. The work of Freise [36] suggests that organic compounds in meteoric waters may be instrumental in the dissolving of gold, which is easily precipitated by neutralization of the acidity or oxidation of the organic compounds. The solution and precipitation of free gold seems to take place chiefly in the oxidized zone, but some gold moves down into the upper part of the zone of secondary sulfide enrichment. Gold tellurides oxidize readily changing into colloidal telluric acid and flour gold, both of which tend to dissipate in surface water. Some supergene gold enrichment occurs in telluride veins, but the gold is always reprecipitated as the metal, never as a telluride.

Throughout the mineral belt the enrichment of the pyritic gold deposits is similar. At the outcrops or a few feet below, there is a noteworthy concentration of gold in the oxidized zone and some residual enrichment of silver and galena. Below the oxidized zone the primary pyritic ores are in abrupt contact with oxidized ore and show almost no evidence of secondary sulfide enrichment unless chalcopyrite is present. In such ore rich auriferous sooty chalcocite is commonly found in a thin zone just below the water table. Many of the base-metal ores have similar oxidized zones in which gold and silver are more prominent than in the primary ores, but, in contrast to the pyritic gold ores immediately below the oxidized zone, supergene enrichment is obvious and important. The silver content in the zone of sulfide enrichment is somewhat higher than in the oxidized zone and much higher than in the primary ore. Commonly the highest-grade ore is found at a depth of less than 300 feet from the surface, and the value of the ore decreases gradually with greater depth. Enrichment of the gold-telluride ores is slight and is limited to the oxidized zone. There is no enrichment of the tungsten ores except for the residual concentration of ferberite at the outcrop of the veins.

The oxidized parts of the different types of sulfide ore are similar and commonly consist chiefly of brown claylike material that contains relatively large quantities of both silver and gold. Residual masses of oxidized galena ore are irregularly distributed throughout the oxidized zone in the galena-sphalerite veins and usually contain much gold and silver (fig. 60, *A*). In the oxidized zone of the tungsten ore the sericitized and kaolinized wall rock is stained brown from the oxidation of the ferrous tungstate, and the resulting brown claylike material is similar to the oxidized zone of the other veins. There is however, no silver, gold, or lead in this oxidized zone but only rounded residual masses of weathered ferberite.

In the secondary sulfide zone of the galena-sphalerite veins sooty masses of secondary copper minerals rich in silver are common, and well-crystallized sulfantimonides and sulfarsenides of silver occur in vugs or fill fractures in the primary ore. According to Bastin,[37] there are two general types of mineral association common in the rich supergene silver ores: (1) The secondary sulfo-compounds of silver, such as pearcite and proustite associated with secondary chalcopyrite, and (2) abundant native silver associated with sooty chalcocite, bornite, and some covellite. The secondary silver minerals were deposited in fractures in the primary ore and also by metasomatic replacement of the primary minerals.

LOCALIZATION OF ORE

General considerations.—The character and localization of ore in the mineral belt were determined by the composition and location of the source magma, the character of the conduit followed by the mineralizing solutions, and by the precipitation gradient existing within the conduit.

The actual sources of the ore are doubtful, but the spatial relations of ores and early Tertiary intrusives suggest that certain porphyries represent magmas genetically related to definite types of ore. There is little doubt that the contact-metamorphic copper ores and the related low-grade auriferous silicified shale in the Breckenridge district were due to volatiles emanating from the same magmatic hearth that was the source of the adjacent quartz monzonite porphyry stocks and sills. The lead-zinc-silver veins between Breckenridge and Silver Plume are found in an area where rhyolite and sodic quartz monzonite porphyry are the latest pre-ore intrusives. Similar rocks are found in other

[35] Lovering, T. S., op. cit., p. 30.

[36] Freise, F. W., Transportation of gold by organic underground solutions: Econ. Geology, vol. 26, pp. 421–431, 1931.

[37] Bastin, E. S., and Hill, J. M., op. cit., p. 152.

parts of the Front Range where lead-zinc-silver ores of this type occur. As the rhyolites are probably derived from the quartz monzonites by filter-pressing, it is believed the lead-silver-zinc veins are most closely related genetically to the sodic quartz monzonite magma. The distribution of pyritic gold ores that are later than the lead-silver-zinc veins coincides with that of dikes and stocks of alkalic syenite, bostonite, and trachyte. These rocks are the latest porphyries that are earlier than the pyritic gold veins and are regarded as representative of the source magma of this type of ore. The gold-telluride ores are intimately associated with potassic biotite latite dikes and intrusion breccias in many places, and the distribution of the telluride veins coincides roughly with the occurrence of rocks of this type. The biotite latite intrusion breccia has been found in some of the gold-telluride veins below or near the bottom of the telluride ore shoot (fig. 24). Apparently fresh specimens of the intrusion breccia and the related biotite monzonite porphyry contain 0.01 ounce and a trace of gold per ton, respectively. The intrusion breccias are earlier than the telluride ores but later than the pyritic gold ores and the bostonites and other Tertiary intrusives of the region. They probably represent the source magma of the telluride ores. The tungsten belt is characterized by much more mafic dikes than the surrounding region, but spectroscopic work by Bray on the intrusive rocks of the tungsten district suggests that the ores are related to the same magma as the telluride ores; the only fresh rocks in which tungsten was found were biotite monzonite porphyry and the biotite latite intrusion breccia.[38]

Two general classes of conduits guided the mineralizing solutions from the source magma toward the surface. The most common were premineralization or intramineralization faults. Most of these faults, which dip steeply and show a larger horizontal than vertical component of movement, became the "true fissure veins" of the mineral belt.

The second type of conduit is primarily a result of igneous activity; it includes the zones of brecciation created adjacent to porphyry masses during intrusion

[38] Lovering, T. S., Origin of the tungsten ores of Boulder County, Colo.: Econ. Geology, vol. 36, p. 261, 1941.

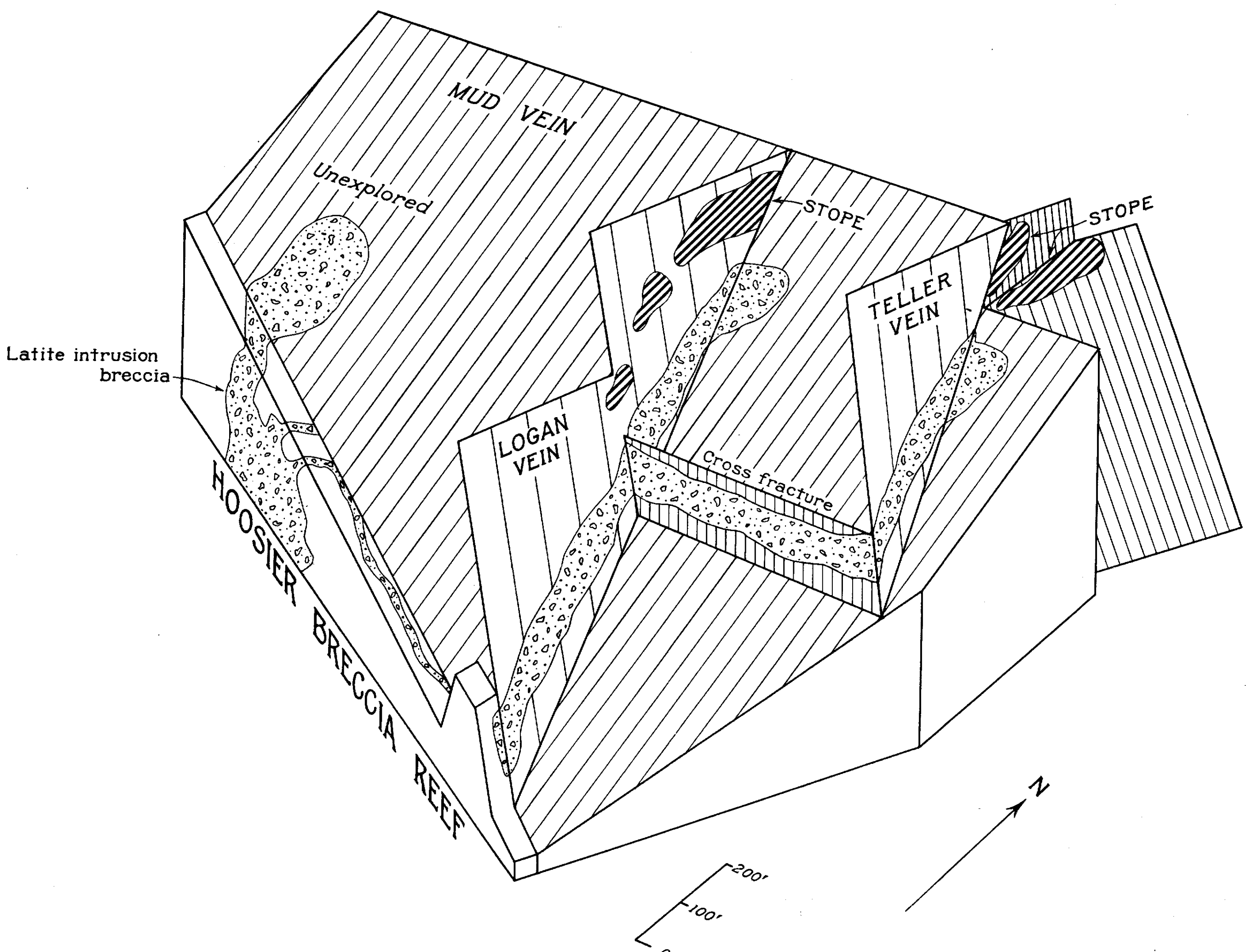

FIGURE 24.—Block diagram showing the relation of intrusion breccia to gold-telluride ore shoots in the Logan mine.

and the openings resulting from explosive volcanism. The zones of brecciation adjoining porphyry masses are related to the direction of emplacement of the intrusive and much more commonly occur along the roof of the intrusive than along its floor. Fracturing of this type diminishes rapidly in intensity with distance from the intrusive, and in plan and cross section the zones of brecciation are closely related to the shape of the intrusive mass. In some localities the pattern of the brecciated zones and their occurrence in the roof or hanging wall of the intrusive suggest fracturing due to the intrusive push, but in other places the arrangements of the zones are more nearly concentric and indicate subsidence of the underlying magma with resulting collapse. An extensive chimneylike zone of brecciation near intersecting fissures may have been caused by a localized but violent upward push of the magma and thus be intermediate between the breccia zone formed by normal intrusion and that formed by explosive volcanism, but where such brecciation is of slight vertical extent it is usually attributable to recurrent fault movements.

Breccias formed by the explosive shattering of the country rock have been found in many places between the Georgetown and the Jamestown districts. They may be divided into two general classes: (1) Those in which no intrusive material is present, and (2) those in which the matrix consists largely or at least in part of igneous material that was originally vesicular and glassy (fig. 17, *A*). Where fresh enough for identification, this matrix material has the composition of latite. The breccias of the first type will here be called explosion breccias, as distinguished from the latitic intrusion breccias that have an igneous matrix presumably of latite. Nearly everywhere breccias of both types were emplaced along preexisting fractures. Both chimneylike and sheetlike masses of explosion breccia occur within veins, but the pipelike masses are most common near the intersection of two or more fissures. The explosion breccias comprise fragments of the walls and underlying country rock through which the mass has moved; these fragments range in size from extremely coarse material to dustlike particles. The latitic intrusion breccias also contain fragments of underlying rock and wall rock showing a similar range in size but these fragments are embedded in an igneous matrix which is usually altered to a purplish-gray clay gouge.

The high water content of the latite and the latite intrusion breccias (pl. 7) is indicative of the high content of volatiles and the high pressure existing at the time of intrusion. It is probable that the volatiles were forced into rock fragments and into the country rock along fissures under very high pressures, before the actual relief of pressure by fracturing. Under these conditions the volatiles absorbed in the minute pore spaces of the rock would expand with explosive violence when suddenly released and cause intense shattering and comminution of the rock. Much of the extreme fragmentation observed in explosion breccias may have such an origin.

The precipitation gradient may be defined as the rate of change of the chemical and physical environment of the ore-depositing solutions. The presence of strongly reactive material out of equilibrium with passing solutions would produce a rapid change in the chemical character of the solution; in other regions it has often been one of the most effective factors in the precipitation of ores, as witness the extensive replacement of limestones and dolomites. The sericitic and kaolinitic alteration of the walls of the veins of the mineral belt reflects the lack of equilibrium between mineralizing solutions and wall rock. Ore formed by replacement of the wall rock or of the fissure filling is relatively rare, however, and almost none of the ore shoots have been formed because of the chemical composition of their walls.

Where the controls of ore localization have been discovered, they are related to the physical factors rather than to the chemical composition of the walls. Of several physical factors that may induce precipitation, changes in temperature and pressure were probably the most important ones in the veins of the mineral belt. It has generally been assumed that pressure increases directly with depth, that the rock pressure at any given depth below the surface is equal to the weight of a column of rock extending to the surface. Similarly, it is customary to assume that the pressure on a mineralizing solution at any point in a fissure below the surface is equivalent to the hydrostatic head at that depth. Neither of these assumptions seems entirely justified. Pressure on a small area is transmitted in an outward-flaring cone of diminishing intensity, and it is thus possible for pressure in a localized area to be built up greatly in excess of the weight of the rock column above it. Although the pressure gradient in an open channel filled with quiet liquid would be approximately the hydrostatic head at any given depth, this is not true of an upward-moving solution passing through a conduit that has a marked constriction between the source and exit of the fluid. Below the constriction the gradient is that of the hydrostatic head plus the driving force used to push the solution through the constriction. Above the constriction the pressure at any depth is much more nearly that of the hydrostatic head. Thus the most rapid change in the pressure gradient should occur immediately above the point of the greatest constriction of the conduit. With intramineralization movement along faults the places of greatest constriction would change from time to time, and sudden access to a new channel might shift the position of the steep pressure gradient either toward or away from the source of the solution.

The temperature drop within a moving solution depends on the difference between the temperatures of solution and wall, the thermal constants of each, the presence or absence of convection, the volume of solution moving past a unit area of the wall in unit time, the outward temperature gradient within the walls, and the heat contributed or absorbed by chemical reactions and changes of state. The higher the thermal diffusivity of the wall rock, the more rapid will be the conduction of heat from the solution and the greater will be the temperature drop of the solution in a given length of time. So far as known, there is little difference in the thermal constants of the different types of fresh wall rocks of the veins, and no information on the altered walls is available. In many schists and gneisses the diffusivity is much greater parallel to the foliation than across it, and solutions should give up their heat most rapidly when moving transverse to the foliation. In channels sufficiently open to allow active convection, the temperature gradient along the walls within the zone of active circulation will be much more uniform than where convection is absent.

The temperature gradient within the wall rock in contact with a hot moving solution varies with the length of time that the solution remains in contact with the wall. The longer the period of time during which the solution passes the wall, the lower will the temperature gradient become and the lower will be the amount of heat taken from the solution. The larger the volume of fresh solution passing a unit area in unit time, the larger is the supply of fresh heat brought to the wall, and the more rapid the flattening of the temperature gradient in the wall, the less rapid is the temperature fall within the solution.

If a fissure were equally permeable along the dip and the driving force were uniform, a given volume of the solution rising through it would pass a unit area of the wall in the same period of time, whether the width of the fissure were great or small. Where the permeability varies along dip and strike and where irregular masses of relatively impervious material surround large semi-isolated areas of porous breccia or open fissure that are connected by restricted channels, the volume of solution passing a given area within the constriction is much greater than that passing a unit area in the enlarged portions in a given time (fig. 25). In the constricted area relatively little heat would be lost from the large volume of rapidly moving solution, and little temperature change would be noted in the solution. In the enlarged portions, where the solution would move much more slowly and a greater surface of wall rock would be in contact with a given volume of solution during a given time, the heat loss would be correspondingly greater and the change in temperature much more apparent. Thus, the most rapid change in temperature gradient in the solution would occur in open zones within the fissures immediately above constrictions in the feeding channel.

The introduction of a hot solution into a cool breccia-filled cavity would result in a much more rapid fall in temperature than its introduction into the same open space lacking the breccia. With continued movement through the breccia-filled opening, the fragments would

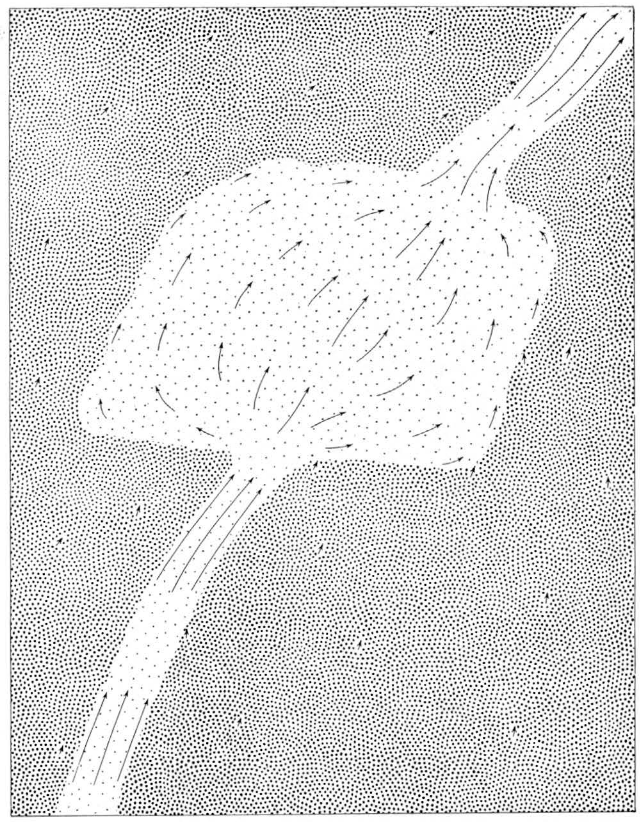

FIGURE 25.—Diagram showing the relative rate of movement of solutions in tight channels and in open spaces in a breccia-filled fissure.

soon heat up to the temperature of the passing solution and thereafter would not exert any cooling effect upon it.

From the foregoing discussion it appears that the physical factors favoring a steep precipitation gradient are (1) The presence of relatively large open areas in a fissure immediately above a constricted feeding channel and (2) the diversion of a mineralizing solution into a new channel.

It would seem that the factors instrumental in determining the localization of ore shoots are primarily those determining the amounts of solution that pass through different parts of the fissure in a given length of time. In general, those portions allowing the largest amount of fluid to pass through them should have the most favorable precipitation gradient as well as the

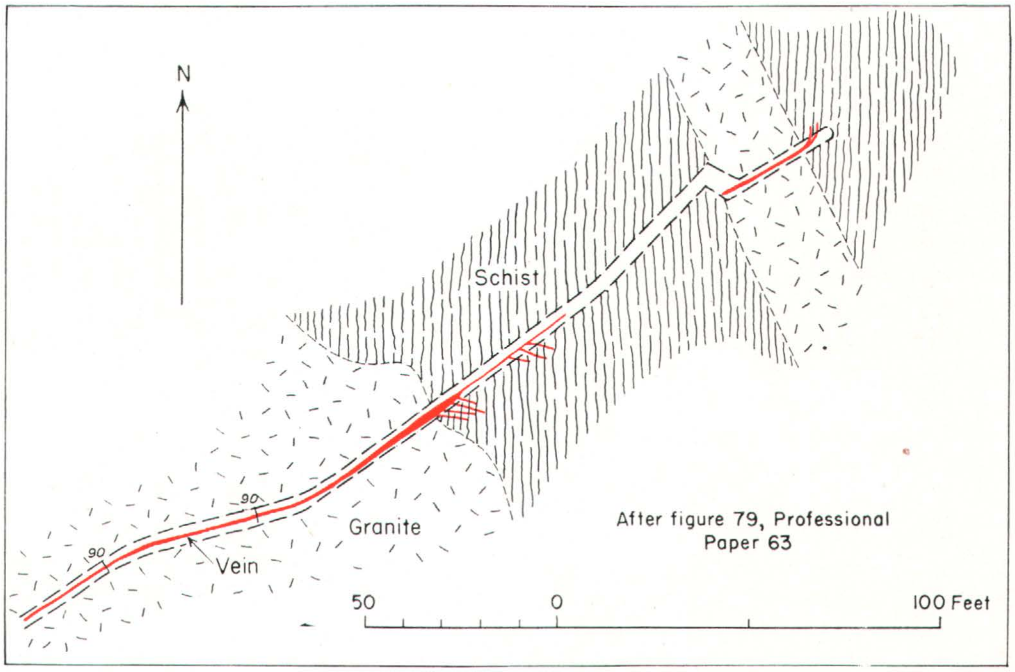

FIGURE 26.—Part of the Terrible vein, Silver Plume district. The difference in influence of granite and schist walls on the localization of ore shoots is well shown in this plan of the northeast part of the no. 4 Dunderberg level. A vein that is strong in granite branches and disappears where it enters gneiss, but farther on, in another bar of granite, a well-mineralized vein appears in line with the other ore shoot.

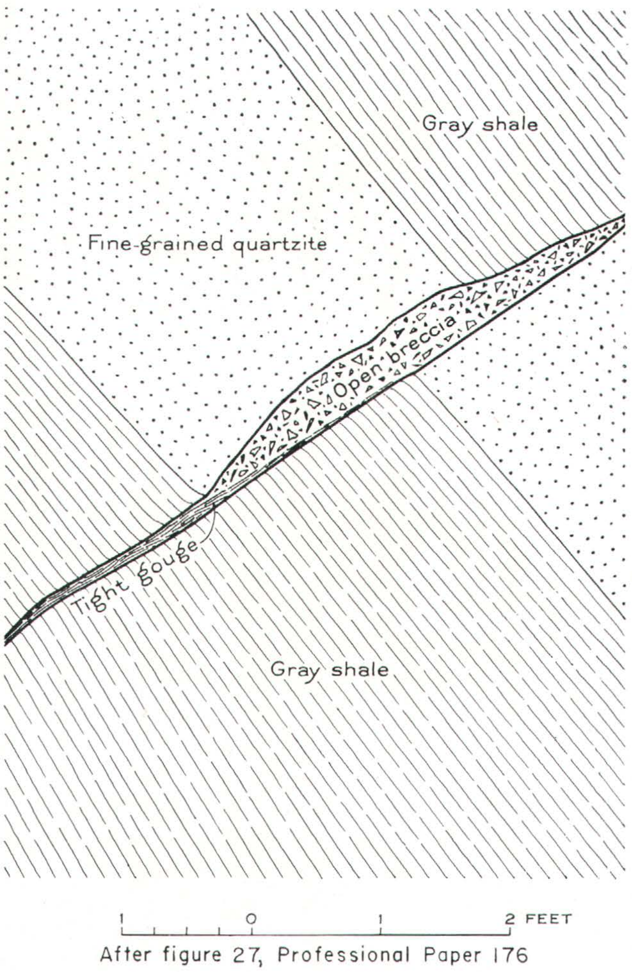

FIGURE 27.—Fracturing of interbedded shale and quartzite, level 6, Wellington mine.

largest supply of the ore-depositing solution, and thus would be most favorable for the occurrence and localization of ore shoots.

In any conduit connected with the source magma, the amount of solution passing through will be governed by the laws of flow of liquids in permeable material. It has been shown by Slichter [39] that the volume of liquid transmitted through soil or other permeable material is directly proportional to the pressure, the area of cross section, and the square of the effective grain size but is inversely proportional to the viscosity and the length of the conduit. Effective grain size is defined as the size of grain which in a uniformly sized aggregate would permit the same flow as that found in a given heterogeneous aggregate. It has been determined by experiment that the effective grain size is generally that which separates 90 percent oversize from 10 percent undersize material. The rate of flow changes with the first power of all the variables except grain size, to which it has an exponential relation. This indicates that variations in the coarseness of the fissure filling would be of the utmost importance in determining the channels followed by the mineralizing solution.

Structures controlling ore shoots.—The coarseness of the fissure filling and the amount of open space within a fissure formed by faulting is determined by the amount and direction of the fault movement, the physical nature of the wall rock, and the irregularities of the fissure itself. A slight movement along a fissure would reduce kaolinized, sericitized, or chloritized rock (whether

[39] Slichter, C. S., Theoretical investigation of the motion of ground waters: U. S. Geol. Survey, 19th Ann. Rept., pt. 2, p. 301 ff., 1899.

fissure filling or walls) to relatively impervious gouge, whereas a silicified part of the same rock or fissure filling would be broken into a coarse open breccia by the movement. In unaltered rock the strength of the walls is a determining factor. The fissure system shown in figure 26 was caused by a slight movement that was absorbed by inconspicuous folding and by slipping along interlaminal planes in the relatively incompetent schist, whereas in the more competent and brittle granite the same movement yielded continuous open fractures. A strong movement that would break through schist might grind it to gouge along the fault, but the movement that comminuted the schist might result in a coarse open breccia in granite. However, a strong continuous fault in granite may be represented by a wide zone of overlapping imbricated minor shear planes within an area of schist. The relative competence of schist and granite is similar to that of the shale and quartzite shown in figure 27.

The irregularities of the original fracture will cause certain parts of the fissure to rub together during movement while others pull apart. In a fissure having a strong horizontal component of movement, if the right-hand wall moves ahead, a swing to the left during the movement will create an open space favorable to ore deposition as illustrated by the Pelican-Bismarck vein (pl. 10). Similarly, the steepening of the walls of a normal fault or the flattening of the walls of a reverse fault favors the creation of open spaces and localization of ore (figs. 28 and 29). In many faults tension cracks

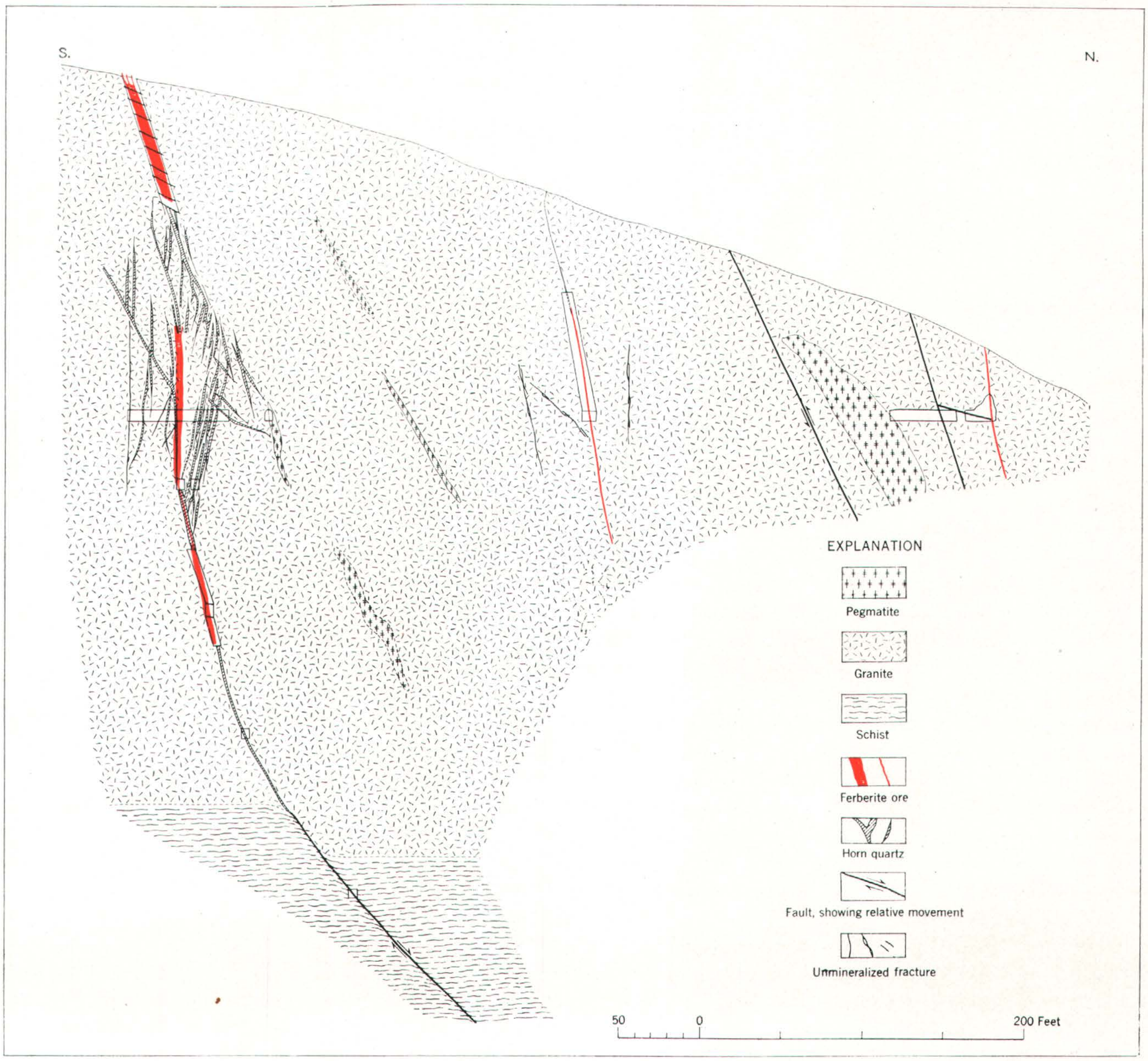

FIGURE 28.—North-south vertical section through the Clyde tungsten mine 30 feet west of the portal of the haulage tunnel, Boulder County tungsten district. Illustrates the localization of ore in the steeper parts of normal faults, the imbrication of a strong normal fault toward the footwall side with depth, and the barren part of the fissure between schist walls.

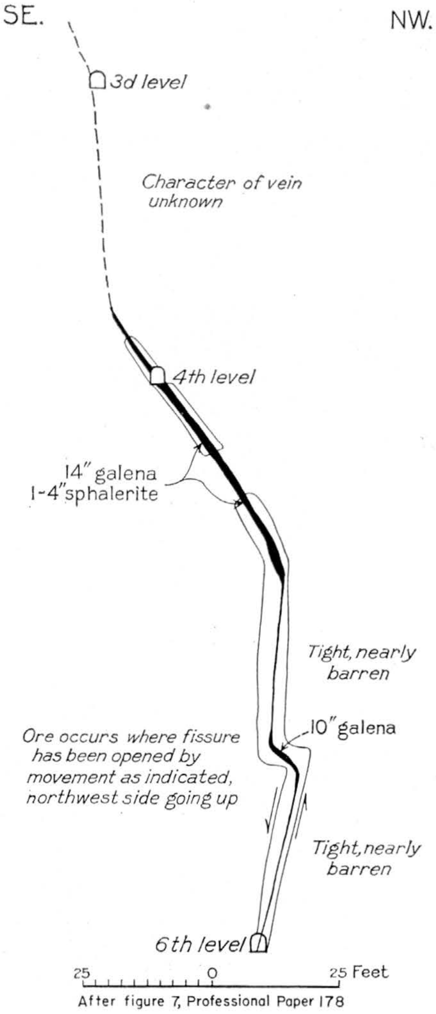

FIGURE 29.—Section along raise on level 6 of the Bell mine, near Montezuma, showing the appearance of ore in the flatter part of a premineral reverse fault.

or feather joints occur within the walls, and mineralization of these openings, the "feeders" of the miners, is a common feature of the veins in the mineral belt.

It has already been noted that relatively few individual veins persist as much as a mile along strike or dip but that overlapping fractures within a more persistent general zone of movement are common. The transition between the ends of the overlapping fractures takes place in several ways but most commonly by echelon sheeting. (See pl. 21.) When a vein maintains its course but weakens and finally ends in a zone marked by parallel oblique veins branching to one side, the main vein will usually be found to have "jumped" a short distance in that direction; echelon branching to the left, such as is shown on plate 21, has been termed left-handed imbrication. With nearly all veins that show a marked curving swing from their average course just before they feather out, the overlapping fracture will be found a short distance to the side away from which the course swings. Thus, if the vein curves to the right as it feathers out, the overlapping vein will be found on the left-hand side of the vein, as is illustrated by the Dives-Dunkirk vein (pl. 10) and the Concrete vein (fig. 30). In a zone of "horsetailing" or echelon veins the individual fractures are diagonal to the main zone of ore deposition. In some overlapping veins and faults the movement is carried from one to the other through a sheeted zone, which is not easily recognizable, and no perceptible swing occurs in the fissure as the transition zone is approached. It has generally been found that, in those fissures along which the right-hand wall moved forward, the overlapping fissure will be found to the left and vice versa (pl. 21). Similarly, where a normal fault disappears with depth an overlapping fault if present commonly will be found in the footwall (fig. 28), and where a reverse fault disappears with depth the overlapping fault is apt to be in the hanging wall.

The common appearance of ore shoots at junctions of intersecting veins or close to the points of divergence of branch veins reflect the high degree of brecciation at such places, or the shift of movement from one vein to another, with the consequent pulling apart of the fissure walls nearby (pl. 11 and fig. 31). Gougy impervious premineral cross fractures may act as baffles or guides to the ore-forming solutions and separate a barren but relatively open segment of vein from a strongly mineralized part (fig. 31). The greatest concentration of ore is usually just below gently dipping cross seams or "flats," but where the ore-depositing solutions were moving horizontally rather than vertically the ore may occur on either the footwall or hanging wall of the cross fracture (figs. 31 and 32). The inclination of the deflecting baffle relative to the path of the ore-forming solutions determines whether the ore "bottoms" or "tops" there. The intersection of two veins is much more likely to enrich than to impoverish them (fig. 33), but in some places the intersection is marked by such impervious altered rock that the "vein goes to pieces," and the ore shuns the actual intersection (fig. 34).

The intersection of a late vein with an early one is generally favorable to the occurrence of ore, especially where the early one belongs to the breccia-reef group (fig. 35). In many places spur faults formed simultaneously with major faults and coincided with the edges of moving, wedge-shaped blocks. Crushing was at a maximum along the narrow front of the wedge, and ore deposition is common at such places (fig. 33). In many veins, ore localization depends on the simple structural control of openings due to change in course or change in dip (figs. 28 and 29).

In some places, however, a vein that is tight in one rock becomes open and ore-bearing in another rock, and the appearance of ore is more directly related to the character of the wall rock than to changes in the course of the fissure (fig. 36). Schist walls are less favorable

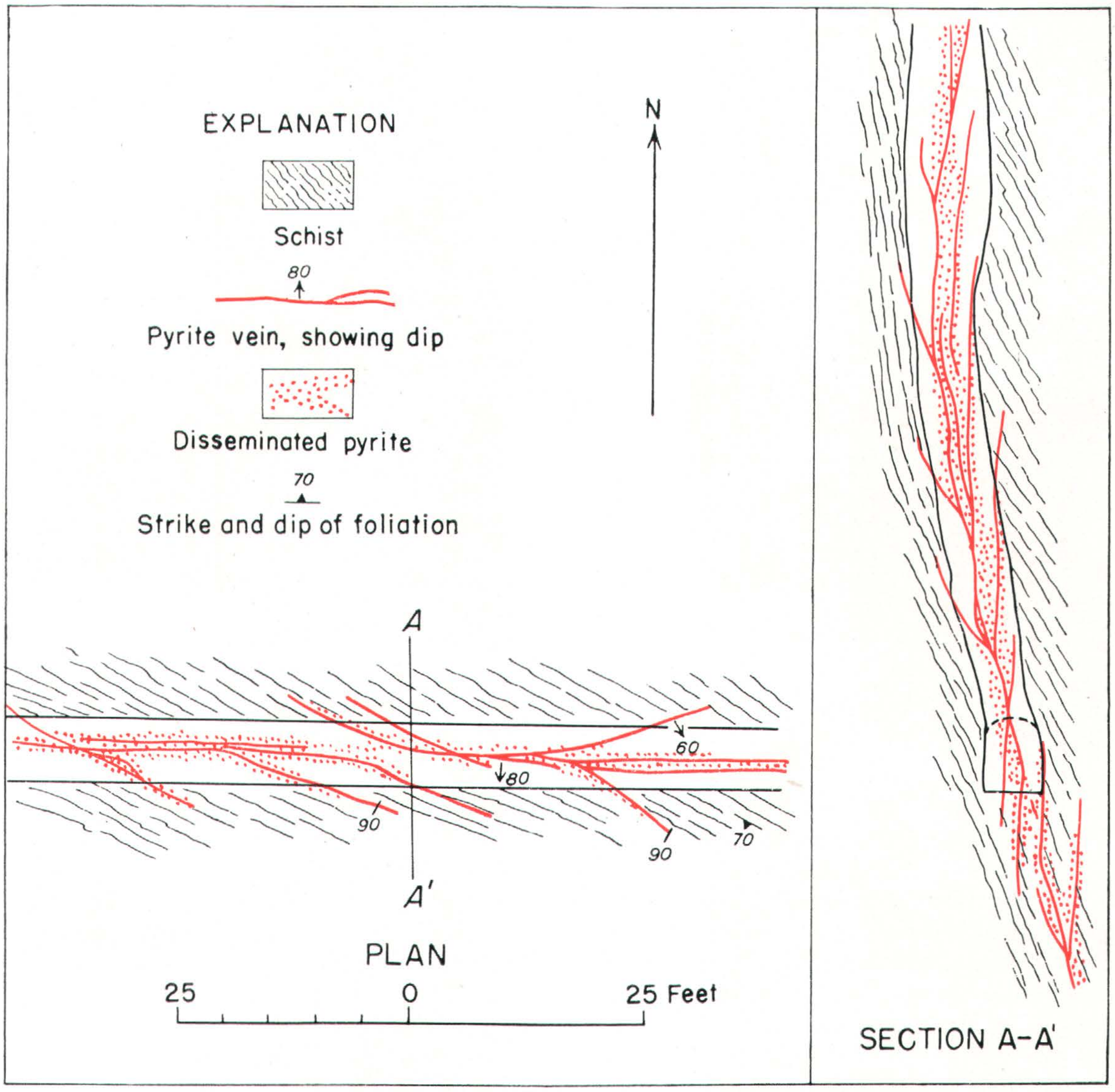

FIGURE 30.—Plan and section of part of the Concrete vein, Central City-Idaho Springs district, 200 feet below the Argo tunnel level. This pattern is characteristic of the feathering out of a vein or the shift of the movement along one vein to a parallel fissure a little distance away.

than porphyry or granite gneiss, and these rocks in turn are less favorable than granite. In some veins the best ore has been found where one wall is schist and the other wall is granite, granite gneiss, or porphyry.

Extensive alteration of the wall rock is commonly associated with important channels of mineralization, but an old fissure in rock softened by alteration is not so likely to afford favorable openings during intramineral movement as is a fissure newly formed in unaltered rock. It thus happens that in many localities important ore shoots are found in little-altered rock where relatively late premineral fractures intersect the major channels of mineralization. This condition is especially true of the telluride and tungsten veins that were formed during the last part of the general period of mineralization.

In many places veins apparently follow premineral dikes of porphyry, suggesting that a subsequent premineral fault took advantage of the plane of weakness made by the dike, but many premineral dikes were intruded along preexisting fault fissures. Postmineral dikes in turn may follow veins, as in the Stanley mine and in several mines in the Ward district. The occurrence of ore in some places, as in the Colorado Central and Little Mattie mines, suggests that the injection of the dike disrupted the adjacent walls sufficiently to create more permeable ground close to it than at a distance. (See fig. 37 and pl. 17.) Later movement of the fault wall might either accentuate or diminish this effect.

Where a late intrusive push from an underlying magma has caused the refracturing of a porphyry stock, the breccia zone generally follows the platy structure of the mass and may result in one or several irregular chimney-shaped bodies of breccia, with one dimension parallel to the original platy structure (pl. 14). In

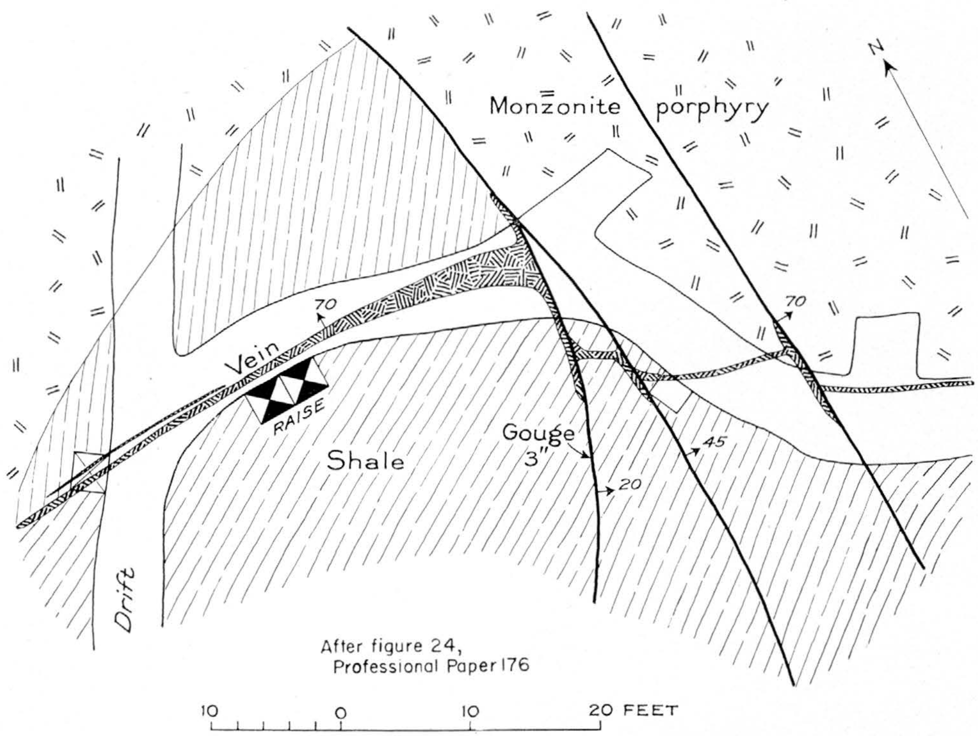

FIGURE 31.—Part of the Oro workings, level 5 of the Wellington mine, Breckenridge district, showing enlargement of ore body in the Main vein on the footwall side of a premineral fault.

such areas the small openings due to the early brecciation may have been subsequently enlarged by reactive mineralizing solutions that dissolved some of the rock adjacent to the fracture—the first step in the "mineralization stoping" suggested by Locke.[40] So far as known, this process did not go far enough to result in collapse structures anywhere in the mineral belt, except for the late brecciation of fluorspar bodies at Jamestown. However, at the Alice stock appreciable enlargement was effected by this process before metalization occurred. More commonly, however, the deposition of barren quartz clogged much of the open space in the breccia zones resulting from intrusion, leaving but little room for subsequent metalization. In such places further fracturing was necessary to create the open spaces favorable for ore shoots. It is believed that some of the breccia-reef mineralization took place after renewed fracturing.

The explosion breccias were much more favorable hosts for ore deposition than the brecciated zones immediately adjacent to the intrusion of porphyry. The open permeable explosion breccias which lack an igne-

[40] Locke, Augustus, The formation of certain ore bodies by mineralization stoping: Econ. Geology, vol. 21, pp. 431–453, 1926.

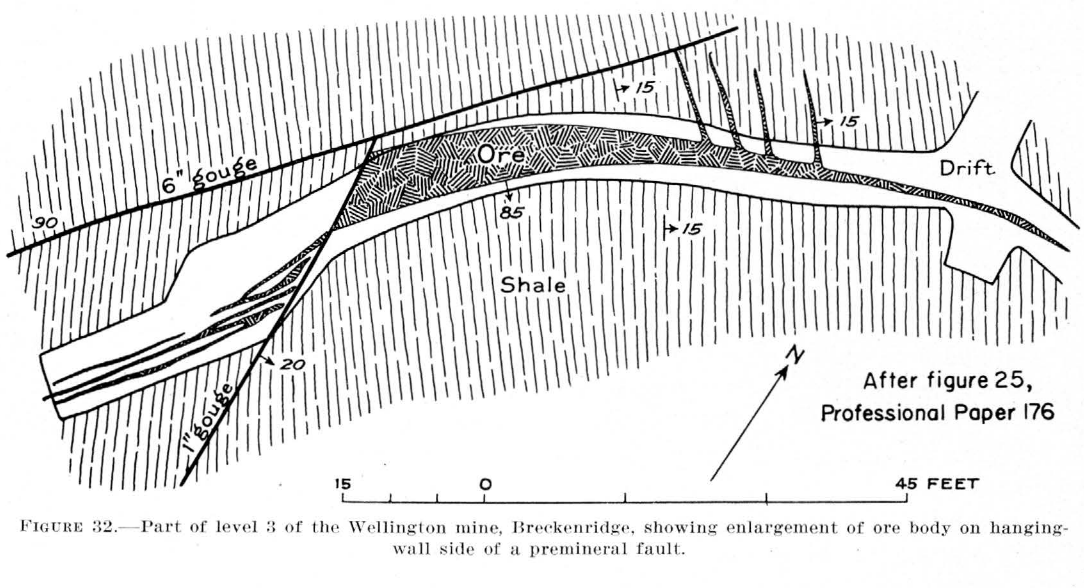

FIGURE 32.—Part of level 3 of the Wellington mine, Breckenridge, showing enlargement of ore body on hanging-wall side of a premineral fault.

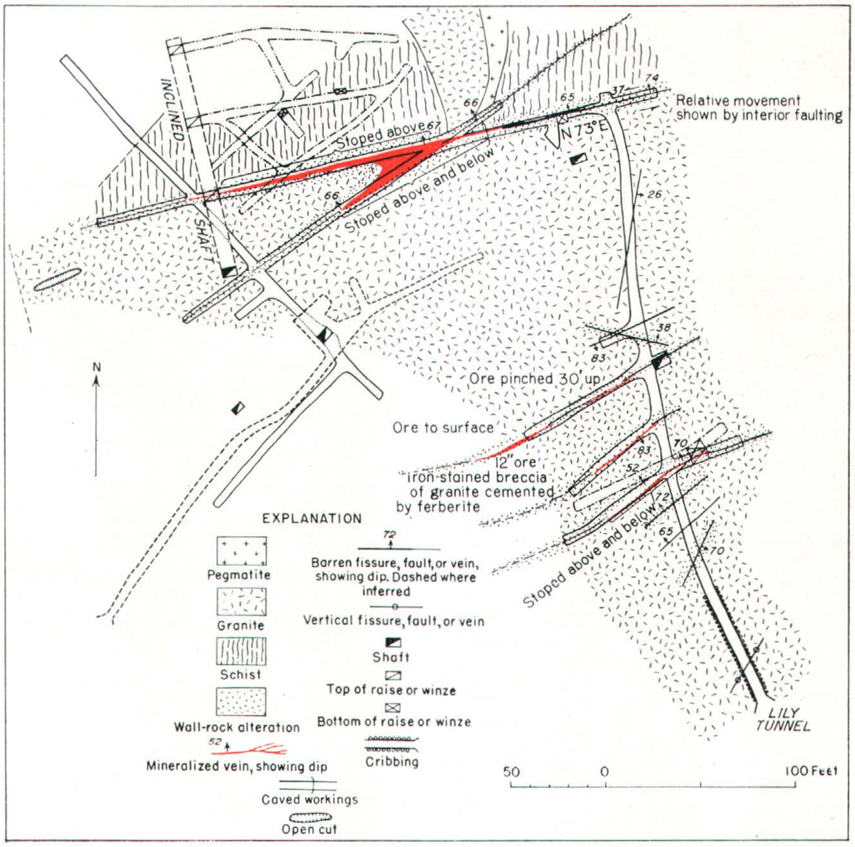

FIGURE 33.—Plan of the Lily tunnel level of the Rakeoff mine, Boulder County tungsten district, showing the mineralization of a narrow wedge between two intersecting veins.

ous matrix, such as The Patch in Central City, provided ideal conduits for the mineralizing solutions, and in them the occurrence of ore is directly related to the relative permeability of the original explosion breccia and the distance above the source magma. The latitic intrusion breccias are mineralized in a few places but very rarely more than a short distance below the upper limit at which the igneous matrix exists. In places, however, commercial telluride ore shoots lie a short distance above them, within the same or connecting fissures, as at the Logan mine (fig. 24). This probably reflects the steep precipitation gradient that existed in a cool fissure immediately following the introduction of a highly heated intrusive breccia whose open vesicular character made it a ready conduit for the volatiles coming from the underlying magma.

PLACER DEPOSITS

The localization of gold in the placer deposits of the Front Range is dependent on the location and character of the primary deposits that were the source of the gold, the physiographic history of the region, and the structure and character of bedrock and gravel.

The pyritic gold deposits and in general the deposits containing gold associated with sulfides in the primary ore commonly disintegrate at the surface and free their gold to form placers in the streams and gulches draining their outcrop area. In contrast to them the gold-telluride deposits are rarely marked by placer ground except where the tellurides are the companions of native gold in the primary ore; for example, the highly productive Cripple Creek district has yielded only an insignificant amount of placer gold.

The physiographic history best suited to the development of placer deposits is one of long-continued but moderately slow erosion. The erosion of the Front Range has been cyclic, periods of quiescence alternating with periods of rejuvenation. During late Pliocene time rich surficial material and hillside wash accumulated in many districts and acted as high-grade feed to the swollen Pleistocene streams. During each interglacial stage new grist was drawn from the outcrop and mixed with that of the earlier stream gravels, and both were further concentrated. The glaciers themselves however tended to scrape off any placer ground over which they moved and scatter the content through their moraines. The glacial streams opposed this tendency by reworking some of the ground moraine and, as shown in figure 38, tended to concentrate gold in the outwash just in front of the terminal moraine more than elsewhere. With increasing distance from the moraine and from the source of the gold the amount of flour gold increases steadily, until at a distance of 15 or 20

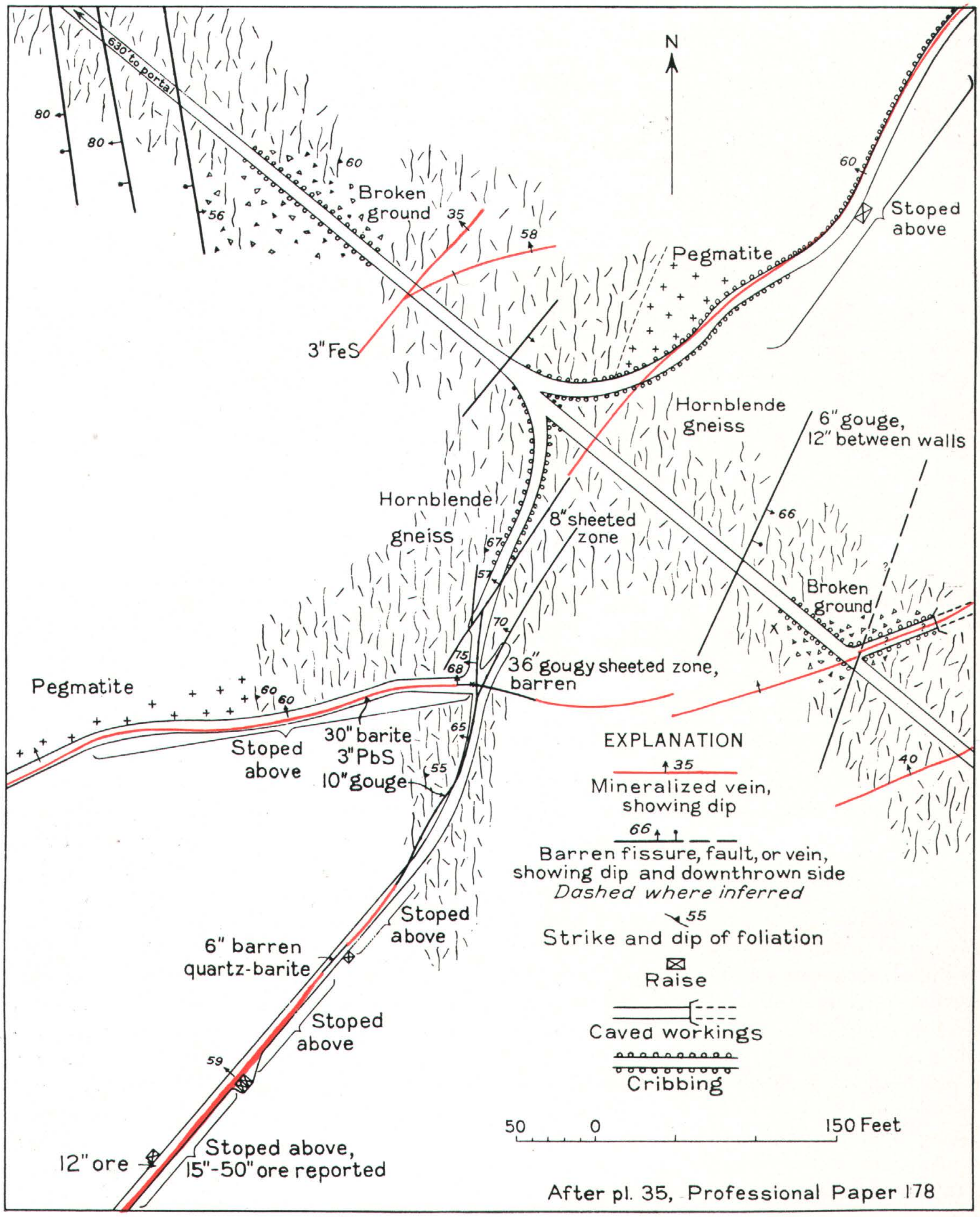

FIGURE 34.—Part of the main tunnel level of the Saints John mine, Montezuma district, showing the impoverishment of the vein at its intersection with another that crosses it nearly at right angles.

miles practically all the gold is in an extremely fine state of subdivision.

The bulk of the gold in placers is usually found within 5 feet of the contact between bedrock and gravel. Where a layer of hard impervious clay occurs in the gravel, rich gold-bearing gravel is commonly found on this "false bottom," but very few of these clay contacts contain as much gold as the underlying bedrock contacts. As much as 90 percent of the gold in a 50 foot gravel bed may be present in the lower 5 feet of gravel and the upper 3 feet of bedrock.

In general a smooth polished bedrock floor holds much less placer gold than a rough surface. Thin-bedded shale and sandstone, steeply dipping schist seamed with pegmatite, or interlayered hard and soft rocks of any sort apparently made natural riffles and

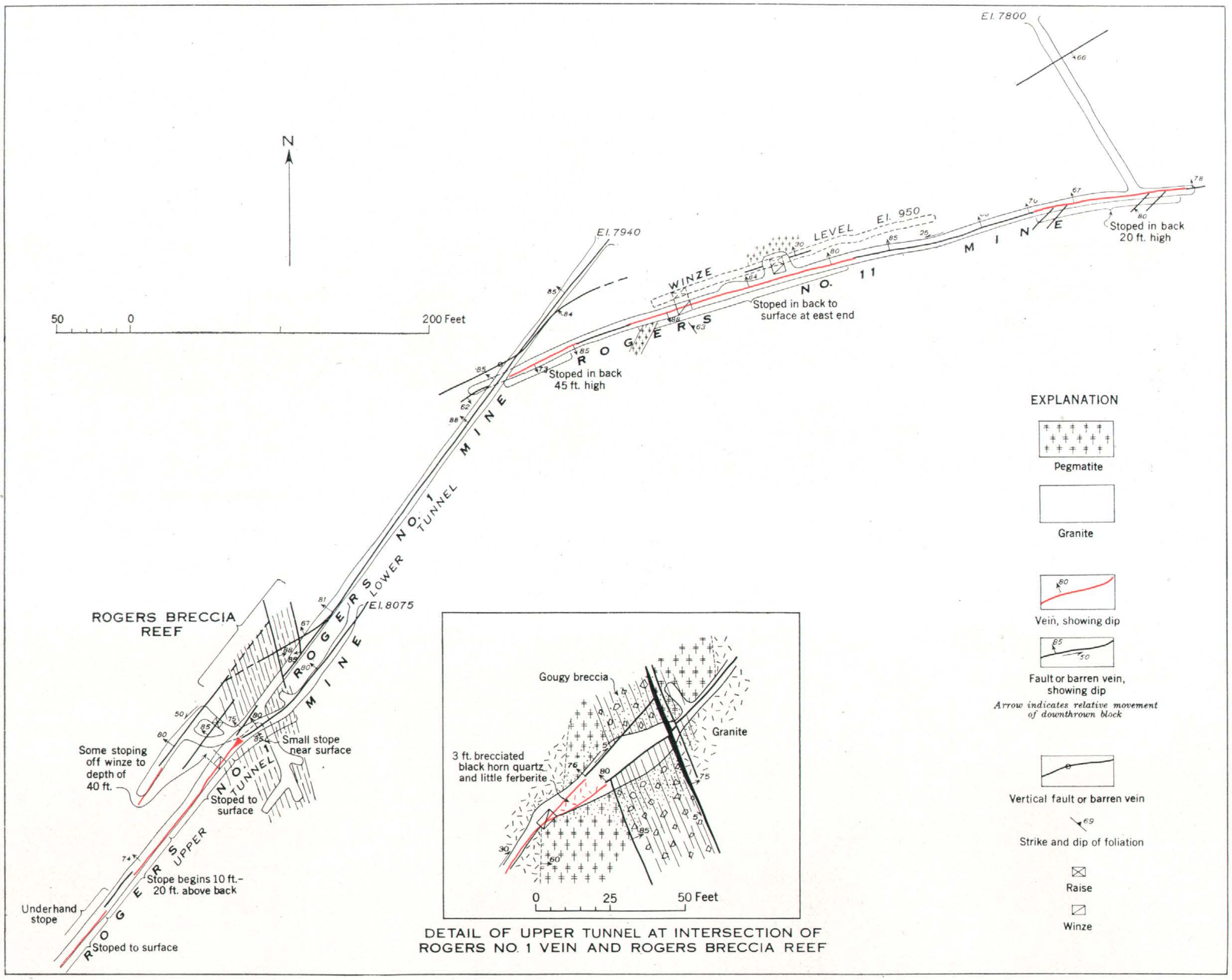

FIGURE 35.—The Rogers No. 1 vein of the Boulder County tungsten district, showing the localization of ore near the intersection of the northeasterly vein with a northwesterly breccia reef.

retained much more gold than the more massive even-grained rocks.

Much of the placer ground in the Front Range is chiefly of historical interest. Although credited with a substantial output during the sixties and seventies, the output has been small since that time, except in a few places where dredging has proved feasible, as at Breckenridge, Pinecliff, and on Clear Creek east of Idaho Springs. The great influx of placer miners during the depression years of 1932–33 served only to show that nearly all the ground suitable for hand methods had already been worked to exhaustion. Floating dredges have operated successfully for many years in the Breckenridge district, but the best of the ground has been moved long since. A considerable area of placer ground suitable for dredging is present in South Park near Fairplay; operations were discontinued several years ago when a suit was brought by the ranchers because of the contamination of the river by tailings,

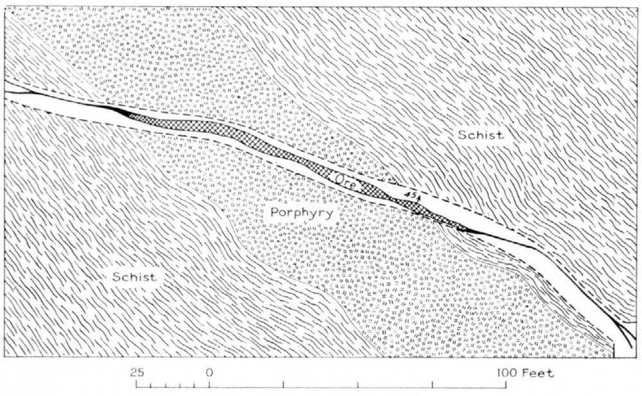

FIGURE 36.—Part of the tunnel along the Maine vein, Silver Plume district, showing the thickening of the ore as the vein passes from schist into the more competent porphyry.

but they were resumed successfully in 1939. A floating dredge was operated on Beaver Creek near Fairplay during 1939–42, and in the first 2 years 9,227 ounces of gold was produced. In 1941, a bucket dredge was put in operation on the bench gravels along the Platte River, but this project as well as the dredging on Beaver Creek was terminated on October 15, 1942, by the gold mining limitation order.

On the eastern slope of the range a dry-land dredge operated successfully during 1935–36 on Clear Creek about 10 miles east of Idaho Springs, at its junction with North Clear Creek, and was rated the second largest producer in the county. Another dry-land dredge was operated on North Clear Creek just below Blackhawk during 1937–41 and in 1938 was the largest producer of gold in the county. A floating dredge obtained 7,796 ounces of gold from the Pactolus placer on South Boulder Creek near Pinecliff during 1937–39. It seems probable that other placers of this type may be found on some of the larger streams of the eastern slope that cut through the mineral belt. The deep outwash below the terminal moraine at Empire has apparently been neglected and may be worth exploiting.

Cherry Creek and Douglas County placers.—The first gold discovered in Colorado was found along Cherry Creek near the site of Denver in 1859, and this stream and its tributaries have been prospected periodically ever since. Annual output, however, has been small, a few thousand dollars during one of the better years but generally less than $1,000. The amount of gold present increases to the south of Denver, and the best placer ground apparently lies in Gold Creek, Russellville Gulch, and Newlin Gulch, near ridges capped with Castle Rock conglomerate.

The bedrock of the streams in this area is chiefly the upper part of the Dawson arkose of late Cretaceous and early Tertiary age; the higher hills are capped with a dense rhyolite or rhyolitic tuff very close to the contact between the Dawson arkose and the overlying Oligocene Castle Rock conglomerate. In some places this conglomerate lies directly on the rhyolite or tuff, but in others a thin wedge of arkose lies between the rhyolite and the Oligocene beds.

The search for gold in the Dawson arkose below the rhyolite has been almost fruitless, except within a foot or two of the surface, and the rhyolite itself is barren. The basal Castle Rock conglomerate, however, contains an appreciable quantity of gold. Much of it contains 0.025 to 0.05 ounce of gold, and a few assays show as much as 0.105 ounce to the ton. The placer gold of the region has been obtained from the alluvium and low-terrace gravels along the streams close to the Castle Rock conglomerate; the richer gravels worked commonly contain 0.01 to 0.035 ounce of gold to the ton. Locally much higher grade pockets are found, but they are comparatively rare.

It seems probable that the Castle Rock conglomerate is a low-grade fossil placer containing gold that was probably derived from the Central City district and other parts of the mineral belt. The gold contained in this rock was set free as the conglomerate disintegrated and was concentrated locally in the Recent gravels derived from the Oligocene (Castle Rock) stream deposits. The general course of the belt in which most of the placer gold has been found trends northwestward toward the Idaho Springs-Central City district.

MINING DISTRICTS IN THE MINERAL BELT

BRECKENRIDGE DISTRICT

LOCATION

The Breckenridge district [41] is about 60 miles west of Denver and 20 miles northeast of Leadville and is at

[41] Lovering, T. S., Geology and ore deposit of the Breckenridge mining district, Colo.: U. S. Geol. Survey Prof. Paper 176, 1934. Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colo.: U. S. Geol. Survey Prof. Paper 75, 1911.

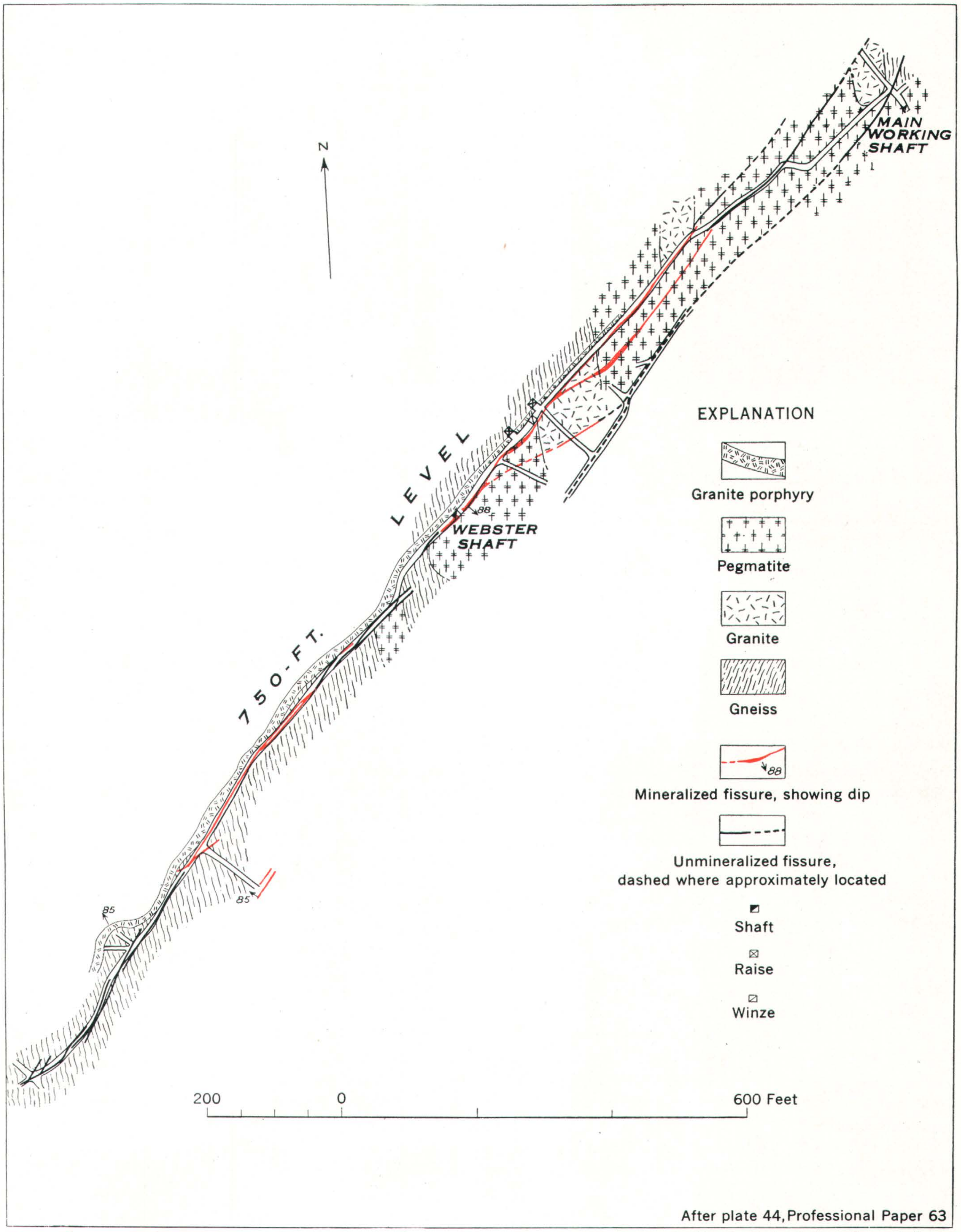

FIGURE 37.—Map of the 750-foot level of the Colorado Central vein, Georgetown district, illustrating the divergence of vein from the wall of a pre-mineral dike. The best ore in the Colorado Central vein is found next to and near the strong porphyry dike that forms the northwest wall of the vein near the Webster shaft.

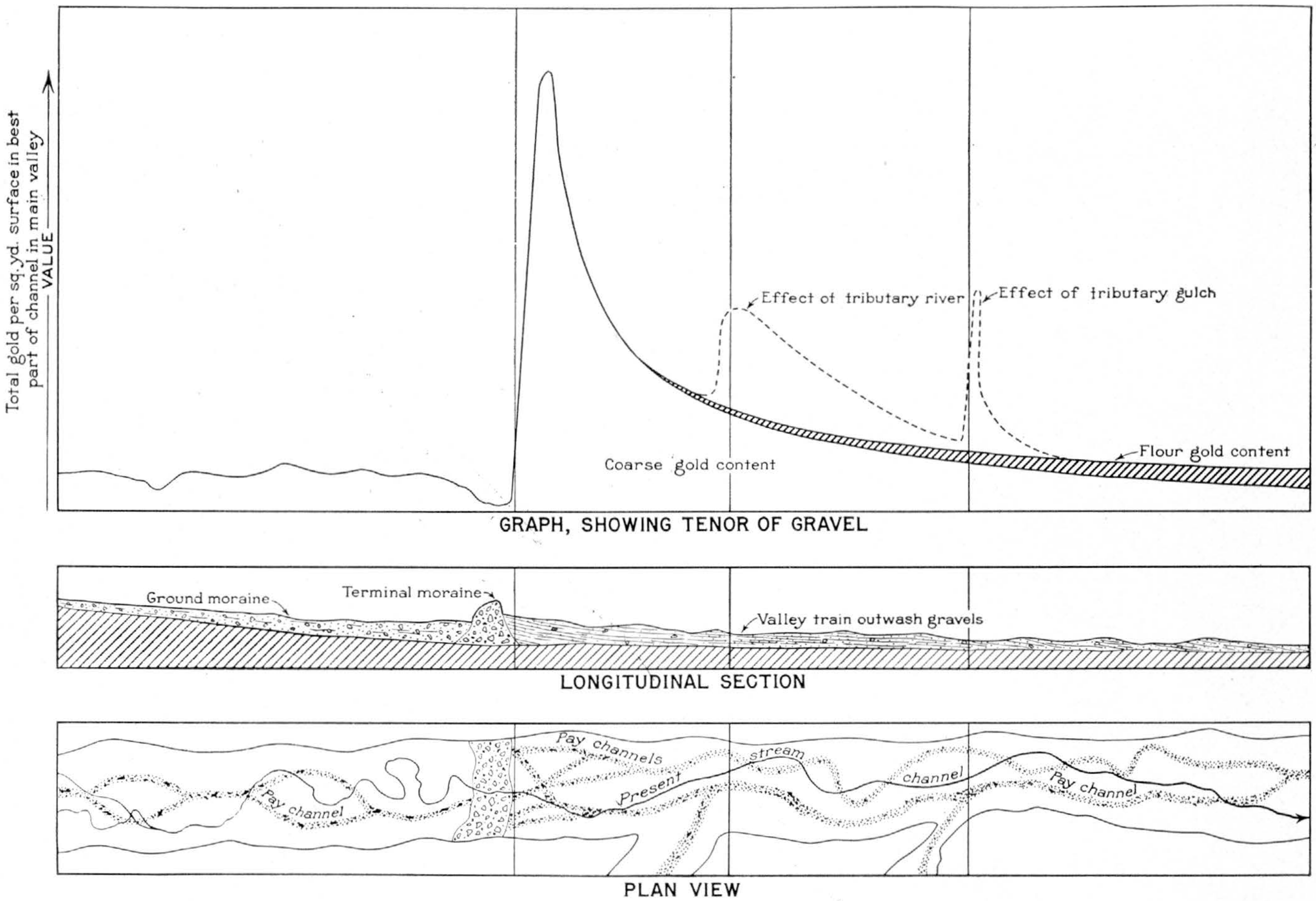

FIGURE 38.—Graph, section, and plan showing the relation of the tenor of a placer to distance from the moraine.

the southwestern end of the Front Range mineral belt. It occupies about 45 square miles at the headwaters of the Blue River. It ranges in altitude from 9,100 to 13,100 feet and is decidedly hilly, though little of it is rugged. The district is famous for its gold placers and for the high-grade gold veins of Farncomb Hill, but it has also had a large output of lead-silver-zinc ore.

HISTORY

In the summer of 1859 a group of prospectors discovered rich placer ground on the north side of Farncomb Hill, and within the next 20 years about $7,000,000 in gold was washed from the placers of the Blue River, Swan River, French Gulch, Illinois Gulch, and their tributary gulches. It was not until 1880 that gold was found in place on Farncomb Hill; for the next 10 years the rich narrow veins of crystallized gold yielded most of the gold output. Gold dredges were introduced in 1898 and have been working the deep gravels of the larger gulches ever since, recovering a total of a little more than $7,000,000 in gold through 1937.

Lead-silver ores were first mined in the district in 1869, but little interest was shown in lead veins until the completion of the railroad from Denver to Breckenridge in 1880. The first flush of lead-silver mining came in the late eighties and early nineties, and following this period the output declined until 1910, when the Wellington mine started active development and was a large and moderately steady producer of lead and zinc until 1929. It supplied most of the lead and zinc ore shipped from the district during this period. Nearly all of the output from stockworks came from oxidized ore mined prior to 1910, but a meager and intermittent output was obtained from the low-grade primary ores through the 25 years following, owing chiefly to the operations of the Royal Tiger Mining Co. The general character of the ore from the district is shown in the following table.

GENERAL GEOLOGY

As shown on plate 2, the rocks exposed in the Breckenridge district are chiefly sedimentary. Pre-Cambrian schist, containing small amounts of injection gneiss and gneissic granite, underlies the sedimentary rocks and is exposed in small areas in the southern and western parts of the district. It is chiefly quartz-biotite schist and has a general northwesterly strike and a dip of about 60° NE. The lower Paleozoic beds are not present in the district and probably were not deposited (pl. 6). The Maroon formation of Permian and Pennsylvanian (?) age lies directly upon the pre-Cambrian basement but is overlapped by the Morrison and Dakota formations to the east and west of the district. The Weber (?) formation, if present, occurs only under a thick cover in the southwest part of the region shown on plate 2.

Composition of ore from the Breckenridge district

	Wellington			Country Boy	Puzzle	Gold Dust	Cincinnati	Minnie	Truax
Kind of material [1]	C	S	[2] S	S	S	S	[3] C	C	[4] S
Gold, ounces per ton	0.02	0.02	0.10		0.07	0.25	0.01	0.03	0.06
Silver, do	10.00	10.00	25.00		24.00	20.00	10.50	16.00	17.00
Lead, percent	50	45	45		[5] 25	55	43.5	67	20
Zinc, do	5	6		43	8	6			
Iron, do	14	10	6		14	4	10	7	
Silica, do	5	7	12		24	7	12	3	42
Date	1909	1909	1909	1909			1901		

	Old Union	Dunkin	Washington	Iron Mask	Brooks-Snider	Mountain Pride		Kellogg	Jumbo
Kind of material [1]	S	S	[6] S	[7] S	C(?)	S	C	[8] S	C
Gold, ounces per ton	0.07	0.60	0.60	0.03	1.3	0.3	1.2	0.06	0.46
Silver, do	8.00	15.00	26.40	21.00	3.0	9.0	8.5	20.00	1.90
Lead, percent	31	40	39	58		50	30	59	
Zinc, do						7	12		
Iron, do	12	8	7	3	3	9	15	4	35
Silica, do	29	32	25	9	71	5.5	6	9	16
Date	1902			1901	1898	1902		1899	

	Cashier	Wire Patch	Jessie	Hamilton	Germania		Carbonate (Bald Mountain)	Etigrade (Little Mountain)	Boss
Kind of material [1]	[7] S	C	C	S	S	S	[8] S	[7] S	[9] S
Gold, ounces per ton	0.55	0.90	1.07	0.67	0.12	0.17	0.4	0.20–1.65	36
Silver, do	10.00	10.00	11.89	4.15	70.00	152.61	25.0	500–726	27
Lead, percent			6		([10])	8.7	40	4–13	
Zinc, do	5		13						
Iron, do	40	34	30	39		3	12	9	
Silica, do	5	10	5	6	80	78	5	66	
Date	1904	1908	1897	1903					1909

[1] S, shipping ore; C, concentrates.
[2] Carbonate ore from surface workings; 1.5 percent of sulfur
[3] 5 percent of sulfur.
[4] Partly oxidized.
[5] Below average.
[6] Horn tunnel; 5 percent of sulfur.
[7] Oxidized ore.
[8] Oxidized ore; 1.5 percent of sulfur.
[9] Tailings from a rich pocket.
[10] Otherwise similar ore contains as much as 30 percent of lead.

The Maroon formation consists of 600 to 900 feet of red, gray, and black micaceous sandy shale, with some limestone and some red, and red and gray micaceous grit and conglomerate. It occurs in a wide northwestward-trending belt in the southern part of the district, which is cut off in the central part by porphyry intrusives but continues as a narrower belt to the northwest.

The Maroon formation is overlain by about 200 feet of the sandstone and variegated shale of the Upper Jurassic Morrison formation. The Upper Cretaceous Dakota quartzite rests upon the Morrison formation; it is 125 to 165 feet thick in the central part and 20 to 225 feet thick elsewhere in the district. Probably because of its rigidity and its ability to retain open fractures, ore bodies are commonly localized in the quartzite where veins pass through it. The Morrison and Dakota formations occur in the western part of the district in a broad north-northwesterly band, which is cut by porphyry intrusives and is much complicated by folding and faulting.

The Dakota quartzite is overlain by about 360 feet of dark-gray Benton shale; this in turn is overlain by the Niobrara formation, which is about 350 feet thick and consists of black or gray limy shale interbedded with thin-bedded dark-gray limestone. These two formations occur in a narrow irregular belt extending from the southeast corner to the northwest corner of the district.

Overlying the Niobrara formation is the Pierre shale, whose thickness is approximately 2,500 feet about 2 miles northwest of Tiger. It consists chiefly of dark-olive and dark-brown clay shale and occurs throughout the northeastern half of the district. The shale is much cut up by irregular intrusive stocks and sheets of porphyry, and along the northeast border of the district it is cut off by the strong northwestward-trending Williams Range thrust fault, on the east side of which is pre-Cambrian hornblende gneiss with some schist and granite.

Quaternary glacial and stream deposits occupy an extensive area along the Blue River Valley. Breckenridge is built on the outwash gravels of the Wisconsin glacial stage about half a mile below a terminal moraine. Placer deposits have been found in the early and late glacial outwash gravels and in the late glacial ground moraine south of the terminal moraine.

Intrusive monzonitic porphyries of the Laramide revolution are common throughout the Breckenridge district. Hornblende monzonite of group 4 (fig. 12) occupies a large area in the central and southeastern parts of the district. It occurs chiefly in the form of sills, some of which are very thick, and only breaks across the sedimentary rocks in a few places. Intermediate quartz monzonite porphyry of group 5 forms a thick sill in the Benton shale. Quartz monzonite porphyry of the Lincoln type, belonging to group 6, is abundant throughout the northeast half of the district, forming stocks, dikes, and sheets. Dikes of this porphyry cut both of the other porphyries.

Intrusion of the larger sills of monzonite rarely caused much change in the rocks invaded, but stocklike masses of quartz monzonite porphyry were the loci of profound changes in many places; for example, garnet, epidote, dark-green amphibole, quartz, specularite, magnetite, and small amounts of pyrite and chalcopyrite were formed in the limy shales of the Morrison formation near a small stock in French Gulch, due east of Breckenridge. Garnetization was generally limited to the formations within 1,500 feet of the stock, whereas epidote and quartz replaced favorable beds at much greater distance. The other contact-metamorphic minerals are locally abundant but in general are subordinate.

The hydrothermal alteration of the wall rocks of the veins was accomplished largely by solutions of reducing character, which changed the bright-red beds of the Maroon formation to green or gray, both in the contact-metamorphic zones and near ore channels. Where alteration was intense, silicification occurred on a large scale; much of the dark Cretaceous shale near the Wellington mine was completely converted into jaspery silica, similar to the flint or jasperoid of the Leadville district. Near the veins the porphyritic rocks in places were completely altered to sericite, quartz, and ankerite, with minor amounts of pyrite. A more widespread type of alteration is that by which the ferromagnesian minerals of the porphyry were changed to calcite and epidote and the feldspars incompletely converted to calcite, sericite, and kaolinite.

The principal structural feature of the Breckenridge district is a structural trough about 10 miles wide, which extends north-northwestward from South Park to Middle Park. The belt of sedimentary rocks in this trough is about 8 miles wide and is flanked by pre-Cambrian rocks on the east and west (see pl. 1). The Cambrian, Ordovician, Devonian, and Carboniferous formations of western South Park have been progressively overlapped to the north and are absent in the Breckenridge district. Owing to isoclinal folding, the regional dip is eastward throughout the structural trough. About 5 miles east of Breckenridge the sedimentary rocks are limited by an overturned fold somewhat sliced by strike faults, which passes northward into the Williams Range thrust fault. The trough of the overturned fold was apparently a weakened zone, especially favorable to intrusive activity, for throughout its extent from South Park to Dillon it is marked by an almost continuous series of large porphyry masses.

The main part of the Breckenridge district is on the western limb of the regional syncline about 2 miles west of its axis, and, as shown on plate 2, the local structure is exceedingly complex. Southeast of Breckenridge the prevailing northeasterly dip is broken by an open anticline and a compressed syncline, both of which trend northwestward. Two broken, downfaulted belts cross these folds and intersect near the Wellington mine 2 miles east of Breckenridge. One belt trends north-northeast and the other east-northeast, and in them both normal and reverse faults are common. The most productive mines of the district—the Wellington, Washington, Golddust, Duncan, and Puzzle-Ouray—follow premineral faults of small throw in the north-northeasterly downfaulted belt. Nearly all the productive veins strike between N. 40° E. and N. 80° E., and the fissures that they occupy are generally older than the faults that strike N. 10° W. to N. 20° E. The bulk of the porphyry of the district was intruded after folding was completed; part of it is later than the initial easterly and northeasterly faults, which were later mineralized. The large Williams Range thrust fault along the eastern side of the district is earlier than the coarsely porphyritic quartz monzonite, but much of the northeasterly and north-northeasterly faulting is later than the latest porphyry masses.

Most of the monzonite in the central part of the area is part of one large irregular intrusive sheet, which formerly extended from Prospect Hill south to Nigger Hill and southeast to Bald Mountain; in it are found most of the productive veins. This mass was intruded through many conduits and is probably a composite of many originally distinct sills that united to form the larger body. The base of the larger intrusive sheet is irregular and follows different horizons in different places but most commonly occurs a short distance above or below the Dakota quartzite. In general the crosscutting bodies of porphyry followed the early northeasterly and northwesterly lines of weakness, but in places they broke across the sedimentary rocks in a north-south line.

ORE DEPOSITS

A wide variety of ore and gangue minerals has been found in the Breckenridge district, but the only ore minerals sufficiently abundant to be of commercial importance are gold, various silver minerals, sphalerite, galena, and pyrite. Contact-metamorphic ores, stockworks, veins, blanket ores, and placers have been exploited, but most of the output has come from the veins and placers. The primary mineralization is believed to have been related to solidification of the deeper parts of the quartz monzonite porphyry and to have occurred later than any of the porphyry intrusions. Supergene enrichment has greatly modified many of the deposits.

A few of the many mine descriptions given by Ransome and by Lovering are summarized on pages 112–122 to bring out more clearly some of the features of the ore deposits discussed briefly below. In the selection of the mines for consideration here, the writers have chosen those that best illustrate some general type of deposit or some features of ore localization. The selection is not based on relative commercial importance; however, most of the properties described show a creditable output, because the productive properties have been more generally available for study.

Contact metamorphic deposits.—Deposits formed by contact metamorphism are of little economic importance, but in several places dense irregular masses of silicates intergrown with metallic oxides and sulfides have been formed in the limy beds of the Niobrara and Morrison formations. They are best developed on the south side of Prospect Hill bordering a small stock of quartz monzonite porphyry. These deposits are resistant to weathering and show little evidence of enrichment. Some of them contain appreciable amounts of gold and copper, but their ore bodies are usually small, spotty, and irregular and cluster closely around the stock of quartz monzonite porphyry.

Stockworks.—Stockworks are found chiefly in the northeast quarter of the Breckenridge district in a narrow zone trending east-northeast through Tiger toward the south end of the Williams Range thrust fault. Four productive stockworks are found at Tiger and to the southwest at intervals of about a mile, namely, the I. X. L. and Royal Tiger, the Cashier, the Hamilton, and the Jessie (pl. 3). The country rock of each deposit is quartz monzonite porphyry, but in the I. X. L. the quartz monzonite porphyry is crowded with fragments of Upper Cretaceous Dakota quartzite and shale. The alinement of the stockworks in a zone of shearing at the south end of the Williams Range thrust fault suggests that they resulted from the underthrusting of the Upper Cretaceous rocks beneath the pre-Cambrian, but, as the quartz monzonite porphyry that contains the stockworks is younger than the thrust fault, they must have formed after the major movement was finished. They probably represent a response to residual stress in the shear zone between the major thrust fault and the overturned fold to the south. As would be expected from their position, the dominant trend of the strongest fracture zone in the stockworks is east-northeast, but the country rock is fissured in many directions. The individual fractures are not persistent, and each stockwork seems to be a wide slightly crushed zone in which the movement along single fractures was slight. Mineralization of these broken masses resulted in low-grade primary deposits several hundred feet wide, with length not greatly exceeding width. Most of the mineralization occurred in small open fissures with little replacement of the country rock and produced low-grade pyritic gold ore containing small amounts of galena and sphalerite. Commercial ore seems limited to a depth of 350 feet or less from the surface and seems largely dependent on secondary enrichment. Each of the four deposits named is credited with an output of several hundred thousand dollars in gold. Nearly all the supergene ore has been removed from these stockworks, and it is unlikely that mining can be carried on profitably on the primary ore unless costs are greatly reduced. There is, however, the distinct possibility that other stockworks will be found in this same general zone.

Further details of the occurrence of ore in a typical stockwork will be found in the description of the Jessie mine on page 112. The I. X. L. property and the Royal Tiger mine are classed as stockworks but may be intermediate between the stockworks of the type described above and the intrusion breccias described below.

Intrusion breccia.—In the southwestern part of the district, in the Wire Patch mine, there are deposits similar in appearance to the stockworks described above but different in origin. Here the aggressive intrusion of the quartz monzonite porphyry brecciated the somewhat baked Upper Cretaceous shale adjacent to it and incorporated the fragments in the upward-moving magma. Continued movement of the main body of the porphyry during the freezing of the igneous matrix in the crust of the breccia caused a network of small fissures to break through the porphyry matrix, the fragments, and the adjacent wall rock. This late brecciation was most intense in the intrusion breccia near its contact with the country rock, and subsequent mineralization of the interlacing fissures developed ore deposits intermediate in character between the stockworks and the lodes in broad shear zones. The galena-silver-gold ore found in the Wire Patch mine is somewhat different in character from the pyritic ores of the stockworks to the north. The reader is referred to a description of this mine on page 115 for further details.

Veins.—The hypogene ores are largely confined to northeasterly premineral faults, but many of the veins are related to channels of mineralization that trend more nearly northward than the veins themselves.

Most of the productive veins lie in a short, narrow northeasterly belt, which extends from Little Mountain to Mineral Hill. (See pl. 3.) With the exception of the rich narrow gold veins of Farncomb Hill, very few veins outside this belt have contributed materially to the output of the mines. Most of the veins occupy normal faults striking N. 40°–80° E. and dipping 60°–80° SE. or NW. and show pronounced irregularities in both strike and dip. The most productive veins, named according to their positions in the belt from southwest to northeast, are the Germania, Golddust, Puzzle-Ouray, Washington-Emmett, Dunkin, Juniata, Country Boy, and Oro-Wellington group.

All the bedrock formations in the district are cut by veins, but most of the ore has been found where the vein walls are of monzonite porphyry or Dakota quartzite. The chemical character of the wall rock has been less influential than its physical properties in determining the presence of ore, but certain limy layers in the Cretaceous beds are replaced by ore next to some of the larger veins. The ore shoots were localized in the more open parts of faults of moderate movement, and these open parts formed where the faults broke through the more rigid wall rocks. The distribution, continuity in depth, and the permeability of the premineral faults determined the course of the mineralizing solutions and the site of ore deposition. In some places extensive but comparatively tight gougy faults guided solutions from depth but were not sufficiently open for commercial ore bodies to form in them.

The primary ores of the productive veins consist largely of lead, zinc, and iron sulfides with some native gold and some silver whose form is uncertain. Ankerite, calcite, quartz, and sericite are the common gangue minerals. Some of the veins have produced chiefly pyritic zinc-blende with little galena; ore of this type commonly changes abruptly downward into a nearly pure pyrite, as shown in the description of the Great Northern vein of the Wellington mine (pp. 119–120).

Practically no high-grade zinc ores have been found in the upper parts of veins that come to the surface in areas where preglacial topography is well preserved. The largest zinc shoots have all been found several hundred feet below the level of the Tertiary erosion surface; this fact and their negative relation to the old topography probably reflect the leaching of zinc sulfide from the zone above the Tertiary ground-water level.

More abundant than the zinc ores are the primary zinc-lead ores, which have a much larger proportion of galena throughout the vein and commonly pass upward rather abruptly into a zone of sphalerite-free galena near the surface. The sulfides are generally massive and show no evidence of depositional banding or crustification.

High-grade galena ores and gold ore appear to be limited to a zone that ranges from 200 to 300 feet in depth, corresponding roughly to the present topography. The mixed zinc-lead ores show a much greater range than the high-grade lead ores, and in the Wellington mine they have a vertical range of more than 800 feet.

The general order of primary mineral deposition as worked out for the Wellington mine is as follows: (1) Pyrite; (2) quartz (locally); (3) sphalerite (variety marmatite) and intergrown chalcopyrite; (4) sphalerite and galena; (5) sphalerite and chalcopyrite; (6) galena and pyrite; (7) galena, sphalerite, and gold; (8) quartz; and (9) ankerite, siderite, calcite, and barite.

As the pyrite and sphalerite on the lower levels were deposited earlier than galena and as galena is contemporaneous with much of the sphalerite on the upper levels, the sphalerite in the lower part of an ore shoot was probably formed at an earlier stage of mineralization than the sphalerite in the upper part of the same shoot. In other words, the deposition of the sulfides extended over an appreciable period of time, and ore formed in large amounts at the bottom of an ore shoot sooner than it did at the top. The character of the ore in the veins fed from the Great Northern-J fault zone and the relative position of the ore shoots also lead to the conclusion that the ore stage lasted some time and that during the early part of it sphalerite was deposited with little galena but that the reverse was true later. (See p. 120.)

A study of the topographic, mineralogic, and textural relations of the ores indicates that the presence of high-grade lead ore shoots near the surface is due to the leaching of the more soluble sphalerite and pyrite from a primary lead-zinc ore. Although the oxidized and leached ores are enriched in gold and silver, there has been no secondary deposition of the galena itself. The occurrence of the rich gold ores on the other hand indicates supergene enrichment (figs. 39 and 40).

Gold veins of Farncomb Hill.—The rich gold veins of Farncomb Hill are in a class by themselves and are not known outside the area that embraces the northeast slopes of Farncomb and Humbug Hills. The important veins are limited to the western part of Farncomb Hill, in an area about 2,500 feet long and less than 1,500 feet wide. The general trend of the veins is nearly northeast, and the principal veins from west to east are the Ontario, Key West, Boss No. 2, Boss, McQuery, Reveille, Carpenter, Gold Flake, Graton, Silver, Bondholder, and Fountain. They fall into two groups, which are separated by an interval of 700 to 800 feet between the Reveille and Carpenter veins.

Along the western part of Farncomb Hill the dark Pierre shale, which strikes N. 10°–30° W. and dips about 30° NE. is invaded by an irregular stock of quartz monzonite porphyry. The porphyry body appears to occupy the site of one of the minor conduits that supplied magma for the porphyry intrusion. All around the porphyry the shale is thoroughly brecciated, and the contact zone is marked by a gradation from porphyry containing a few fragments of shale through shattered shale cemented by porphyry to undisturbed shale. The shale has been so baked that it weathers into angular fragments instead of slaking, but it contains no visible metamorphic minerals. The zone of shale fragments is in places fully 100 feet wide and generally contains disseminated pyrite and a little chalcopyrite. The fragments of shale in the porphyry are in part angular and in part pebblelike; most of them have been changed from black to light gray, though their weathered surfaces are coated by brown films of iron oxide.

The rich gold veins lie near the porphyry mass on its north side. Apparently no important pocket of gold has been found more than 300 feet from the main porphyry body, nor have any productive pockets been found within it, although gold has been found in some veins where they traverse thin sheets of porphyry in the shale. The veins have been worked chiefly through tunnels, most of which get in poor condition soon after abandonment.

The Farncomb Hill veins are rarely more than half an inch wide, but nevertheless they cut directly across the bedding of the shale and through the porphyry sills and are surprisingly regular and persistent. One of the strongest of the veins, the Gold Flake, has been stoped or followed for a length of 300 feet and to a depth of about 450 feet. The principal veins are accompanied by smaller, subparallel veins on one or both sides and send out spur veins at small angles. Where a vein passes from shale into porphyry it may split up into a series of stringers. There was little premineral faulting along these veins; they apparently end about 400 to 500 feet beneath the surface, and only a few have been found at this depth.

The veins are faulted by numerous bedding-plane slips, or slips along the contact of shale with porphyry sills. Displacement along the slips is small, rarely exceeding 10 feet, and the greatest slip known is about 35 feet. Nearly all the slips are gently dipping normal faults.

The vein material is generally wholly or partly oxidized. The unoxidized veins contained varying amounts of pyrite, chalcopyrite, sphalerite, galena, and native gold in a calcite gangue. The chief sulfide in some of the veins is chalcopyrite, and in others it is sphalerite. In the oxidized parts of the veins the calcite and sphalerite have largely disappeared, though some of the pyrite, chalcopyrite, and galena remain. The vein material on the whole is a rather spongy earthy limonite in which the flakes and wires of native gold occur. The pockets of native gold are closely related to the small bedding faults that dislocate the veins near the porphyry sills (fig. 39). Nearly all the pockets in a vein occur where it crosses a porphyry sill. The gold is remarkably segregated in these veins. Throughout most of their extent the veins contain too little metal to be of value, but here and there are the famous "pockets" where a section of the vein 2 or 3 feet in diameter and as much as an inch thick may consist of a nearly continuous hackly mass of crystalline gold

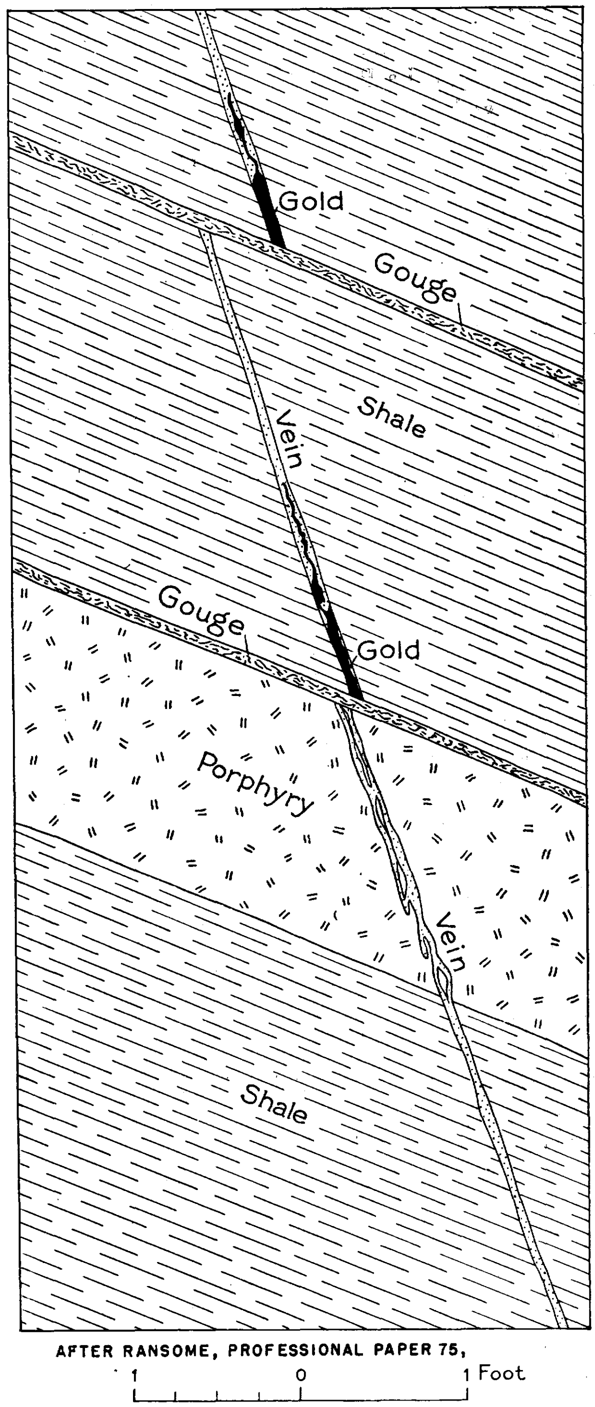

FIGURE 39.—Occurrence of secondary gold in Farncomb Hill veins.

ramifying through a matrix of limonite. In 1909, in a section about 3 feet long and 2 feet broad, $1,000 worth of gold was taken from the Reveille vein. Another small pocket contained $3,000 to $4,000 worth of gold.

The fact that these pockets are localized just above the bedding-plane slips and are limited chiefly to a zone within 300 feet of the surface seems to indicate clearly that they were formed by supergene enrichment. The localization of the veins in the slightly baked shale within 300 feet of the quartz monzonite porphyry is believed to have genetic significance. Samples of the silicified or baked shale adjacent to the quartz monzonite bodies in the Breckenridge and Montezuma districts everywhere show the presence of gold in small amounts. The gold was probably deposited with the silica from emanations given off by the deeper part of the quartz monzonite magma while solidifying. Pyrite and some chalcopyrite are disseminated through the shale in the vicinity of the veins on Farncomb Hill, and assays on the partly oxidized baked shale taken in recent years have ranged from 0.01 to 0.05 ounce of gold to the ton. It therefore seems probable that the high-grade gold found in the pockets in the veins has been leached from this low-grade disseminated material and deposited at slightly greater depth by downward-circulating solutions.

The gold found in the Farncomb Hill veins occurs both as wire gold and leaf or plate gold and is very spectacular. Ransome [42] gives detailed descriptions and illustrations of some very beautiful specimens taken from these veins and now on exhibit in the Colorado Museum of Natural History in Denver.

Blanket deposits.—The replacement deposits that lie along bedding planes, locally known as "contacts" or "blankets," are practically limited to Gibson Hill, Shock Hill, and Little Mountain and occur in replaceable beds of the Dakota quartzite and Maroon formation. Both primary and secondary ores of this type have been mined, but the most valuable ores have apparently been enriched by the action of surface water. The most favorable situation for these replacement deposits seems to be in the sandy shale of the upper Dakota quartzite where it is cut by small bedding-plane faults near minor veins. (See description of Detroit-Hicks mine, p. 115.)

Placer deposits.—The placers of Breckenridge may be divided into (1) gulch washings; (2) bench or high-level placers, which merge with those of number 1; and (3) deep or low-level placers, which occupy the main valley bottoms. The gulch washings are small steeply sloping placers in the bottoms of the minor gulches, but they include some of the most productive properties in the district. Those clustering around Farncomb Hill include the Georgia, American, Dry Gulch, and Wire Patch placers and are credited with a total output of more than $5,000,000. The shale detritus, angular blocks of porphyry, and unconsolidated soil that make up these placers attain a maximum thickness of about 25 feet at the bottoms of gulches. On the north slope of Farncomb Hill the shale strikes across the gulches and dips downstream, forming ideal natural riffles for catching the gold. The softness of the bedrock made these riffles very amenable to placering and they have long since been worked out. The gold was coarse, and most of the nuggets showed the wiry and flaky texture characteristic of the Farncomb Hill veins, leaving no doubt as to the local origin of the placer gold.

Nearly every gulch leading down from a known gold-bearing deposit in the district has yielded placer gold. In many places the productivity of the placer is not proportional to the importance of the gold-bearing lode known nearby; thus, the placers of Galena Gulch are more productive than those of Summit Gulch, and yet no important mine is known in the Galena Gulch drainage. The slope of the bedrock in the gulch washings is generally much steeper than the drainage of the large streams, and rich gold has been found on slopes of 1 to 5 in the Farncomb Hill gulch placers. Although most of the gulch placers known in the district have been worked out, streaks of pay gravel are found from time to time, and nearly every year one or more of the gulches contributes a small quota of gold to the output of the district.

The bench placers occur in gravel that is probably the outwash from one of the stages of glaciation that preceded the last or Wisconsin stage; they occur well above the present valley bottom. The terrace gravels are found chiefly along both sides of the valley of the Blue from the Wisconsin moraine a mile south of Breckenridge northward at least as far as Dillon. Most of the bench placers, however, are found within a few miles of Breckenridge. Near the edge of the present stream valley the bench placers obviously represent an ancient stream bed that must have had a width of at least 2½ miles near Breckenridge, but as the gravels are traced back toward the hills they merge with older hillside wash and gulch placers, and in many places it is difficult to distinguish the exact boundaries of the three varieties of material. In a few places the gravels merge with the Wisconsin outwash along the edge of the valley of the Blue, but more commonly the base of a bench placer is 75 to 250 feet above the level of the present stream. In most places the bench gravels are not more than 25 feet thick, but in some localities, for example, between Shock Hill and Barton Gulch, banks of old gravels 75 to 100 feet high have been exposed by hydraulicking. The boulders in the gulch gravels are well rounded. A few are as much as 4 feet in diameter, but most of them are less than 2 feet.

The bench placers have been worked by the ordinary hydraulic method in the past and have yielded a substantial quantity of gold. The richest and most accessible parts of the bench placers have been worked out, and for many years little placering has been done because of the difficulty and expense involved in bringing in new supplies of water that would be necessary for further development.

Although the bench gravels are most extensive along the banks of the Blue River, prospecting in these gravels

[42] Ransome, F. L., op. cit., pp. 81–82.

has not been as successful as in the bench gravels along French Gulch, Swan River, and Gold Run Gulch. As with the gulch washings, the most successful bench placers are those whose bedrock is shale, from which it is a comparatively easy matter to collect all the gold. Probably the most productive of the bench placers are those of Gold Run Gulch, whose total output amounts to about $750,000.

The low-level gravels occupy the bottoms of the present stream valleys and are largely in the outwash formed during the Wisconsin glacial stage. The related moraines themselves are practically barren; the ground moraine and intermingled fluvioglacial deposits upstream from the terminal moraine half a mile south of Breckenridge contain some gold, but unless fed by rich tributary gulch placers they are less productive than the outwash or valley-train deposits below the terminal moraine. Extensive drilling in the Breckenridge and Alma districts has demonstrated a remarkable relation between the tenor of the placers and the distance from the terminal moraine. This relation is illustrated diagrammatically in figure 38. Almost no concentration has occurred in the unsorted material that makes up the terminal moraine, but the glacial streams discharging from beneath the ice under pressure issued with great velocity from the ice front and carried a tremendous load of debris. The velocity was checked very rapidly below the moraine, and as a result most of the load was dropped within a mile of the ice front; from here on downstream the carrying power of the stream was more nearly constant. The size of the gold particles, however, diminished as distance from the ice front increased, until at a distance of 10 or 15 miles a large proportion of the gold present was in the form of flour gold not easily recoverable by placering. Above the terminal moraine the gold present in the gravel was chiefly supplied by the stream discharging from the front of the retreating glacier and by the tributary streams. The character of these upstream deposits suggests that the time interval during which they formed was much shorter than that during which the ice stood nearly stationary while the terminal moraine was forming. This fact probably accounts for the lower output from the upstream placers. It must be remembered that these upstream gravels are commonly much thinner than those downstream, and that a much smaller yardage of productive ground will be found per acre in the ground moraine than in the valley train. This difference may be advantageous in working the deposits but must be kept in mind when a comparison of the value per cubic yard is made. In both the valley train and ground moraine nearly all the gold has been concentrated in the upper 3 feet of bedrock and the lower 6 feet of gravel, except in a very few localities. Gold is distributed throughout the gravel near the junction of the Swan River and the Blue River, but elsewhere the upper parts of the gravel contained very little gold.

The thickness of the gravel along the Swan River and French Gulch and along the Blue River Valley at the lowest junction with Swan River rarely exceeds 50 feet. Above this junction the gravel thickens in the Blue River, and near Breckenridge it is more than 90 feet thick. The width of the gravel-filled valley bottoms ranges from 600 to 3,000 feet along the Blue River, 500 to 1,200 feet along the Swan, and 700 to 1,500 feet along French Gulch. Only part of this gravel contains gold in commercial quantities. The "channel" of the dredgers is usually 180 to 400 feet wide and follows a winding course along the valley that has no regular relation to the present stream and does not everywhere correspond to the deepest part of the bedrock trough. This gold-bearing channel is clearly affected by tributary gulches in many places, as the tenor rises near the junctions with the rich gulch placers. Although the low-level placer ground consists of only one channel in most places, the channel divides and bifurcates a short distance below the terminal moraine, and as many as five auriferous channels may be present for a short distance.

As would be expected, the low-level gravels contain many large boulders, the largest being found near the terminal moraine. In the Gold Pan placer, close to the terminal moraine near Breckenridge, boulders more than 18 inches in diameter constitute a large proportion of the deposit, but boulders more than 6 feet across have been found, and rocks 3 to 4 feet across are common. The size of the boulders decreases downstream, but even near the mouth of the Swan River boulders more than 3 feet in diameter occur. In general, the gravels in the Blue River Valley are larger than those along Swan River and French Gulch, but along all three streams boulders 18 inches to 2 feet in diameter are common. As with the other placers, the most complete recovery of gold is made where the channel bottom is shale; it is difficult to excavate to the necessary depth in bedrock where the valley bottom consists of quartzite. Efforts to work the low-level gravels by other means than dredging have not been successful, but for many years one or more dredges have worked the gravel along the Blue River. The total value of the output from dredging is in the neighborhood of $7,000,000. The cost of dredging has varied considerably; it was least along the Swan River where the breakage and wear caused by large boulders and hard bedrock were less than along Blue River or in French Gulch. According to Bradford and Curtis,[43] the cost of dredging in 1908 averaged about 8 cents a yard. According to Mr. Radford, the dredge superintendent, the cost of dredg-

[43] Bradford, A. H. and Curtis, R. P., Dredging at Breckenridge, Colo.: Min. and Sci. Press, p. 366, Dec. 11, 1909.

ing in 1925 along the Blue River a few miles north of Breckenridge ranged from 7 to 9 cents a yard for a dredge whose capacity averaged about 4,000 yards a day. In this operation the costs were divided about as follows: $4,000 a month for electric power, $3,000 a month for payroll, and about $500 a month for upkeep. The dredge was operated an average of 20 hours a day; the recovery ranged from 400 to 600 ounces a month but did not average more than 500 ounces. The gold

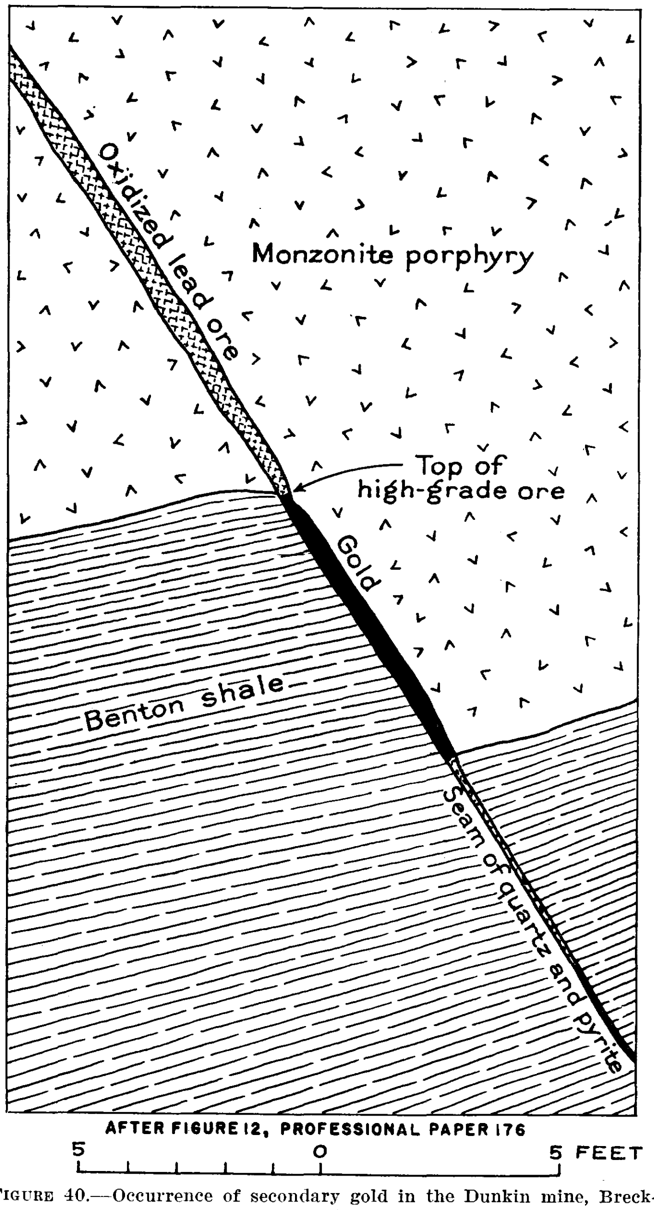

FIGURE 40.—Occurrence of secondary gold in the Dunkin mine, Breckenridge district.

content of the graved dredged ranged from 7 to 12 cents a yard, but only the coarse gold was recovered. The very fine material, which made up an appreciable percentage of the total gold in this part of the Blue River Valley, was left. Assays of the mud at or just above the bottom of the dredge pond showed the presence of $2 worth of gold to a ton of solid material.

DUNKIN MINE

The Dunkin mine is on the southeast side of Nigger Hill, about 1½ miles northeast of Breckenridge. It has been worked intermittently since 1895 and has supplied oxidized lead ore containing some gold, but it is best known for the shoots of well-crystallized gold found on its bottom level. The workings consist of three main adits, the Gallagher, the Railroad, and the Redwing tunnels, driven northeastward into Nigger Hill between altitudes of 10,000 and 10,300 feet.

The vein follows a fault of small vertical displacement that trends northeastward in the mine but swings east a short distance beyond the end line of the Redwing claim. The dip of the vein is irregular but averages about 57° SE. The productive part of the vein is almost wholly within the thick monzonite porphyry sill that forms much of Nigger Hill; the vein becomes nearly barren after passing into the underlying Benton shale on the Redwing tunnel level.

The ore occurred in several lenticular shoots separated by barren ground where the vein pinched to a tight narrow seam of gouge. The shoots ranged from 50 to 100 feet in stope length and from 200 to 500 feet in pitch length, but only one extended continuously from the bottom level to the surface. The shoots pitched 60°–70° NE., and the width of the ore ranged from 6 to 40 inches between the porphyry walls; where the vein passed into shale the ore narrowed to less than 6 inches. The ore in the upper levels consisted almost entirely of cerussite containing about 1 ounce of gold and 12 ounces of silver to the ton. Below the Railroad tunnel galena and some anglesite were found in addition to cerussite. The gangue is chiefly sugary iron-stained quartz and brown jasper containing some jarosite.

At the bottom of the most extensive ore shoot a rich seam of native gold was found. The shoot was 100 feet in stope length in the bottom level, and throughout this distance gold was found in paying quantities. At several places it occurred in spongy masses of coarsely crystalline gold 1 to 4 inches thick and as much as 40 inches in length and height. This rich gold ore was limited to the upper 10 feet of the shale and was best developed where the shale and porphyry overlapped each other on different sides of the vein. (See fig. 40.) The oxidized condition of the ore and its structural relations indicate that it was formed by downward enrichment. The horizon at which the gold occurred is about 300 feet above the Dakota quartzite. The vein has not been sought in the quartzite, and it is uncertain whether the vein persists through the thick layer of overlying shale.

JESSIE MINE

The Jessie mine is on the northeast side of Gold Run, about 2½ miles northeast of Breckenridge at an altitude of 9,600 feet. It has been one of the most productive of the stockworks but has not been operated for many years. Its production was made prior to 1910, when estimates of the value of the total output ranged from $800,000 to $1,500,000. Work on the property began in 1885 but was not carried on steadily, probably in large part because of the excessive amount of dead work required to find the high-grade streaks of gold ore, the irregularity and lack of persistency of these streaks when found, and the low extraction obtained in the mill. According to Ransome, the extraction prior to 1899 was about 40 percent, and after that date certainly was not more than 80 percent and was probably under 60 percent.

The productive part of the mine is almost entirely in quartz monzonite porphyry near the western edge of a large irregular porphyry tongue that extends northwestward from the main stock. The tongue is in part a sill-like mass in the Pierre shale, whose regional dip in this locality is about 45° NE., but in places is crosscutting. The deposit is oval, with the long dimension striking nearly east-west; it has a length of about 900 feet and a maximum width of about 700 feet. Within this oval nearly all the porphyry is traversed by small veinlets containing pyrite, sphalerite, and some galena; these minerals are also disseminated through the porphyry and are accompanied by sericite, which is especially abundant in the large orthoclase phenocrysts of the porphyry.

Along certain zones the fissures are closely spaced, and the proportion of sulfides to waste is greater than for the stockworks as a whole. It is in these lodelike zones that most of the stoping has been done. Ordinarily there are no definite walls to the strongly fissured zones; groups of stringers may be nearly parallel and present the appearance of a strong stringer lode for 100 feet or more along the strike either ending or merging with another group of different trend (fig. 41). The zones of fissuring strike from northeast to east, and the general dip is from 30° to 90° NW., but a few zones dip southeastward.

Most of the sulfide veinlets are less than an inch thick and fill cracks of no great persistency. Even some of the larger stringers, as much as 4 inches in width, die out completely in a short distance, and some of the zones stoped for widths of as much as 15 feet dwindle to insignificant tight cracks when followed along the strike. The cracks contain little gouge, and there is no evidence of any considerable movement along them.

No important body of ore has been found in the shale. The cracks either end at the contact or continue in diminished number and smaller size for only a few feet. The depth to which the stockworks extend is not determinable, but it is probable that much of the porphyry is underlain by shale. The lowest workings are chiefly in shale and are about 350 feet below the top of the hill.

The ore consists of pyrite, sphalerite, and galena in a gangue of altered porphyry. The galena generally occurs in the cracks or in the immediate vicinity of them, and its presence has invariably been a sign of good ore, but sphalerite and pyrite, though present also in veinlets, are widely disseminated through the altered porphyry. The value of the ore as mined ranged from $3 to $6 a ton. The ore from the Revette stope is said to have had a gross value of $77,000, averaging $4.03 in gold and $0.48 in silver to the ton.

PUZZLE-OURAY MINE

The Puzzle-Ouray mine is a mile southeast of Breckenridge, on the south side of Dry Gulch. It was opened about 1885 and was productive from about 1888 to 1900; since then an intermittent output has been made by lessees, though the total has not been large. Ransome estimated that the value of the total output prior to 1909 was about $960,000. As shown on the stope map on plate 12, it is opened by several adits, two shafts, and one winze. The principal tunnel level, known as the Willard, serves both the Puzzle mine and the Golddust mine, northeast of the workings shown on plate 12.

The predominant country rock of the Puzzle vein at the surface is the Dakota quartzite. The vein cuts diagonally across a local anticline, which has a steep southeast limb and a gently dipping northwest limb. Benton shale is found at the surface both to the north and to the south of the vein, but is not cut by it so far as known. A thick monzonite porphyry sill underlies the Dakota quartzite on the northwest side of the vein and forms one wall of most of the vein on the Willard tunnel level. Gray shale of the Morrison formation forms the southeast wall throughout most of this level. Mining was profitable only where one or both walls of the vein consisted of quartzite or porphyry. The appearance of the gray shale of the Morrison formation along the vein coincided with a marked decrease in the value of the ore, even where the other wall was porphyry.

The ore itself shows little evidence of enrichment below the upper levels. Material shipped from the Puzzle-Ouray mine was largely a galena ore containing moderate amounts of silver and less than 8 percent of zinc. On the upper levels some anglesite and cerussite occurred, but even there galena made up most of the material mined. The vein was 1 to 15 feet wide, probably 3 to 5 feet wide in most places.

The apparent relationship of the ores to the surface is misleading. Both the erosion surface and the localization of the ore are related to the superior hardness and competency of the quartzite (pl. 12). In the Wellington mine, where a tight gougy fissure in shale passes into an open breccia in quartzite, the factors determining the preference of ore-forming solutions for quartzite walls is well illustrated on a small scale (fig. 27). The localization of the primary ore in the Puzzle-

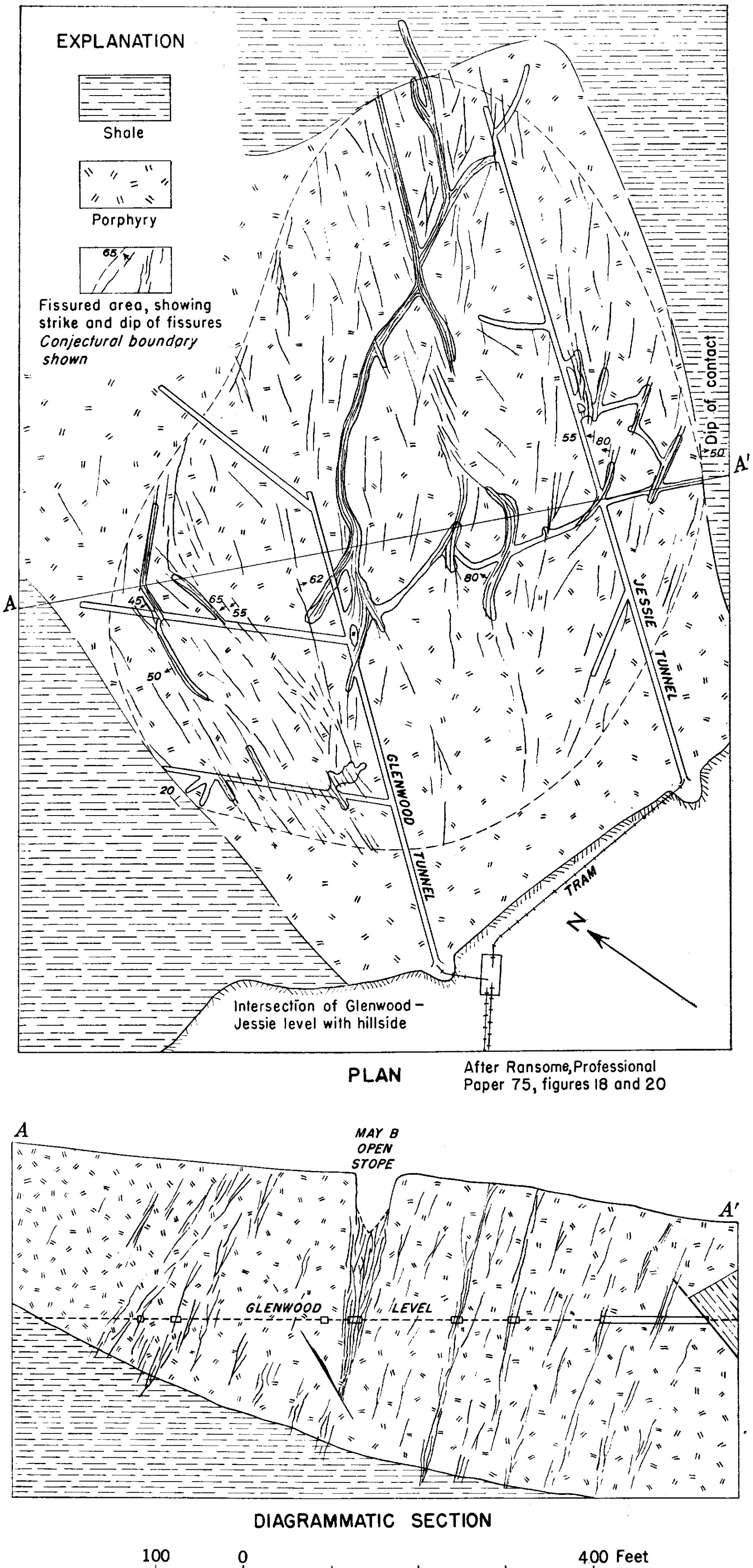

FIGURE 41.—Plan and diagrammatic section of the Jessie mine, Breckenridge district.

Ouray vein was undoubtedly related to the pervious character of the fissure where the walls were of quartzite and porphyry and to the relative imperviousness of the same fissure where one or both walls were of shale.

The vein follows a normal fault that strikes N. 50°–70° E. and dips about 80° N. The original vertical displacement of the fault was probably about 120 feet, but the intrusion of the porphyry sill in the hanging wall raised the overlying beds and decreased the initial displacement by varying amounts, depending on the varying thickness of the sill. Locally the porphyry cut through the fault and formed thin sills in the footwall of the vein, but in general it followed the fault line closely and spread into the hanging wall rather than the footwall.

STANDARD OR DETROIT-HICKS MINE

The Standard or Detroit-Hicks mine is representative of the blanket deposits of the district. It lies 1¼ miles northeast of Breckenridge and about 1,000 feet east of the summit of Gibson Hill at an altitude of 10,325 feet. It was first worked about 1890, when rich gold ore was taken from a bedding-plane deposit in the Dakota quartzite through an inclined shaft. In 1930 the mine was opened by two vertical shafts—the "old shaft," 151 feet deep, connecting with a productive stope, and the "new shaft," 80 feet deep, sunk to develop possible ore bodies southwest of the old shaft. Drifts aggregating 2,000 feet have been turned from the old shaft, and the mining has been largely confined to the No. 1 and No. 2 levels at depths of 40 and 90 feet.

The ore occurs in bedding-plane deposits or blanket veins in replaceable beds of the upper members of the Dakota quartzite. The general dip of the quartzite near the mine is about 20° SE., but locally sharp monoclinal folds cause steep dips, and near porphyry masses the beds are much disturbed. Many small normal faults occur either parallel with the bedding planes or cutting through them at small angles. In several places the faults have cut through the top of a steep monoclinal fold and produced open, broken ground very favorable to the localization of ore. The gently dipping bedding-plane faults are cut by a set of steeply dipping normal faults striking north to northwest and dipping 55° to 80° east or northeast.

On the first level the Standard stope extends southwestward from the shaft for a distance of 200 feet and has an average dip width of 60 feet. The hanging wall is a thin-bedded shaly quartzite, and the footwall or floor is massive quartzite. The ore not only occurs in gouge seams of bedding-plane faults but invisibly impregnates shale and shaly quartzite; the ore shoots can be delimited only by sampling. The best and thickest ore coincides with the axis of a "shale roll" where a small monoclinal fold has been cut by a bedding-plane fault. There the distance between the floor and the back of the stope is 10 feet. The ore was followed downward to the northeast but became limited to a narrow zone near some of the bedding-plane faults, which gradually diverge from the gently dipping fault that forms the floor of the stope under the shale roll. To the northwest the ore decreased in thickness as the fault forming the floor approached the back of the stope.

Nearly all the ore was oxidized (fig. 60, *A*), but some sulfides, chiefly galena, were found in the deeper part of the Standard stope. A strong northwesterly fault forms the northeast limit of the stope, and along it the ore-bearing beds have been dropped to the second level. On the second level ore was found at two horizons northeast of the fault that cuts off the Standard stope. The largest ore body, that found in the Sulphide stope, was probably the unoxidized equivalent of the Standard stope ore body. In the Sulphide stope silver-bearing and gold-bearing galena had replaced black sandy shale between two layers of quartzite about 4 feet apart. In some places the shale was entirely replaced by galena, and as much as 4½ feet of solid ore was mined from the best parts of the stope. This stope was limited on the east by a northward trending fault, beyond which no commercial ore was found. About 15 feet above the Sulphide stope a thin seam of high-grade ore was mined. It consisted chiefly of galena but contained some sphalerite and pyrite and lay beneath a thin bedding-plane slip in black shale 3 to 12 inches thick. A few steeply dipping seams of lead-zinc ore were cut 100 feet southwest of the shaft, but they were narrow, and no attempt was made to follow them.

WIRE PATCH MINE

The Wire Patch mine is situated on the southwest slope of Farncomb Hill, 4 miles east of Breckenridge, at an altitude of about 10,550 feet. The Elephant ore body, from which most of the output came, was discovered about 1882, and shipments were maintained steadily until about 1889, but since that time the output has been intermittent and small. The total value of output is probably in the neighborhood of $140,000.

The country rocks of the Wire Patch mine are Pierre shale and quartz monzonite porphyry. The shale has a general dip of about 25° NE. but has been much disturbed by the intrusion of the porphyry, which cuts it irregularly. Near its contact with the shale the porphyry is crowded with inclusions of shale, and in some places for a distance of 100 feet there is an apparent gradation from porphyry containing a few bits of shale to a breccia of massive shattered shale in a matrix of porphyry. On the lower tunnel level, the tunnel, after passing through shale for 270 feet, enters the monzonitic intrusion breccia, which is little mineralized, but just above it is the Elephant ore body, a large irregular mass that has been stoped for more than 200 feet eastward and up to the surface. The ore within this stope consisted of shale fragments surrounded by shells of pyrite, sphalerite, and galena. According to Ransome, the sulfides were deposited on the surface of the shale by replacement of the porphyry matrix of the intrusion breccia. The lower or Elephant tunnel passes through 350 feet of the unmetalized prophyry and again reaches shale. About 150 feet from the second contact the porphyry is crowded with shale fragments. Partly in this material and partly in the porphyry above the tunnel another irregular ore body has been stoped. The two principal ore bodies thus occur on opposite sides of an irregular porphyry dike, both sides of which are marked by a coarse intrusion breccia. The western, or Elephant ore shoot, dips about 75° E., and the eastern shoot apparently dips about 45° W. Exploration of the projected junction of the two shoots in the Mill tunnel was disappointing.

Beyond the east ore body the Elephant tunnel passes through 100 feet of shale and again enters porphyry, within which it follows a thin northeasterly gold vein for 150 feet. Three hundred feet higher, in the Ontario tunnel, this vein is chiefly in shale.

According to Ransome the ore in the Elephant stope consisted of sericitized porphyry containing pyrite, sphalerite, galena, and a little pale-pink ankerite or impure rhodochrosite. The minerals filled numerous irregular fissures and interstices in the fractured porphyry and in part replaced the rock. Pyrite was by far the most abundant sulfide, and galena was rare, occurring in small bunches of crystals as much as an inch across. The concentrates in 1908 contained about 0.9 ounce of gold and 10 ounces of silver to the ton, 34 percent of iron, and 10 percent of silica.

WELLINGTON MINE

The Wellington mine is on the north side of French Gulch, about 2 miles due east of Breckenridge, at an altitude of approximately 10,000 feet. It has been the most productive mine in the Breckenridge district, and the most valuable metals mined have been silver and zinc. The total output is unknown, but from 1887 to 1928 a total of 23,249 tons of crude ore was shipped to smelters, and from 1905 to 1928 a total of 508,628 tons of lead-zinc ore was treated at the Wellington mills to make 205,137 tons of concentrates. The smelting ore yielded 1,500.77 ounces of gold, 150,699 ounces of silver, 7,975,922 pounds of lead, and 14,760,518 pounds of zinc. From the concentrates 5,001.08 ounces of gold, 598,582 ounces of silver, 32,738,470 pounds of lead, and 149,796,317 pounds of zinc were recovered. The total known output thus amounts to 737,014 tons yielding 6,501.85 ounces gold, 749,281 ounces silver, 40,714,392 pounds of lead, and 164,556,835 pounds of zinc.

The Wellington mine includes both the original Wellington and the Oro properties. The original Wellington mine is opened by several adits, of which the longest is the X–10–U–8, driven north-northwest at an altitude of about 10,040 feet. This adit connects with the collar of the underground inclined Wellington shaft, from which five lower levels have been turned. The vertical Oro shaft is 1,700 feet S. 35° W. of this shaft, close to the Wellington mill. The two shafts are joined by their fifth and sixth levels, but the others connect with only one shaft. The deepest level, the Oro 8, is not directly connected with the Oro shaft but is opened by a winze near the east end of the seventh level. The total extent of the drifts and crosscuts in the Wellington and Oro workings was 66,570 feet, and the depths of the shafts aggregated 1,346 feet in 1930.

Nearly all the output of the mine has come from the primary ore, which consisted essentially of pyrite, sphalerite, and galena in various proportions with relatively little gangue. Such waste as occurred within the ore bodies consisted mainly of "horses" and small fragments of metalized porphyry or of pyrite containing too small a proportion of galena and sphalerite to be classed as ore. The gangue, where present, consists of siderite or barite. These materials, however, are nowhere abundant and are younger than the sulfides, in which they form veinlets or line vugs.

The prevailing texture is that of a granular aggregate of galena, sphalerite, and pyrite, the three being combined in different proportions in different places and showing much variation in coarseness of crystallization.

A characteristic feature of the Wellington ore is the manner in which it is traversed by white or pale-buff veinlets of carbonate, an ankerite approximating siderite in composition (fig. 23, *D*). In some parts of the veins these veinlets are parallel with the walls of the Main vein, giving the ore a banded appearance; in others they branch irregularly through the sulfides in all directions; and in a few spots the sulfides have been brecciated, and the fragments are now cemented by the ankerite. The ankerite veinlets are common in the sulfide ore of the eighth level and are undoubtedly primary.

The ore in the deepest workings does not differ appreciably in appearance from much of the ore found in the upper levels; nevertheless, there are changes in composition that are related to depth and structure. The highest-grade lead ore was found close to the surface and usually became more zinciferous in depth. In some places high-grade lead ore changed downward into a heavy pyritic ore, which marked the bottom of that part of the ore shoot. Ores composed chiefly of sphalerite bottomed in some places with no appreciable change in composition and in other places gave way to massive pyrite both vertically and laterally. Abrupt changes in composition commonly mark the top, bottom, or sides of an ore shoot, but most of the ore from a given shoot is remarkably similar and is commonly characteristic of the particular shoot from which it was taken.

The general geology of the surface is shown on plate 2, and the structure and the vein system are shown in figure 42. Two strong northerly premineral faults, the Bullhide and the Great Northern-J lie to the west and east, respectively, of a broken, downfaulted block. Most of the Oro workings lie in this block, but the Wellington levels follow veins both within this graben and in the upthrown Wellington fault block, east of the Great Northern-J fault zone. The upper levels are almost wholly in monzonite porphyry, but the lower levels expose Pierre, Niobrara, Benton, Dakota, and Morrison beds. The monzonite porphyry is part of the northern border of the large, irregular mass that forms much of the upper part of Bald Mountain and that was formerly continuous with the porphyry mass of Nigger Hill to the west. At the surface, a short distance west of the Oro shaft, Dakota quartzite crops out along the Bullhide fault, which has brought it against the thick monzonite porphyry sill that is underlain by Pierre shale just east of the Bullhide fault. Although not exposed at the surface, Pierre shale forms the bedrock of French Gulch east of the Bullhide fault for some distance, as shown by a study of the dredge tailings.

The monzonite porphyry exposed underground was intruded in large irregular bodies subparallel to the bedding of the Cretaceous sediments but broke across them in many places along early faults. In places the planes of weakness followed by the cross-breaking porphyry were reopened many times; the Main vein in part occupies a fault fissure that closely parallels the intrusive contact of the monzonite porphyry mass (fig. 43). As shown in the cross section (fig. 42), gray siliceous shales of the Morrison formation are present on the sixth level, southeast of the Wellington shaft, and massive light-gray Dakota quartzite also occurs on the same level. The Benton shale is present on the seventh and eighth levels of the Oro, and the limy shales of the Niobrara formations are well exposed on the sixth, seventh, and eighth levels of the Oro. Some of the limy shale beds of this formation have been strongly silicified near the vein and converted into black jasperoid, and in a few localities ore has replaced favorable beds in the lower part of the formation to a thickness of about 1 foot. Bodies of this type, however, could not be profitably mined. Pierre shale is present on the third and fifth levels of the Oro.

The Bullhide fault, which comes to the surface 500 feet west of the Oro shaft, strikes N. 26° E. and dips 58° E., and has a throw of about 800 feet and a dip slip of approximately 900 feet. There is little evidence of a horizontal component of movement along the fault. The fault zone is 5 to 15 feet wide and is characterized by an abundance of gouge, broken quartzite, shale, and porphyry, having little relation to the adjacent walls. Bunches of sulfide occur in the broken ground. Some are massive and unbroken, but many are shattered and pulverized by postmineral movement. In places veins of sphalerite and pyrite cut across the gouge and clearly were formed after a large amount of movement had occurred, showing that the fault is in large part premineral. The Great Northern-J fault zone strikes from N. 10° E. to N. 20° E. and dips 50°–85° W. In places it is a strong narrow fault, but a short distance southeast of the Wellington shaft it widens to a sheeted zone several yards across. Strong gouge-filled fractures are common in the Great Northern-J fault zone, and, as in the Bullhide fault, massive and broken sulfide pockets are common. The fault probably has a vertical displacement of about 850 feet. The ore found in the Wellington workings has come from a series of east-northeasterly veins in the upthrown block just east of the Great Northern-J fault, and the ore is largely localized close to the intersection with the master fault. In the Oro mine the chief veins exploited occur in a northeasterly set that extends diagonally across the broken graben between the Bullhide fault and the Great Northern-J fault.

In the west part of the Oro fault block an eastward-dipping fracture, the 11–10 fault, has been traced from the surface to the eighth level. It strikes north and dips 30°–40° E. It is a normal fault whose hanging wall moved S. 60° E. for approximately 110 feet, so offsetting the eastern segment of the vein that it is found farther south than the western segment. Many smaller faults dip gently eastward in the Oro fault block, some of which pass into bedding-plane slips and soon disappear. Like the Bullhide and the Great Northern-J, the 11–10 fault is in part premineral and in part postmineral, and as will be shown later it has exercised a great influence on the localization of ore.

The veins in the Wellington fault block east of the Great Northern and J faults strike N. 70° E. in contrast to those of the Oro graben, which strike nearly northeast. Although many small veins were found in the upthrown block east of the Great Northern-J, only four strong veins have been recognized. From north to south they are the East Iron, the East, the Orthodox, and the Great Northern veins. They are about 200 feet apart on the upper levels of the Wellington workings and dip 45°–85° S. (See fig. 42, sec. *B–B′*.) The ore ranged from a mixed lead-zinc ore in the East Iron vein to high-grade zinc ore in the Great Northern vein; the veins contained ore only close to the Great Northern-J fault, becoming unproductive 400 to 600 feet to the east. The ore in each of the veins was more zinciferous than the ore in the vein adjoining it on the north,

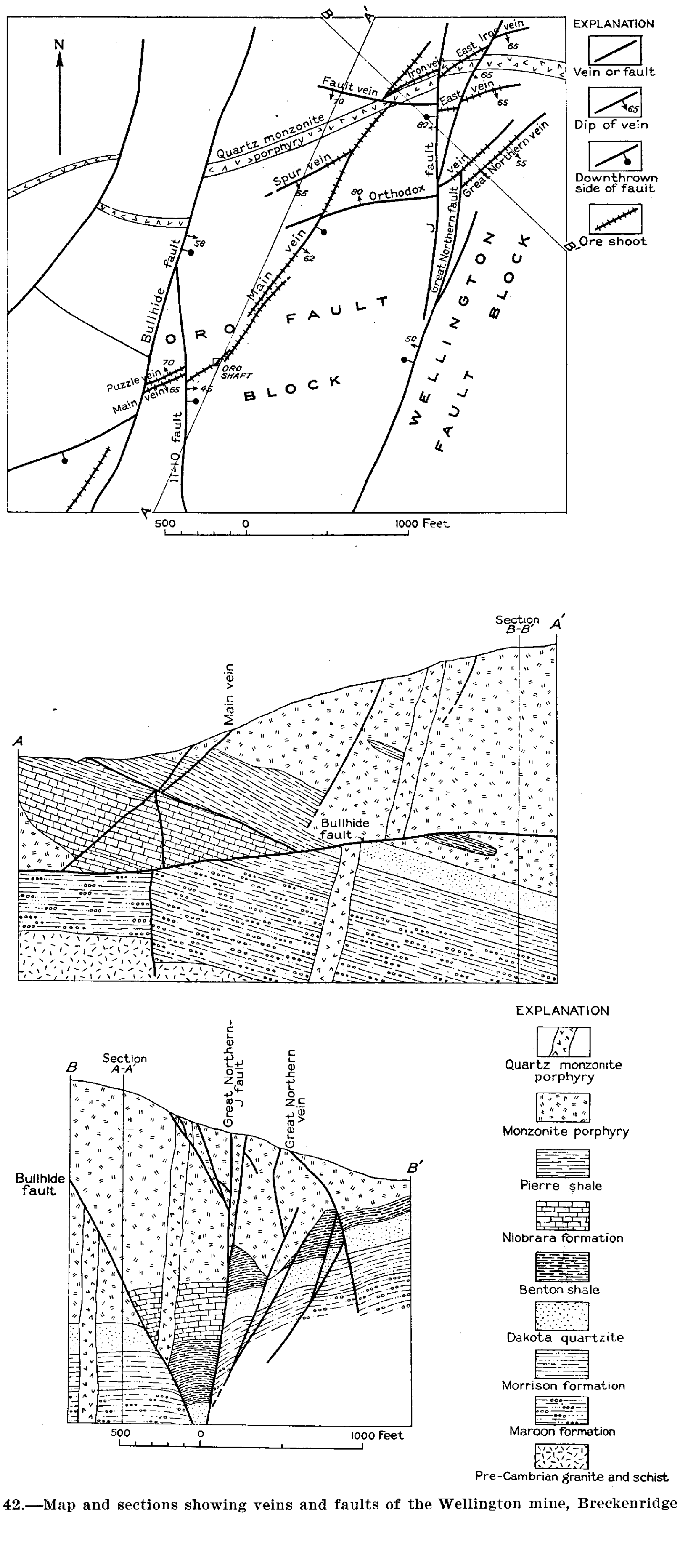

FIGURE 42.—Map and sections showing veins and faults of the Wellington mine, Breckenridge district.

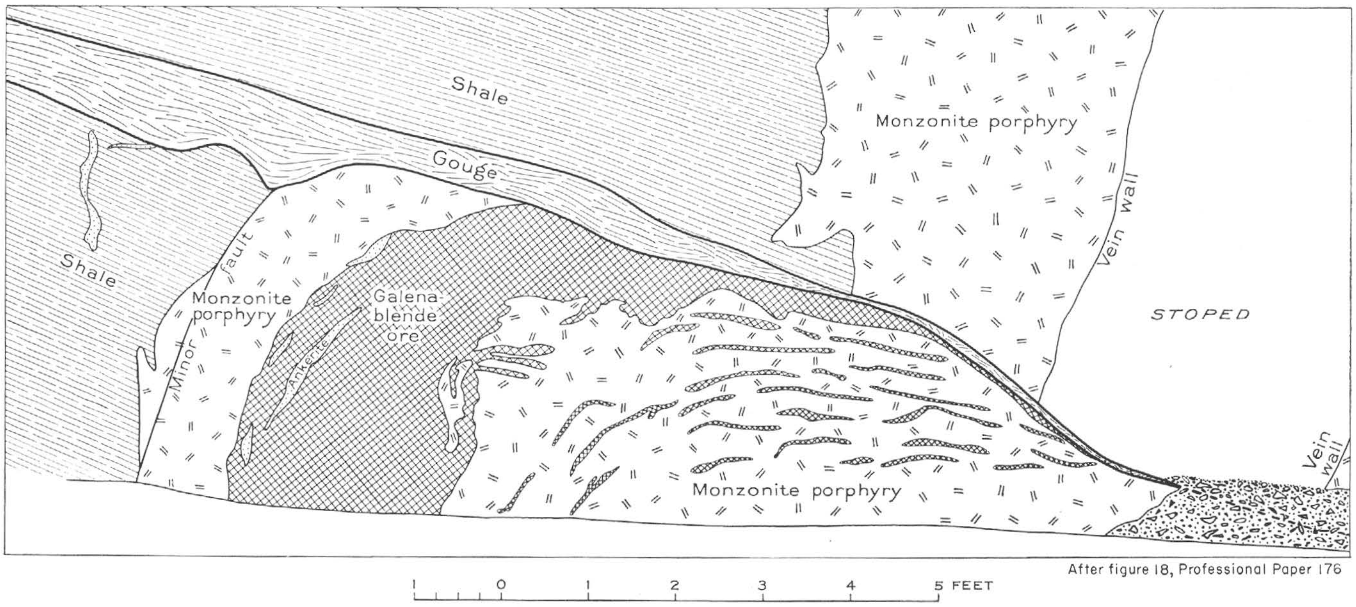

FIGURE 43.—Sketch showing the parallelism of the Main vein of the Wellington mine to the intrusive contact of cross-breaking monzonite porphyry. The dike was so firmly welded to the walls that renewed fissuring took place in the dike rock rather than along the dike contact.

and the ore bottomed at progressively greater depth in each vein to the south.

The most productive vein in the mine was the Great Northern, the southernmost of those found in the Wellington workings. As shown on the stope map (fig. 44), it was almost a blind ore shoot and was found during the course of underground development. The general strike is N. 65° E., and it dips 30°–55° S. The length of the shoot ranged from 800 feet on the fourth level to 500 feet on the first and was less than 200 feet at the surface. The ore bottomed abruptly about 40 feet below the fifth level at an altitude of about 9,560 feet, but because of the gentle dip of the vein the shoot had a dip length of 900 feet. The width ranged from 3 to 20 feet and averaged about 6 feet. Changes in width were unrelated to wall rock, but at many places, notably on

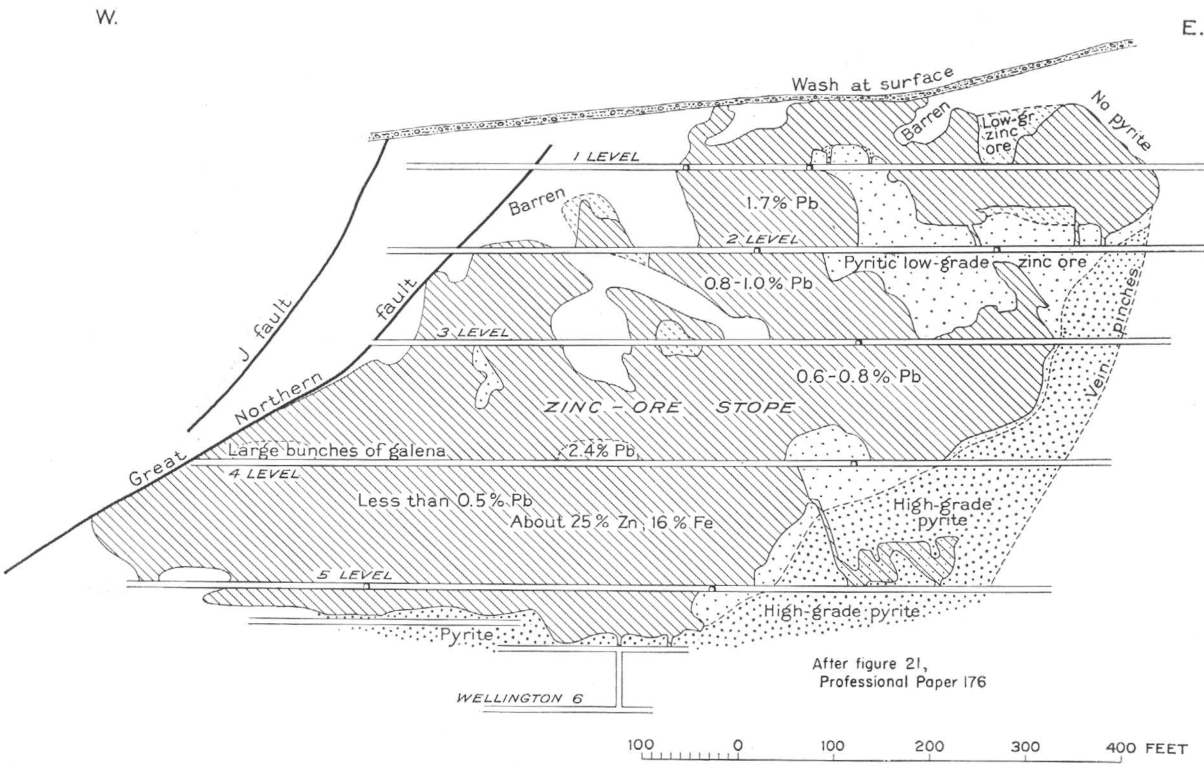

FIGURE 44.—Section showing stopes on the Great Northern vein of the Wellington mine.

the fourth level, the ore widened greatly as the Great Northern-J fault zone was approached, reaching a maximum width of 35 feet at this place.

The ore was largely composed of sphalerite and pyrite, galena rarely exceeding 2 percent of the ore mined; only a few substantial bunches of galena were found, near the Great Northern fault zone on the fourth level. The lead content averaged slightly more in the upper part of the vein than elsewhere, averaging 0.5 percent on the fifth level and 1.7 percent on the first level. At the bottom and east end of the ore shoot the zinc ore changed within a transition zone of about 20 feet into nearly pure pyrite (fig. 44). The change in character was not coincident with a decrease in the width of the vein, and on the fifth level some fair-sized stopes were made in the pyrite, which was used in the manufacture of sulfuric acid. The vein is small east of the pyritic border, and no ore was found in 500 feet of drifting east of the shoot on the fifth level.

In the Oro fault block the most noteworthy vein is the Siam, or Main vein as it is now called. It strikes N. 45° E. and dips about 62° SE. and can be traced from the Oro shaft to a point about 1,500 feet northeast, where it is cut by the eastward-trending Fault vein. The Iron vein, which strikes northeast and dips 65° SE. leaves the Fault vein on the north at a point about 50 feet west of the Main vein. It is probably a segment of the Main vein itself that has been displaced by the Fault vein. The Spur vein branches west from the Main vein about 400 feet southwest of the Fault vein. Near the Oro shaft the Main vein splits into two or three parts. West of the 11–10 fault the northern segment is called the Puzzle vein, and the strongest of the southern veins is called the Main vein. The Puzzle vein dips about 70° N. and trends about N. 70° E., being nearly parallel in strike to the southward-dipping fractures correlated with the Main vein.

One of the best shoots is found a short distance west of the J fault, where the Main vein is cut by the Fault vein. This shoot was roughly triangular in shape, coming down to a point 100 feet northeast of the inclined shaft between the fourth and fifth levels. A northerly fault, dipping 50° E., marked the western edge of the ore shoot; the J fault limited it on the east below the third level; and the Fault vein formed the east side of the shoot above the third level. The ore body was 2 to 18 feet wide and averaged 12 feet throughout the second level. It consisted chiefly of sphalerite but contained moderate amounts of galena.

The so-called Main ore shoot was entered just 500 feet southwest of the fifth station of the Wellington inclined shaft. It was stoped from the eighth level of the Oro nearly to the surface and was one of the largest bodies of ore in the mine. On the eighth level the shoot was only 150 feet long and was cut off on the east by northerly faults dipping steeply to the west. The intersection of the Main vein with these faults pitches gently to the southwest and formed the bottom of the ore shoot between the eighth and the seventh levels. In most places the limits of the shoot are marked only by a decrease in the width and tenor of the vein, but on the seventh and eighth levels the vein splits into several smaller veins soon after it passes into the shale at the west end of the shoot, and the branches contain little workable ore east of the 11–10 fault. In general the strength of the ore shoot decreased as the vein passed from porphyry into shale, but porphyry walls were no assurance that the vein would contain ore. Much of the ore mined above the fourth level averaged 8 percent of lead, 15 percent of zinc, 0.05 ounce of gold, and 5 ounces of silver. The ore from the lower levels contained much less lead and more zinc. In the upper portions of this shoot galena ore was in some places underlain by heavy pyritic material containing very little galena or sphalerite.

Nowhere in the mine are pyrite and sphalerite late minerals, so it is probable that the Main vein was formed before the veins containing more galena, such as those to the north and those in the Oro graben. A gradual increase in galena in the successive veins to the north and the higher altitude of the bottom of the ore shoots suggest that the Great Northern fault acted as a guide for the metalizing solutions, which rose from the south along this master fissure and filled the Great Northern vein before the others. The open fissures communicating with the footwall of the Great Northern-J fault zone would be filled as the northward-moving solutions reached them, and in a general way the southern fractures would be filled and clogged before those to the north. Intramineralization movement along the Great Northern-J fault probably opened ore channels communicating with the Bullhide fault and the Main vein. The ore shoots in the graben contained a much higher proportion of galena close to the Bullhide fault than away from it, suggesting that the solutions did not have access to them until late in the period of mineralization.

The Main vein was very nearly barren in the 800-foot interval between the west end of the Main ore shoot and the Shale shoot. The Shale shoot was narrow and chimneylike, having a stope length of 150 feet and a pitch length of about 500 feet. It bottomed on the 11–10 fault about halfway between the sixth and seventh levels. The ore was of much higher grade but narrower where both walls were shale than where the walls were porphyry. The ore contained more lead than the Main shoot and showed almost no change of tenor with depth. The ore shoots found on the Puzzle vein, west of the 11–10 fault, were closely related to the intersection of the 11–10 fault, which evidently acted as a baffle under

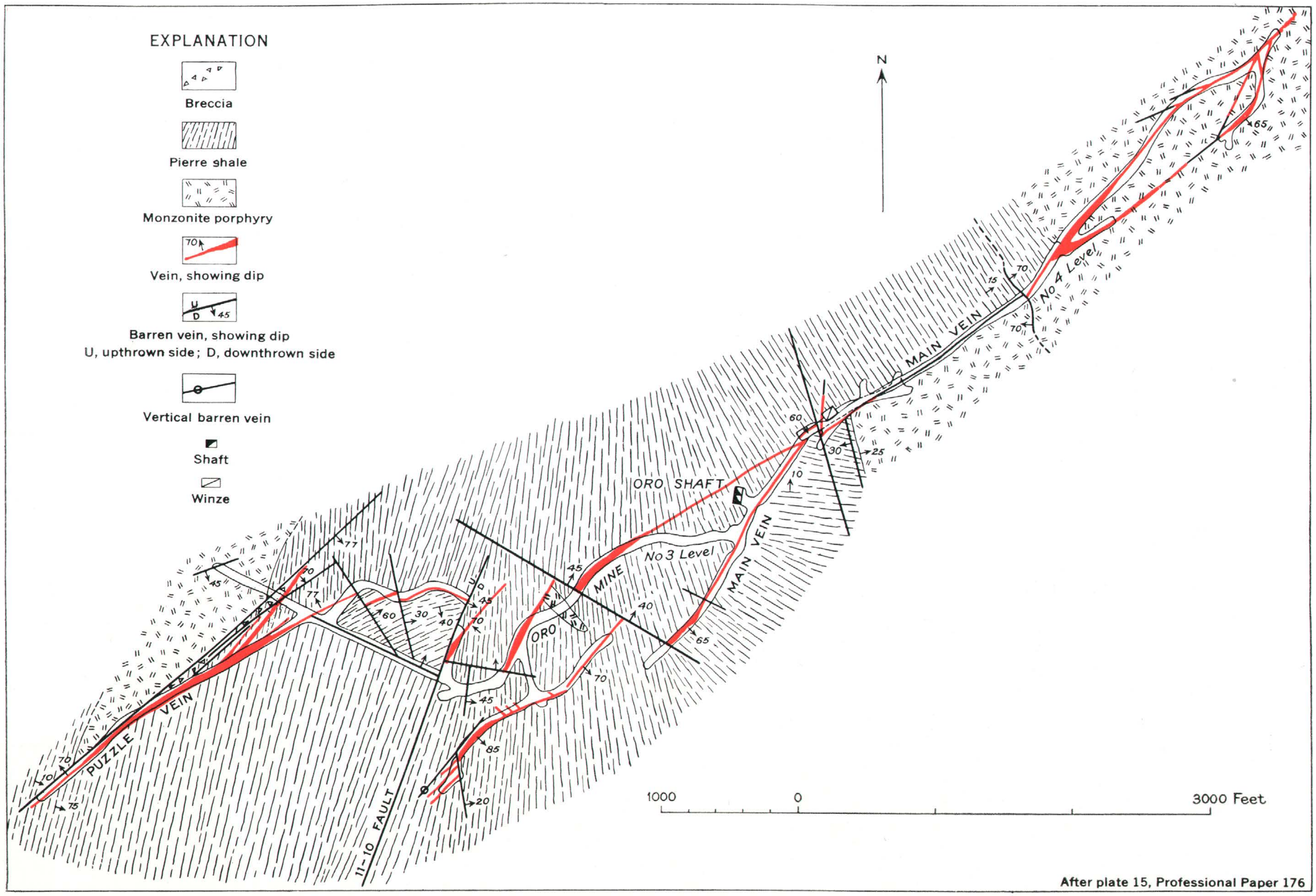

FIGURE 45.—Plan of the No. 3 and No. 4 levels of the Oro workings of the Wellington mine, showing the relation of ore shoots to premineral faults and to junctions.

which the rising solutions moved toward the surface. These shoots contained more galena and more gold than the shoots to the east.

In general the ore shoots were stronger and more persistent in porphyry or jasper than in unsilicified shale. In some places premineral cross faults, such as the 11–10 fault, acted as guides to the mineralizing solutions and determined the limits of an ore shoot; in other places the cross faults opened up the vein on one side and closed it on the other, thus causing local enlargements and "pinches" in the ore. (See fig. 45.) Some of the ore shoots seem to be related to the variations in the dip or strike of the vein. All veins of the Wellington mine except the Great Northern are in normal faults, and ore shoots mostly occur where the vein becomes steeper or where it changes its course. The bottom of the ore in the Great Northern vein coincides with a marked steepening of the vein (fig. 44), but the steepening of the Main vein in the upper levels is marked by an increase in the width and length of the Main ore shoot. Striations and deep grooves in the walls of the Main vein pitch 60° SW., suggesting that the hanging wall moved down and southwest; as would be expected from this movement the ore in many places increases in width where the vein swings to the right (fig. 45). Some of the best ore was found at the junctions of splits in the vein; this type of structural control is illustrated by the localization of the Shale shoot at a split in the Main vein 300 feet northeast of the Oro shaft (fig. 45).

OTHER MINES

Data on other representative mines are given briefly below. Detailed descriptions of these and other mines have been given by Ransome [44] and by Lovering.[45]

HAMILTON

Development.—Three main tunnels and a subtunnel.

Production.—Total to 1909, $400,000; very little output since 1909.

Veins.—Tunnel intersects a number of sheeted zones. Strike, N. 63°–85° E.; dip, 75°–90° N. "Veins" are zones of more intense fissuring, generally less than 50 feet apart; they commonly end on reaching large blocks of shale. Sulfides occur chiefly as fissure fillings, some replacement.

Wall rock.—Quartz monzonite porphyry containing blocks of black shale.

Ore and sulfide minerals.—Pyrite, sphalerite, galena, and gold.

Gangue minerals.—Pyritized and sericitized porphyry.

Ore shoots.—Large ore body 150 feet long, 5 to 15 feet wide, and 150 to 200 feet high, formed at intersection of two veins or zones of fissuring. Stopes on one fissure zone nearly opposite those on another.

Tenor.—Value of ore is in gold and silver; lead and zinc are almost negligible.

[44] Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colo.: U. S. Geol. Survey Prof. Paper 75, pp. 134–160, 1911.

[45] Lovering, T. S., Geology and ore deposits of the Breckenridge mining district, Colo.: U. S. Geol. Survey Prof. Paper 176, pp. 33–59, 1934.

I. X. L.

Development.—Original discovery, 1881. Two tunnels, the lower 800 feet long.

Veins.—Stockwork of complexly interlacing and crossing fractures.

Wall rock.—Quartz monzonite porphyry crowded with fragments of Upper Cretaceous sediments, chiefly Dakota quartzite; rocks strongly sericitzed.

Ore and sulfide minerals.—Chiefly sphalerite and bold but some pyrite, chalcopyrite, galena, and bismuthinite.

Gangue minerals.—Chiefly country rock but some quartz.

Ore shoots.—Ore occurs as irregular seams and masses scattered through rock. Oxidized near surface.

Tenor.—Ore much richer in oxidized zone than below.

SALLY BARBER AND LITTLE SALLY BARBER

Development.—Sally Barber shaft 365 feet deep and Little Sally Barber shaft 300 feet deep; 3 levels from each shaft.

Veins.—Sheeted zone. Strike, N. 54° E.; dip, 80° NW.; width, 9 feet.

Wall rock.—Monzonite porphyry.

Ore and sulfide minerals.—Chiefly sphalerite, cerussite, and pyrite but some galena and smithsonite.

Gangue minerals.—Porphyry and some siderite.

Ore shoots.—Ore occurs as bunches and stringers and as metasomatic replacement in crushed porphyry. No ore within 200 feet of surface. Cerussite ore between depths of 200 and 240 feet. Below 240 feet, cerussite ore changed to sphalerite-pyrite ore. Oxidation of pyrite to depth of 250 feet.

MONTEZUMA DISTRICT

LOCATION AND EXTENT

Strictly speaking, the Montezuma mining district includes only the mines in the valley of the Snake River, close to the town of Montezuma, but the closely related Swan River district on Wise Mountain, the Geneva Creek district at the head of Geneva Gulch, and the Hall Valley district at the head of Hall Valley Gulch are all discussed under the general heading of the Montezuma district (pl. 4). The geology and ore deposits of the Montezuma quadrangle have been discussed by Lovering [46] and by Patton.[47] As used in the present report the term "Montezuma district" applies to the part of the mineral belt that lies between the Breckenridge district, 5 miles southwest of Montezuma, and the West Argentine district, about 4 miles to the northeast. The major part of the district is on the western slope of the Front Range, in the Snake River drainage basin, but the veins near the headwaters of Hall Valley and Geneva Gulch lie just southeast of the Continental Divide. The region is very rugged, and the relief between the valley floors and the adjacent mountain ridges is 2,500 to 4,000 feet. The district is well supplied with timber and water, but the mines on the headwaters of the major streams have only a short season during which snow does not impede operations.

[46] Lovering, T. S., Geology and ore deposits of the Montezuma quadrangle, Colo.: U. S. Geol. Survey Prof. Paper 178, 1935.

[47] Patton, H. C., The Montezuma mining district, Colo.: Colorado Geol. Survey 1st Ann. Rept., 1908.

The nearest railroad shipping point for the mines on the western slope of the district is at Leadville, 34 miles southwest of Dillon. Ore mined in Hall Valley and Geneva Gulch must be moved by truck a distance of 75 miles to Denver or 100 miles to Leadville, but the roads are excellent, except for a few miles near the mines. A paved highway connects Dillon and Denver by way of Loveland Pass, and the branch road from it to Montezuma is well maintained and has no steep grades.

Most of the ore mined in the district has been valuable for its silver-lead content, but both zinc and gold have contributed substantially to the output. (See the following table.)

HISTORY

The first silver lode discovered in Colorado was found in 1864 on Glacier Mountain, about a mile south of Montezuma, by a prospector named Coley. The announcement of his discovery led to the immediate prospecting of the region between Montezuma and Silver Plume and resulted in the discovery of silver, not only in the Montezuma district, but in the Argentine and Silver Plume-Georgetown districts as well. In spite of the relative inaccessibility of the Montezuma district, the Saints John and several other veins were discovered in the next few years. A toll road was soon built along the Snake River to Webster Pass, down Handcart Gulch to Hall Valley, and thence to the North Fork of the South Platte River, and for many years this was the chief stage route from Denver to the Montezuma district. Toll roads were built from Georgetown to Montezuma by way of Argentine Pass and Loveland Pass, and about 1883 completion of a narrow gauge railroad to Dillon greatly simplified the problem of transportation. Since that time most of the freighting has been on the valley road between Dillon and Montezuma. The railroad was abandoned in 1938, and all freight now moves into and out of the district by truck.

Representative shipments of ore from the Montezuma district [1]

Mine	Year	Ore (tons)	Concentrates (tons)	Gold (ounces)	Silver (ounces)	Lead (pounds)	Copper (pounds)	Zinc (pounds)
Bell California	1886	155	----------	----------	3,875	139,000	----------	----------
	1926	760	----------	10.06	12,640	439,957	3,312	441,668
Bullion	1926	30	----------	.70	749	1,393	3,996	----------
Fisherman	1906	27	----------	1.11	1,012	34,944	14,202	----------
Ida Belle	1922	29	----------	.70	385	13,823	----------	6,565
	1928	28	----------	4.40	366	19,069	47	----------
Missouri	1923	73	----------	54.81	9,176	3,056	5,979	906
	1928	27	----------	2.42	912	14,611	2,620	2,917
New York-Alladins Lamp	1926	25	----------	.86	115	----------	9,164	6,839
Revenue	1881	43	----------	54.02	12,055	----------	13,345	----------
	1911	2	----------	.08	328	569	98	----------
Saints John	1887	94	----------	----------	3,354	23,174	----------	----------
	1914	181	----------	.99	6,842	110,234	327	----------
	1928	13	----------	.30	411	11,694	----------	----------
Silver Wave	1912	291	----------	19.66	8,714	91,672	10,074	----------
	1917	28	----------	1.38	520	21,945	----------	----------
	1917	----------	4	.25	130	3,511	74	----------
	1917	----------	5	.06	148	479	212	3,734
Whale	1916	28	----------	9.09	1,040	2,988	1,021	----------
Winning Card	1887	1	----------	----------	1,915	----------	761	----------

[1] Lovering, T. S., Geology and ore deposits of the Montezuma quadrangle, Colo.: U. S. Geol. Survey Prof. Paper 178, 1935.

Most of the productive mines on Glacier Mountain were discovered before 1870 and were actively developed during the next decade. The baritic lead-silver ores of Hall Valley and Geneva Gulch were discovered about 1871 and were acquired by a British syndicate, which built three blast furnaces, a reverberatory furnace, and a wet concentrator to dress the ore before smelting it. This syndicate was unable to separate the barite from the sulfides, and the whole enterprise was abandoned. Since that time many unsuccessful attempts have been made to treat the baritic ores of Glacier Mountain and the Hall Valley and Geneva districts. The flotation mill, built in 1917 at the head of Hall Valley, was one of the first ore-dressing plants to treat this refractory ore successfully. The greatest activity in the district probably took place between 1881 and 1888, when the mines of Glacier Mountain, Teller Mountain, Revenue Mountain, Collier Mountain, and Santa Fe Mountain were being actively explored. The amount of ore mined was not great, however, and since that time mining has fluctuated greatly from year to year.

GENERAL GEOLOGY

The most outstanding geologic feature of the Montezuma district is the large porphyritic quartz monzonite stock formed during the Laramide revolution, just north of the town. It is nearly surrounded by pre-Cambrian rocks, but at its western end it has invaded and baked Cretaceous shale, which underlies the upwarped plane of the Williams Range thrust fault (pl. 2 and fig. 46). Smaller and finer-grained porphyritic bodies are abundant in the region south of the large stock. Porphyritic

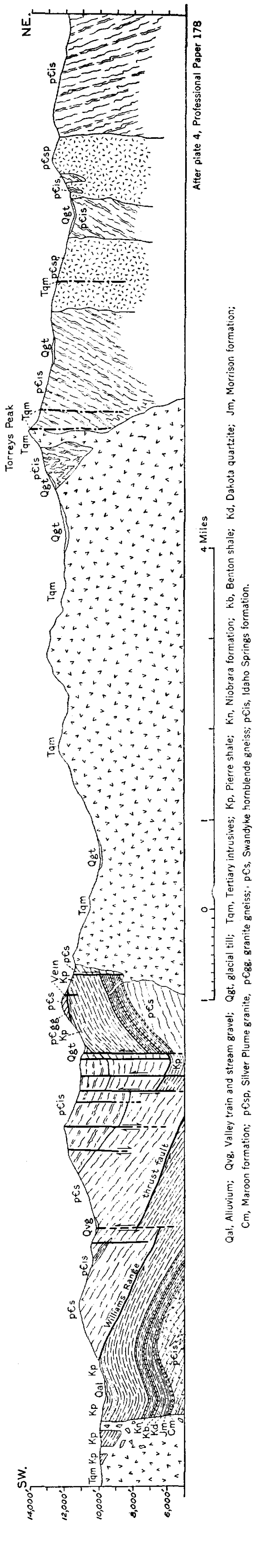

FIGURE 46.—Geologic structure section extending N. 57° E. through Torreys Peak. The Williams Range fault is here represented as an underthrust.

rocks similar to those of the Montezuma district occur in the Cretaceous shales in the adjoining Breckenridge district.

Pre-Cambrian rocks.—The Idaho Springs formation covers most of the eastern half of the district outside of the quartz monzonite stock and is also present in the western part of the Swan River area. Quartz-biotite-sillimanite schist and gneiss are the most common rocks, though quartz gneiss, quartz schist, and garnetiferous schists are locally abundant. The quartz schists are found chiefly at the top of the Idaho Springs formation in a narrow belt extending south-southeast from Montezuma; they are bordered on the west by the Swandyke hornblende gneiss. In places granite intrusions have converted the schist to an injection gneiss, and the formation everywhere is intensely metamorphosed. Isoclinal folds within the schist are common. The regional structure, though modified near granite masses, has a north to northeast trend.

The Swandyke hornblende gneiss occupies most of the western half of the district. It is probably a much metamorphosed dioritic or andesitic rock that originally formed sills or intercalated lava flows in the upper part of the Idaho Springs formation. Like the latter, the Swandyke hornblende gneiss has been changed to injection gneiss in many localities by the widespread injection of pegmatite and aplite.

A few masses of granite gneiss, the aplitic facies of the Boulder Creek granite, occur in the western half of the syncline of Swandyke hornblende gneiss south of the Montezuma stock. The small bodies of granite gneiss are lenticular and sill-like, but large bodies show an irregular contact with the older schist and gneiss. In some places the granite gneiss forms sills directly related to zones of injection gneiss in the earlier schist.

Small stocks of Silver Plume granite occur on Landslide Peak, a few miles southeast of Montezuma, and in the region northeast of this peak in the headwaters of Geneva Gulch. This granite is a typical, medium-grained pinkish Silver Plume granite, having well-oriented tabular feldspars and unoriented biotite. A much coarser variety of Silver Plume granite occurs in small masses on Bear Mountain west of Montezuma and on the north slope of Keystone Mountain, just west of the fenster (window) of Cretaceous shale exposed in Jones Gulch. Pegmatites and aplites related to the Silver Plume granite, Pikes Peak granite, and Boulder Creek granite are abundant throughout the area and occur chiefly as short dikes and small irregular masses in the metamorphic rocks. Throughout most of the district the mineral composition of the late pre-Cambrian rocks is extremely simple, as only quartz, biotite, muscovite, orthoclase, and microcline are present. The pegmatites of the Geneva Gulch area, however, which are more closely related to the large batholith of Pikes Peak granite than to the bodies of Silver Plume, contain less common minerals in many localities. Magnetite, sillimanite, garnet, and tourmaline are conspicuous in the pegmatites of this part of the district.

Cretaceous sedimentary rocks.—Baked Cretaceous shales are exposed in a fenster at the western end of the Montezuma stock, about 3 miles west of Montezuma. Only the Pierre shale is exposed at the surface there, but 4 miles farther west a good section of the Pierre shale and underlying rock is exposed along the Snake River. As shown on plate 2 and figure 46, the Pennsylvanian (?) and Permian red beds of the Maroon formation, the Jurassic Morrison formation, and the Upper Cretaceous Dakota quartzite, Benton shale, Niobrara formation, and Pierre shale are present just west of Keystone. Regional studies, however, indicate that the Maroon and Morrison formations are overlapped by the Dakota quartzite in the vicinity of Keystone. The Dakota quartzite thins rapidly eastward, and as a conglomerate at the base of the Benton shale a mile east of Dillon contains fragments of Dakota quartzite and pre-Cambrian rocks it is possible that the Dakota quartzite itself is missing a few miles farther east, although it is represented in figure 46. The thickness and general character of the sedimentary rocks are shown on plate 6.

Laramide intrusives.—The earliest igneous rocks of the Laramide revolution in the district are the gabbro and augite diorite porphyry of group 2 (pl. 7 and figs. 10, *E*, and 12). These rocks occur in many places in the form of small irregular masses or dikes and unlike the later intrusive masses are not limited to the mineral belt but are distributed irregularly throughout the region to the north and south.

Monzonite and diorite porphyries (fig. 10, *F*) of group 4 are most numerous in the southwestern part of the district in the Swan River area. The rocks of this group are not strikingly porphyritic and commonly range from porphyritic hornblende diorite to porphyritic hornblende augite diorite and monzonite. Except where they occur in proximity to veins, the rocks of this group are very fresh and differ notably in this respect from the granite porphyry of the mineral belt.

The intermediate quartz monzonite porphyries of group 5 are not abundant in the Montezuma district and are found chiefly in the southwestern part. The porphyritic quartz monzonite (fig. 13, *B*) of group 6, correlated with the Lincoln porphyry of the Leadville district, has many times the volume of all the other post-Cambrian rocks in the district. The stock north of Montezuma, which is composed of this rock, has a surface area of 16¼ square miles, and many dikes and small stocks of this same rock occur in the mineral belt to the south and southeast of the major stock. (See pl. 2.)

Sodic quartz monzonite porphyry of group 6 is common in the mineral belt northeast of Montezuma but rare to the southwest. It forms short dikes, none of which in the district is more than a few hundred yards long. They are less abundant near Montezuma than in the Argentine district to the northeast. Like the sodic quartz monzonite porphyries, the related granite and rhyolite porphyries (fig. 13, *C*) of group 7 are found only in the northeastern part of the Montezuma district and are less abundant here than in the region farther northeast. The rocks of group 7 in general are much more altered than the earlier porphyries. This condition implies intense hydrothermal action closely following their intrusion, and it is believed that their intrusion preceded ore deposits by only a short interval. Rocks of group 8 have not been definitely identified in the district, but the sodic rocks at the head of Geneva Gulch approach the more mafic rocks of group 8 in composition and appearance.

The Montezuma stock exerted a feeble contact metamorphism on the pre-Cambrian schists and gneisses, which are slightly pyritized for a distance of 50 to 200 feet from the contact. Metamorphism at the western end however, is much more intense, and Cretaceous shales have been converted into a dense hornfels as much as a mile horizontally from the stock, though the vertical distance to the underlying stock is probably less. Finely disseminated pyrite and graphite are abundant in the hornfels and in some places it is strongly silicified and contains garnet. Numerous assays of the silicified hornfels on the north side of the Snake River, west of the stock, show that gold in minute quantities is widely disseminated through it. The gold content of assayed samples ranged from 0.01 to 0.05 ounce to the ton. No ores of contact-metamorphic origin however, are known in the district.

STRUCTURE

In the southwestern part of the Montezuma district the schists of the Idaho Springs formation dip 45°–70° NE. under the Swandyke hornblende gneiss, which occupies a northwestward-trending syncline about 5 miles wide. Several minor folds occur on the sides of the major syncline, and complex crenulations of small magnitude may be found anywhere. The eastern edge of the Swandyke hornblende gneiss is nearly vertical, and except at the head of Geneva Gulch the foliation of the Idaho Springs formation dips steeply throughout the district. The gentler dip at the head of West Geneva Creek is due to a westward-plunging anticline; dips of 20° to 40° are common in this locality (pl. 2).

During the Laramide orogeny the metamorphic rocks were greatly broken by faulting and by the intrusion of the porphyry stocks and dikes. The Williams Range thrust fault, which borders the Montezuma district on the southwest and separates the pre-Cambrian terrain from the Cretaceous rocks of the Breckenridge district, extends more than 50 miles to the northwest (pl. 1). Near the Swan River area the thrust fault passes into an overturned fold, which is sliced by minor thrusts but which can be followed south through Georgia Pass into South Park (pl. 2). At Keystone the fault dips about 35° E., and the overlying pre-Cambrian rocks are underlain by approximately 4,000 feet of sedimentary rocks. The horizontal component of movement of the thrust fault in this area is more than 4 miles. Three miles east of Keystone, at the western edge of the Montezuma stock, the fault plane is domed and exposed in a "window" along the Snake River and Jones Gulch. In this area the primary structure of the stock shows that it was intruded at a low angle from the southwest, and it is therefore inferred that the doming of the thrust plane in this locality was probably due in part at least to the intrusive thrust of the porphyry magma. Regional studies suggest that the thrust fault is properly classed as an underthrust and not as an overthrust. (See p. 59.)

As shown on plate 2, several strong northwesterly faults occur in the region south of the Montezuma stock. They are poorly mineralized and are earlier than the much less persistent northeasterly fractures. Most of the ore found in the district, however, has come from the northeasterly veins that occur close to the intersections of the north-northwesterly Hall Valley fault. From Glacier Mountain to the Argentine district most of the ore has been found in a narrow belt 1 to 2 miles wide along the southeastern border of the quartz monzonite stock. It is possible that the lack of ore in the region in line with this area to the southwest is due in part to the presence of underthrust impervious Cretaceous shales. Little or no ore has been found north of the stock, and this region seems much less fractured than the area to the south. A few easterly veins in the thrust plate immediately overlying the baked Cretaceous shales contain ore but are productive for only short distances above the breccia in the thrust fault itself. The Montezuma stock is relatively unfractured, but a few small high-grade silver veins have been found in its north-central part and a moderate number of short lead-zinc-silver veins in its southern part east of Montezuma.

In the premineral faults of the district along which the directions of movement could be ascertained the upthrown wall was consistently on the north, and the direction of movement was moderately steep. This movement is probably due to step-faulting related to the formation of an easterly anticline, associated with the intrusion of the Montezuma stock. The veins found in the thrust plate close to the underlying shale strike nearly east, and along them the north walls have moved almost horizontally to the east. Postmineral faults are uncommon, except on Glacier Mountain just south of Montezuma. Most of those observed are normal faults striking north and dipping east, and the dip slip along some of them may amount to as much as 350 feet.

The dikes in the Montezuma district are generally less than 1,000 feet long, and many of them are only a few rods long. Nearly all the dikes strike from east to northeast, but northwesterly dikes are not uncommon in the southwestern part of the district. Most of the intrusives are steep; but at the head of West Geneva Creek sill-like offshoots from the irregular monzonite porphyry mass on Revenue Mountain lie between gently dipping schist layers not far from the crest of the eastward-trending pre-Cambrian anticline. In some places porphyry that is not exposed at the surface is cut underground, and some dikes that die out along the strike are succeeded by small masses of porphyry in line with them, probably upward projections from a continuous mass at depth. It is probable that dikes are more abundant at depth than at the surface.

ORE DEPOSITS

The ore deposits of the Montezuma district are mesothermal veins containing gold and silver, sulfides of lead, silver, zinc, arsenic, antimony, copper, and bismuth, and their supergene alteration products. Within the northern and central parts of the stock high-grade silver veins have been found, such as the Winning Card and American Eagle, but the ore shoots discovered have been small and narrow. Thus far no large output has come from deposits of this type. In the south-central part of the stock, intersecting but nonpersistent fractures contain sphalerite and galena with little gangue, though locally silver is an important constituent. Ores composed of barite and gray copper are abundant in a southeasterly branch of the mineral belt extending from Glacier Mountain to Hall Valley. These ores contain galena, sphalerite, and pyrite, and rich silver minerals are commonly associated with them. In both the Hall Valley and Geneva Gulch areas veins containing bismuth and silver are common and are associated with chalcopyrite in a quartz gangue. East of Montezuma and southeast of the Montezuma stock, in the Silver Wave-Pennsylvania vein system and the nearby parallel veins, substantial quantities of both gold and silver are present in the chalcopyrite-sphalerite-galena ores. Quartz and ankerite are the chief gangue minerals and barite is scarce. Throughout the district, however, the gangue minerals commonly make up a relatively small part of the vein matter in ore shoots. The veins in the southern part of the Montezuma stock consist chiefly of sphalerite and pyrite and contain only moderate amounts of galena and quartz-ankerite gangue.

In many of the ores gold and silver are associated with chalcopyrite, and silver is commonly associated with light-colored tetrahedrite and tennantite. The ores containing chalcopyrite but not gray copper commonly have a gangue of quartz or ankerite, but veins containing gray copper usually have a gangue in which barite is the chief mineral. Most of the abundant silver minerals, such as miargyrite, pyrargyrite, stromeyerite, and native silver, are associated with manganiferous ankerite or rhodochrosite gangue. The bismuth-silver minerals, emplectite and schapbachite, are associated with quartz, pyrite, and chalcopyrite and are probably later than the galena-sphalerite ores. The veins of massive pyrite, or pyrite and quartz, contain very little gold in the primary ores, but close to the surface they have a high gold content due to secondary enrichment.

Galena is usually more abundant in the upper part of a vein than in the lower part. The copper content generally increases slightly with depth, and chalcopyrite is relatively more abundant than gray copper in lower levels. The silver content in the veins shows little relation to depth from the surface. In Glacier Mountain the ores are generally richer in silver in the deeper parts of the ore shoots than in the upper parts. Most of the silver is primary, but secondary or supergene silver minerals have enriched the uppermost parts of veins that crop out on high erosion surfaces. In the veins that crop out on the Flattop peneplain in the Swan River area, rich free gold was found only to a depth of 25 feet, where the ore changed abruptly to low-grade pyrite containing 0.1 to 0.2 ounce of gold per ton.

The vertical range of ore deposition in the district is at least 2,000 feet and probably more than 3,000 feet. Hard strong rocks such as pegmatite, granite, porphyry, and gneiss are the common walls of the persistent ore shoots. The relation of ore to wall rock is well illustrated in the Ida Belle mine (fig. 47), where the vein opens out to a width of several feet in the gneiss and silicified breccia of the Williams Range thrust fault and pinches to a narrow seam of pyrite in the underlying Cretaceous shale. Ore bodies occurring between schist walls are generally in those parts of the veins that cut across the strike and dip of the enclosing schist, a relation well illustrated in the Silver Wave mine. (See fig. 48.) Where the veins lie in schist and are parallel to the structure of the metamorphic rocks valuable ore shoots are rare. As in other parts of the Front Range, most of the ore shoots occur near the junctions of branching veins, at the intersections of veins with barren premineral faults, and where marked changes in the dip or strike of the vein favored the creation of open spaces during the movement of the irregular walls.

The intersection of two mineralized veins nearly at right angles does not seem especially favorable for ore. The ore shoots in the New York mine (fig. 49), are in general much poorer at the intersections of cross veins than between them. The intersection of the No. 5 and No. 7 veins in the Saints John mine showed less ore than either of the veins a short distance away, and the richest ore shoot was apparently localized in the No. 5 vein along its junction with a strong barren fault. (See fig. 50.) The ore in the Missouri mine occurs chiefly in northeasterly veins and is found at or close to their junctions with a strong barren premineral north-northwesterly fault. In the Silver King mine the best ore shoot was found at the intersection of the main vein and a strong barren cross fault nearly at right angles to it, which probably acted as an impermeable barrier to the solutions advancing toward it along the main vein. The junctions of branch veins or "splits" that make acute angles with the main vein localized many ore shoots. This type of control is shown by the ore shoots in the Silver Wing adit on the Bell vein, which are closely related to minor branch fractures, swelling from an inch in width on one side of the spur fracture to 18 inches or more on the other side.

Reserves of high-grade ore are probably small, but many of the veins may yield profitable amounts of ore when mined on a small scale. Reserves of baritic lead-zinc ore are larger than those of any other class and can now be concentrated in flotation mills. The presence of ore in the Ida Belle (fig. 47), Rainbow, and Copenhagen mines indicates the possibilities of finding ore bodies in the brecciated zone of the Williams Range thrust fault where it is crossed by mineralized fissures. Exploration of possible intersections between northeasterly veins and some of the strong northwesterly premineral faults, such as the Jones Gulch fault, has been neglected.

CARRIE MINE

The Carrie mine is on Wise Mountain between the north and middle forks of Swan River, at the head of Garibaldi Gulch, 5 miles south-southwest of Montezuma. It supplied a moderate tonnage of gold ore prior to 1900, but little ore has been produced since then. The mine workings include an adit 900 feet long, a 90-foot shaft, and 3,000 feet of drifts. A mill and the portal of the adit are near timber line at an altitude of 11,750 feet. The Carrie, in common with several other veins at the top of Wise Mountain, contained rich gold ore in a shallow oxidized zone close to the surface, but profitable mining ceased at a depth of about 25 feet. Heavy pyrite, found at greater depth, contains almost no lead, copper, or zinc, and the value of the gold and silver, as recorded in several assays, ranges from $2 to $4 a ton. The adit was driven before the secondary origin of the gold ore at the surface was recognized; after cross-cutting many strong low-grade pyritic veins and drifting on some of them to points directly below the

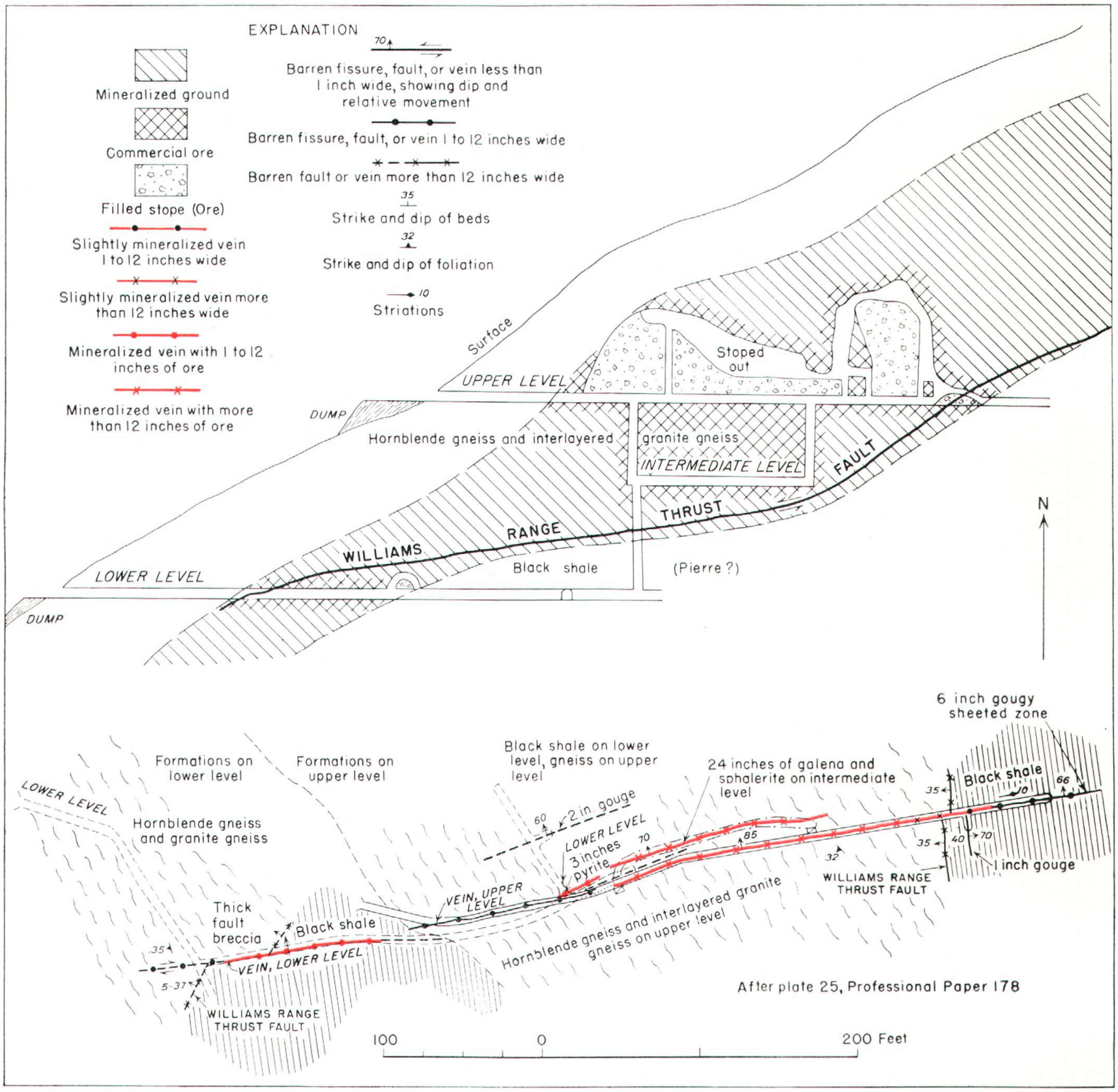

FIGURE 47.—Plan and section of the Ida Belle mine, showing localization of ore in thrust-fault breccia above shale footwall.

rich surface ore, work was discontinued in 1902, and almost no work has been done since then.

The Carrie and other veins on Wise Mountain strike a little north of east and are almost vertical. The country rock is granite gneiss and quartz monzonite porphyry, both of which are impregnated with pyrite. The top of Wise Mountain is at about the general level of the Eocene Flattop peneplain, and the free gold found in the shallow oxidized zone at the top of this mountain is probably the result of enrichment during Tertiary time. Similar concentration of gold is not found in the pyritic lodes exposed on the glaciated flanks of the mountain.

IDA BELLE MINE

The Ida Belle vein is on the west slope of Independence Mountain, 3 miles west-northwest of Montezuma, at an altitude of 11,450 feet. It was discovered in 1880 and developed by three adits in the next few years. Its output was steady but small during most of the next decade, but it lay idle between 1889 and 1916, and since then it has been intermittently productive. The known output from 1888 to 1930 is 143 tons containing a total of 25.89 ounces of gold, 2,016 ounces of silver, and 86,707 pounds of lead. Two adits, both of which were 440 feet long in 1928, are shown in figure 47. The upper adit,

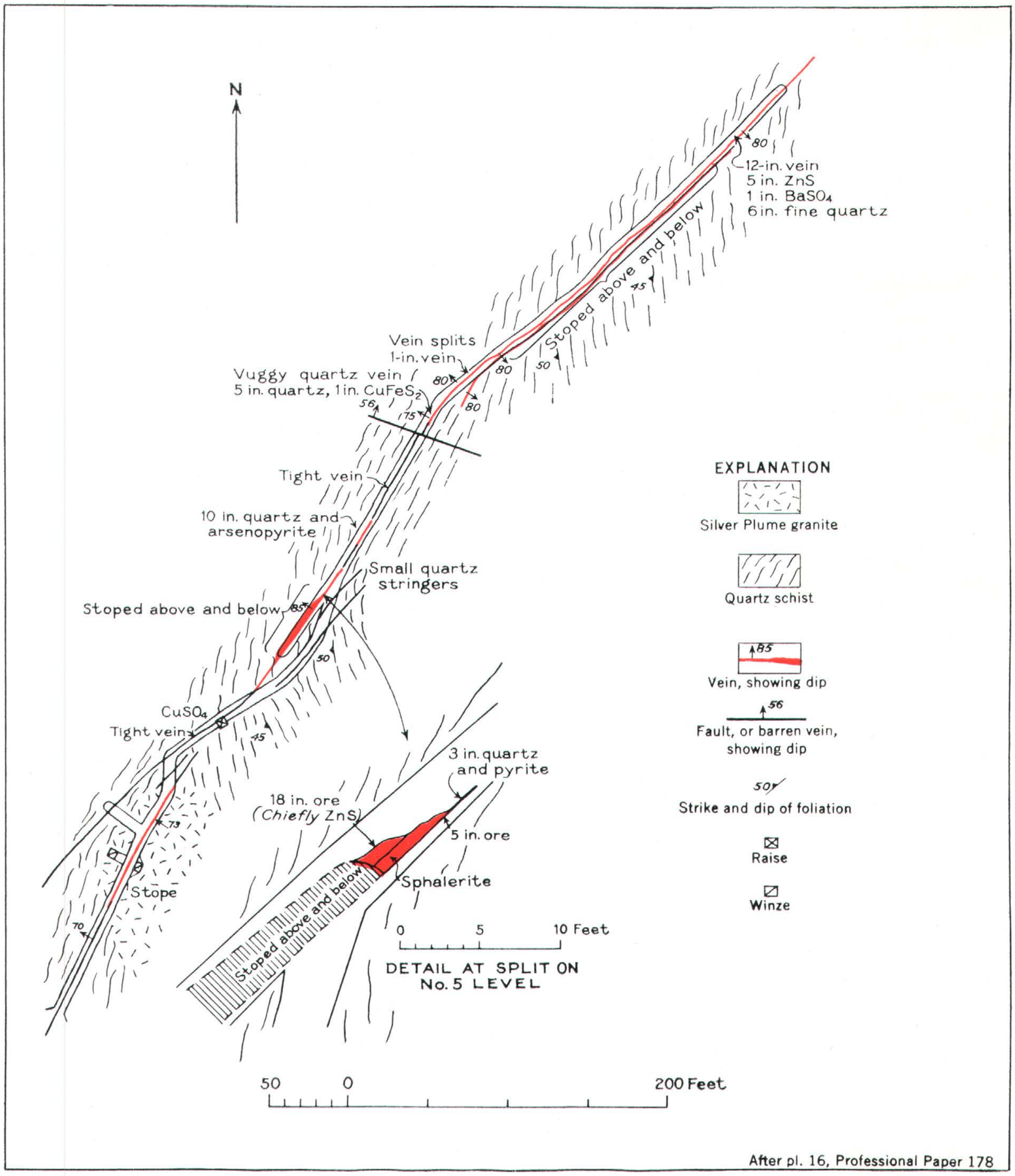

FIGURE 48.—Plan of level 5 of the Silver Wave mine near Montezuma, showing localization of ore where the vein breaks across the foliation of the schist walls.

165 feet from its portal, is connected with the lower one by a winze 125 feet deep. Most of the upper adit follows the Ida Belle vein, which strikes about N. 80° E. and dips 65°–90° N. The lower adit in part follows the vein and in part follows a barren fissure a few feet south of the main vein.

The gently dipping Williams Range thrust fault, which separates pre-Cambrian gneiss above from Cretaceous shale below, is cut by both adits (fig. 47). The fault breccia is 40 to 70 feet thick and dips 5°–40° W., averaging about 16°. The Ida Belle fissure offsets the thrust fault, and the contact of the shale with the overlying brecciated gneiss is 5 to 40 feet farther east on the north side of the vein than on the south side, the north side moving down and to the east at an angle of about 10°. Within the shale the Ida Belle fissure is a gougy sheeted zone 2 to 6 inches thick; within the breccia of the Williams Range thrust fault it is a crushed,

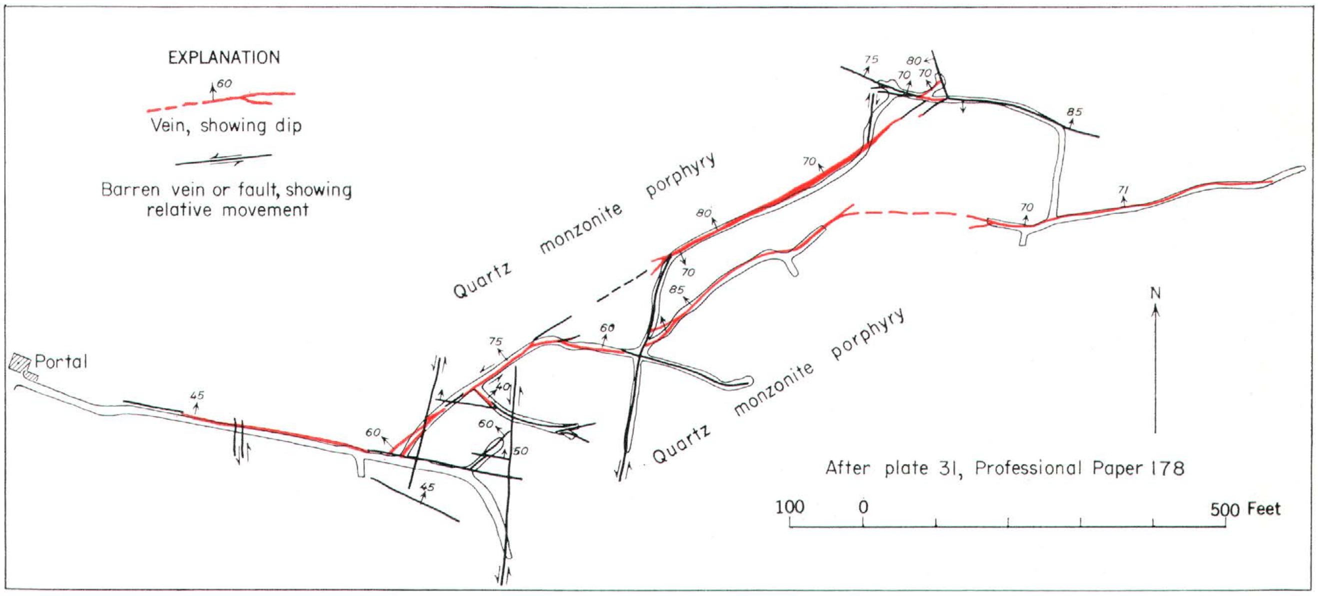

FIGURE 49.—Plan of the New York tunnel, showing unfavorable effect of gougy intersections on localization of ore shoots.

brecciated zone 24 to 60 inches thick, and in the overlying gneiss the fissure zone is 12 to 45 inches thick.

Mineralization was strongest in the thrust fault breccia and weakest in the shale and was better close to the contact of the shale than 50 feet above it. Both galena and zinc blende are present, and there is little waste in the ore close to the contact, but in the upper part of the breccia zone the ore consists of many seams of ore separated by altered country rock in a zone 2 to 4 feet thick. Most of the mineralized ground within the shale walls is pyritic; little galena or sphalerite was found. It is probable that ore shoots, if present in other similar veins, will be found close to the contact of the shale with the overlying breccia and will pitch from 15° to 20° W.

MISSOURI MINE

The Missouri mine is near the head of Hall Valley, 4 miles south of Montezuma, at an altitude of about 12,100 feet. It is reached by an automobile road from Webster, 9 miles to the southeast. The mine was discovered in the late seventies and was one of the chief producers during the period when the Hall Valley and Geneva Gulch mines were being actively exploited for the Hall-

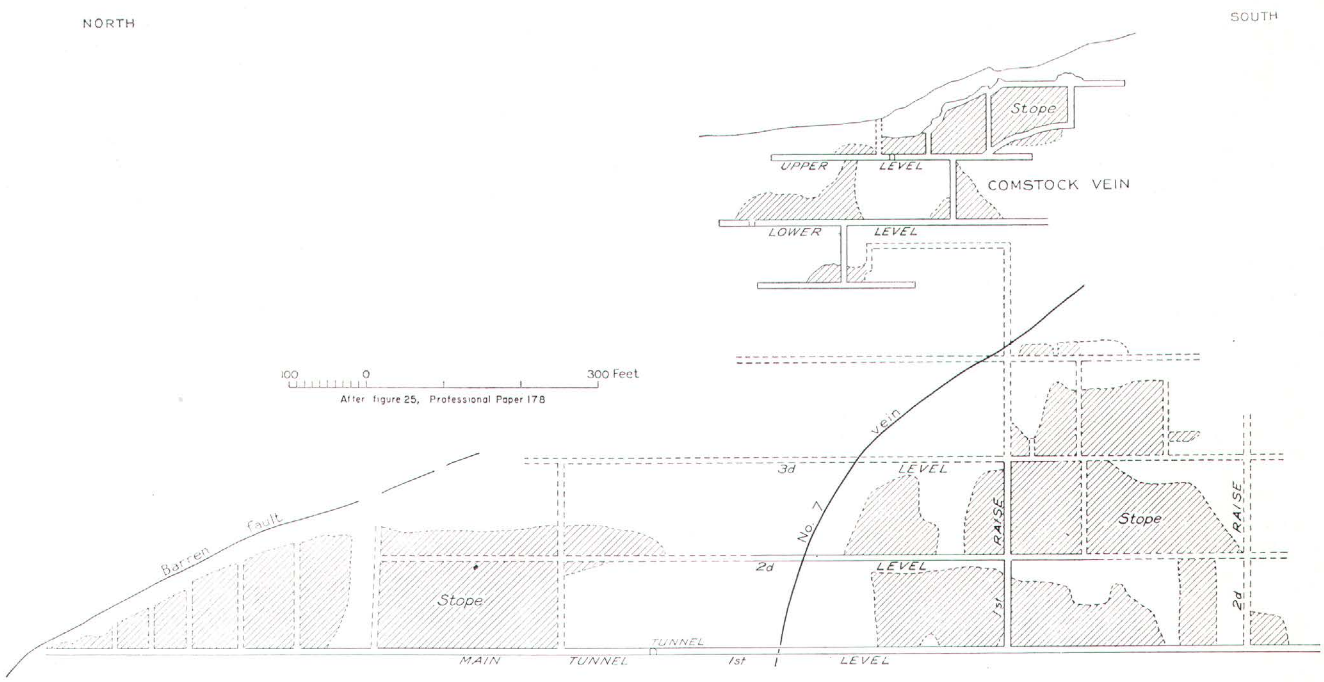

FIGURE 50.—Section showing stope on the No. 5 vein, Saints John mine, Montezuma district. Shows relation of ore shoots to intersection of No. 7 vein and a barren fault.

town smelter. The ore mined during the seventies and the eighties ranged from 6 inches to 3 feet in thickness and contained silver, gray copper, bismuth, chalcopyrite, pyrite, and some gold. The early output of the vein is unknown, but the gross amount of metal recovered from the ores shipped in 1920–28 was 296 tons containing a total of 198.67 ounces of gold, 24,152 ounces of silver, 26,203 pounds of lead, 28,948 pounds of copper, and 4,927 pounds of zinc.

The country rock of the veins comprises injection and hornblende gneiss of the Swandyke hornblende gneiss. The foliation strikes N. 25° W. and dips 65°–85° E. It is cut by several strong bedding-plane faults later than the vein fissures though probably earlier than the vein filling. The distribution of the ore in the Missouri vein and in other veins of the region suggests that steep persistent north-northwesterly foliation-plane faults acted as regional guides to the rising solutions that mineralized northeasterly spur and cross fractures intersected by the northwesterly faults. From various data it seems probable that the east wall of the fault moved downward and southeastward past the west wall at an angle of 45°–50°. Little ore has been found in the veins on the west side of the fault on the main adit level, and most of the output of the mine has come from the Missouri vein just east of the northwesterly fault. Small masses of ore have been found in several other veins, but all the ore has occurred close to the northwesterly fault.

The Missouri vein contains lead and bismuth ores, but the bismuth is generally separate from the galena ore. The vein strikes N. 50° E. and dips about 45° NW., though locally steeper and flatter dips occur. The lode is a wide sheeted zone, and the ore is chiefly on the footwall. The ore shoots are close to the northwesterly Hall Valley fault, whose gouge is highly oxidized and brilliantly colored by the yellow oxide of bismuth at the intersection with the vein. To the east of the fault the ore grades rapidly into sulfides, and a short distance away there is little evidence of oxidation, even at the surface. The sulfide ore occurs in two well-defined seams, known as the high-grade or footwall streak and the low-grade or hanging-wall streak, separated from each other by 1 to 40 inches of gouge and highly altered sheeted rock and vein matter. The thickness of the footwall seam ranges from that of a knife blade to 12 inches but is generally half an inch to 5 inches. The low-grade ore is chiefly quartz, pyrite, chalcopyrite, a dark tetrahedrite, and galena. The thickness of the seam ranges from 6 to 36 inches but is usually about 15 inches. Where the high-grade streak is unoxidized the chief minerals are clear fine-grained quartz, "bismuth silver" (cuprobismutite), and bismuthinite, with some chalcopyrite and galena. Chalcopyrite is more abundant on the upper than on the lower levels, and the gray copper is more abundant between levels 4 and 5 than elsewhere in the mine. The ore rich in chalcopyrite contains more gold and silver than the gray-copper and lead ores. The pure galena assays about 18 ounces of silver to the ton and the dark tetrahedrite about 100 ounces of silver to the ton. The high-grade ore commonly contains 5 to 10 percent of bismuth, 1 to 8 ounces of gold, and 100 to 1,200 ounces of silver to the ton. One of the richest pockets of bismuth ore in the mine occurred in a large wrinkle in the Missouri vein, between levels 3 and 4 and 30 feet northeast of the main northwesterly fault. The biggest masses of ore are coincident with a marked flattening of the ore seams, suggesting that the Missouri vein follows a premineral reverse fault.

The ore in the Leftwick vein to the west of the Hall Valley fault is chiefly a galena-gray copper-chalcopyrite ore in a quartz-barite gangue. The thickness of the ore ranged from 3 to 24 inches but was commonly about 6 inches. Some ruby and native silver are reported from the upper levels, and most of the ore was found above the workings on the Missouri vein.

NEW YORK MINE

The New York mine is at the southeast edge of Montezuma at an altitude of about 10,350 feet. Several veins have been cut by the New York tunnel, the largest of which are the New York and the Alladins Lamp (fig. 49). The ore is typical of that in veins that cut the Montezuma stock, but little ore of this type has been shipped. The country rock throughout the mine is quartz monzonite, which is cut by northeasterly and easterly mineralized fissures and by northward-trending barren fractures. Many of the mineralized fissures persist for only a few hundred feet along the strike. The barren fractures are nearly vertical and are later than the mineralized fissures, and displacements along them are small.

The New York vein is the strongest one in the mine and has been followed for about 900 feet. It strikes northeast and dips about 70° NW. In many places it is barren, but for most of its length it contains sphalerite, galena, and pyrite and a quartz-ankerite gangue. The ore seam is 4 to 10 inches thick in most places, but in the main shoot, 1,000 feet from the portal of the tunnel, it is 10 to 36 inches thick for a distance of 300 feet. Channel samples taken at many places averaged about 35 percent in combined lead and zinc. The quantities of lead and zinc are nearly equal in places, but in some samples one metal may be five times as abundant as the other. The ore in the Alladins Lamp vein is 3 to 6 inches thick and is similar to that in the New York. Most of it contains about 10 ounces of silver to the ton, but in some places assays of 20 ounces have been obtained.

The New York is the largest and most continuous body of ore seen in any mine lying within the Montezuma quartz monzonite. The ore shoots do not occur at the junctions of fractures as in some of the other mines; on the contrary, the ore becomes poorer in most places where two fractures intersect. A strong well-mineralized fissure commonly splits and branches at its junction with another vein, and both become nearly barren. The lack of continuity in individual veins and their branching character is illustrated on the mine map, figure 49.

SAINTS JOHN MINE

The Saints John is the oldest producing mine in the Montezuma district and one of the oldest silver mines in Colorado. It is on the west slope of Glacier Mountain, about a mile southwest of Montezuma, and has been mined chiefly through an adit at an altitude of about 10,800 feet. It is accessible from Montezuma by a steep automobile road.

The Comstock lode of the Saints John mine was discovered in 1865 and extensively developed during the next 15 years. The complex barite-zinc-silver ores mined in the early seventies were not satisfactorily smelted by the small furnaces built near the mine, and this type of ore was not successfully handled even after the construction of a flotation mill in the early twenties. Most of the output has been from the high-grade ruby silver ore found on the No. 5 vein in the main tunnel level and from the shipping grade of galena-silver-gray copper ore. Almost no record of the early production of the mine is at hand, but the figures, though incomplete, show that from 1889 to 1930 the mine has produced 3,654 tons of ore from which 4.30 ounces of gold, 80,690 ounces of silver, and 2,448,222 pounds of lead were recovered. Some copper was also produced.

The country rock of the mine is hornblende gneiss and pegmatite of the Swandyke hornblende gneiss, which strikes from north to northeast and dips 50°–90° E. Most of the ore has been obtained from the Comstock vein, commonly known as the No. 5 vein. It strikes northeast and dips steeply northwest and crosses vein 7, which strikes north of east and dips about 55° N. Vein 7 contains much more barite than the Comstock and has been exploited only to a moderate degree because of the failure of the mills to treat the ore satisfactorily.

The Comstock vein has been followed more than 800 feet north of the main crosscut adit and about 1,100 feet southwest of it and has been stoped for much of its length. The northern ore shoot was rich in ruby silver and was almost continuous from the main tunnel to a point 750 feet northeast, where the vein is cut by the strong northward-trending fault. The vein becomes poorer as it turns into the fault zone and is nearly barren for the last 50 feet in which it is exposed. The decrease in mineralization coincides with increase in gouge. Quartz, pyrite, and barite predominate as the fault zone is approached, and galena and sphalerite gradually increase as the vein is followed away from it. The general character of the vein a short distance south of the fault is shown in figure 51. The vein splits a short distance southwest of the main crosscut adit where two overlapping parallel northeasterly fissures about 80 feet apart are connected by northerly bedding-plane fractures. The vein continues southwest on the eastern fissure but is barren near the junction of the northerly and northeasterly fissures (fig. 34). About 120 feet south of the junction ore was found and was stoped almost continuously for 850 feet farther south. The ore was chiefly gray copper and galena with moderate amounts of barite and quartz. Some rhodochrosite was present. In the productive part the vein dips 55°–60° NW., but steeper dips were observed in lean pillars that came down to the level of the drift. Throughout most of the stoped area the vein is reported to have been 6 inches to 2 feet in width.

About 170 feet south of the main tunnel on the lower level, the Comstock vein crosses the No. 7 vein without displacement (fig. 34). The No. 7 vein strikes just north of east and dips 48°–60° N., averaging 55°. It has been stoped east of the junction for 100 feet above the main level. At the top of the stope west of the junction the vein is about 12 inches wide and consists largely of rhodochrosite, with moderate amounts of galena, sphalerite, and quartz and little barite. It becomes barren and tight at the west end of the drift on the main tunnel level and is barren a short distance east of the place where it is cut by the main crosscut tunnel. The length of the ore shoot is about 650 feet. The vein has not been exploited close to the surface, and nothing is known of the character of the ore above the third level.

The strike, dip, and character of the ore of the Comstock vein are almost identical with those of the Tiger vein at its outcrop a few hundred feet to the southeast, and it is believed that the Tiger is a faulted continuation of the Comstock. The intersection of the Tiger vein with the northward-trending fault that cuts off the northern part of a high-grade silver ore shoot on the Comstock would pitch about 50° N. If the Tiger vein is the faulted continuation of the Comstock, the dip slip on the fault would be about 350 feet.

The Comstock vein follows a premineral reverse fault. The maximum width of ore reported on the vein is 4 feet. An interesting feature of the mine is the presence of richer silver ore on the lowest level than on the upper levels. According to available information ore less than 150 feet from the surface consists chiefly of galena with moderate amounts of sphalerite, tetrahedrite, and, rarely, polybasite. The ore coming from the mine when

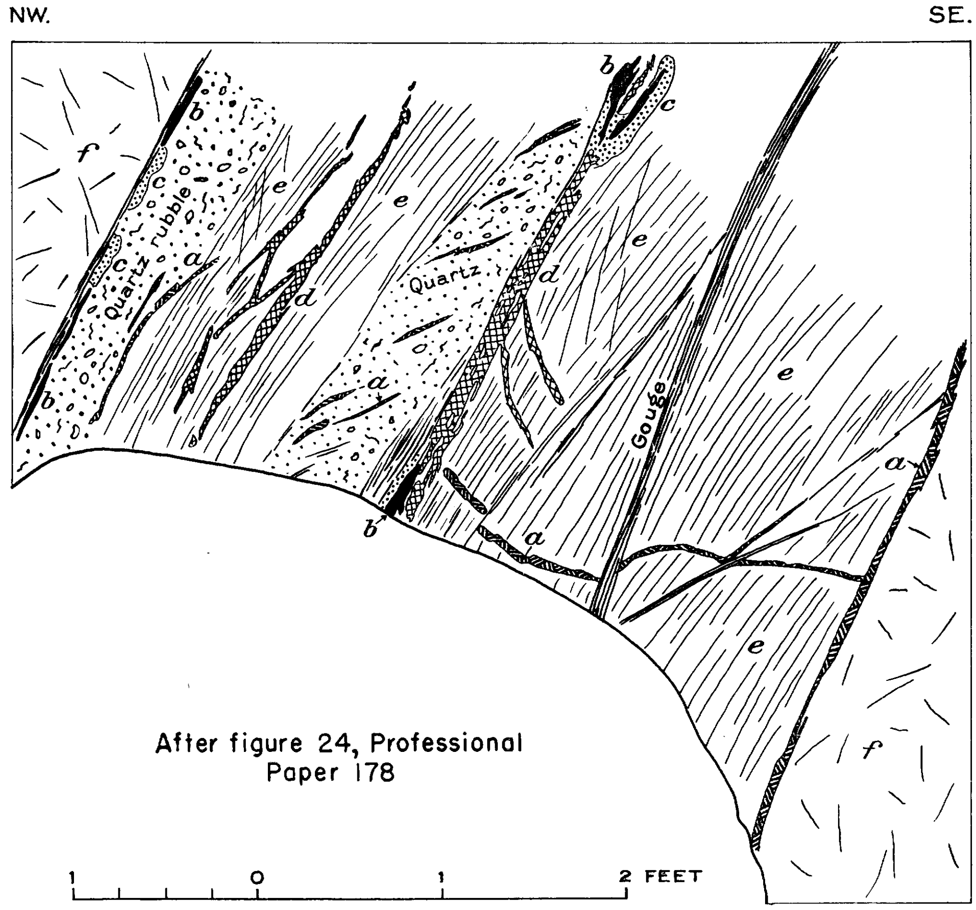

FIGURE 51.—Looking north at No. 5 vein in the Saints John mine. *a*, Pyrite; *b*, galena; *c*, sphalerite; *d*, ankerite; *e*, strongly sheeted altered granite; *f*, slightly fractured gneiss.

the workings had been deepened 75 feet more is reported to have consisted chiefly of galena, though sphalerite, pyrite, and chalocopyrite were abundant, and argentite and brittle silver were not uncommon. The richest ore, however, was found at greater depth and consisted mainly of proustite, polybasite, stephanite, and argentiferous tetrahedrite, with only a small amount of galena and sphalerite, in a rhodochrosite and barite gangue. The rich ore did not continue more than 100 feet above the main tunnel level and showed no signs of oxidation or evidence of enrichment. The top of this ore shoot was probably 600 feet below the surface (fig. 50).

SILVER WAVE MINE

The Silver Wave vein is in a small gulch between Santa Fe Peak and Sullivan Mountain, on the west slope of the Continental Divide, 2 miles southeast of Montezuma. The vein has been traced far to the northeast beyond the Silver Wave workings and is one of the most productive in the Montezuma and Argentine districts. To the northeast it includes the Rainbow, Delaware, Pennsylvania, and Peruvian veins, all of which have been productive. The Silver Wave mine is developed by six adits, between altitudes of 12,987 and 12,657 feet. The lowest or No. 6 adit is connected with the valley of the Snake River by an aerial tramway 1,650 feet long. The Silver Wave vein was discovered in 1882 and actively developed during the next few years, but most of the output of the mine has been made since 1900. Because the shipments of ore were included with those of the Silver King mine for part of the time the exact output of the Silver Wave mine is not known. The total output is probably about 117 ounces of gold, 35,475 ounces of silver, and 537,710 pounds of lead. The copper output since 1910 has been estimated at 27,169 pounds and the zinc output from concentrates since 1913 at 188,550 pounds.

As shown in figure 48, the country rock is largely the quartz schist of the upper part of the Idaho Springs formation, which strikes N. 25° W. to N. 55° E., though in most places it strikes nearly due north. The schist dips west to northwest at 45°–75° and in places is parallel to the vein, which strikes N. 27°–50° E. and dips steeply northwest throughout its length. A small mass of Silver Plume granite is present 130 feet from the No. 5 adit portal, and several dikes of pegmatite also are cut in the mine workings. Several ore shoots have been found in the course of the underground development.

The ore is 6 inches to 2 feet thick in most places and consists chiefly of chalcopyrite, zinc blende, and pyrite, with some galena and a little gangue. In the silicified walls of the main sulfide vein and in the barren spaces between the ore shoots arsenopyrite is common. The Silver Wave vein is typical of the veins that are productive between walls of schist; it is a mineralized sheeted zone whose individual fractures branch, intertwine, or gather together into a single strong fissure. In many parts of the barren stretches the vein is followed with difficulty because of the common occurrence of diverging fracture planes. The ore shoots widen within distances of 5 to 10 feet from narrow seams to commercial bodies 12 to 24 inches wide and pinch as abruptly into lean, unprofitable streaks. The vein is nearly barren on levels 5 and 6 where it has followed the foliation of the wall rock, but ore occurs wherever the vein breaks across the foliation of the quartz gneiss for any appreciable distance. The ore in the upper levels is largely galena and contains moderate amounts of gray copper, but the ore on the lowest levels is chiefly sphalerite and chalcopyrite.

OTHER MINES

Data on other mines of the district are given briefly below. Detailed descriptions have been given by Lovering.[48]

BALTIC AND REVENUE

Development.—Chiefly from Britannic tunnel, 1,080 feet long.

Production.—1880–81: Gold, 114.64 ounces; silver, 19,880 ounces; copper, 34,402 pounds. 1887–91: Gold, 62.89 ounces; silver, 48,616 ounces.

Veins.—Baltic: Strike, northeast; dip, 45°–75° NW., the steep dips being in the upper part; width 8 to 14 inches. Revenue: Strike N. 55° E.; dip, 75° NW.; average width, 6 inches. Both veins nearly parallel to foliation of wall rock.

Wall rock.—Largely injection gneiss and quartz-sillimanite-biotite schist. Strike, northeast; dip, 55° NW. Dikes of monzonite and quartz monzonite porphyry at surface.

Ore and sulfide minerals.—Chiefly chalcopyrite and gray copper but some pyrite, sphalerite, galena, and gold.

Gangue minerals.—Chiefly quartz but some barite.

Tenor.—In 1874 average was $124 per ton in silver. Silver content increases with gray copper. Gold content increases with chalcopyrite. Revenue vein had higher proportion of gray copper and more galena than Baltic vein.

BELL, METEOR, AND WING

Development.—Original discovery 1866. Opened by about 3,000 feet of drifts and crosscuts, 6 adits, and a short sublevel.

Production.—1882–91: Silver, 50,460 ounces; lead, 1,832,709 pounds. 1925–28: Gold, 14.19 ounces; silver, 17,119 ounces; lead, 671,536 pounds. Total: Gold, 14.19 ounces; silver, 67,579 ounces; lead, 2,504,245 pounds.

Veins.—Bell: Strike, N. 30°–70° E., average, N. 40° E.; dip, 40°–80° NW., average 65° NW.; width, 3 to 24 inches, average 4 to 12 inches. Follows premineral reverse fault; offset by several minor faults. Apparently terminated on 4th level by a fault that trends north and dips 70° E. and contains a 3-inch gouge seam.

Wall rock.—Biotite gneiss of Swandyke hornblende gneiss. Strike, N. 25° E.; dip, steeply east near portal of main adit, steeply west in southwest half of workings.

Ore and sulfide minerals.—Chiefly sphalerite, galena, and ruby silver but some pyrite, silver, gray copper, and gold.

Gangue minerals.—Chiefly quartz but some ankerite.

Ore shoots.—Steep dip or strike of N. 30° E. unfavorable; gentle dip or strike of N. 45° E. favorable. Sphalerite in northeast half of mine and galena in southwest half; change lateral and apparently unrelated to depth.

CASHIER-CHAMPION

Development.—Original discovery, in the early seventies. Opened by 4 adits over vertical range of 450 feet.

Production.—Early seventies and late eighties: $90,000 in silver.

Veins.—Cashier: Strike, northeast; dip, steeply northwest; width, 4 feet; ore seams, 2 to 24 inches. Breaks across foliation of wall rock.

Wall rock.—Swandyke hornblende gneiss. Strike, N. 25° W.; dip, 70° W.

Ore and sulfide minerals.—Galena and gray copper.

Gangue minerals.—Chiefly quartz but some barite.

Tenor.—Average, $90 to $200 per ton.

MORGAN

Development.—Three adits, aggregating 1,800 feet.

Production.—1889: Silver, 23 ounces; lead, 1,738 pounds. 1901: Silver, 40 ounces; lead, 5,647 pounds. 1917: Gold, 1.25 ounces; silver, 401 ounces; lead, 14,952 pounds; copper, 662 pounds; zinc, 47,689 pounds. 1919: Gold, 0.10 ounce; silver, 27 ounces; lead, 3,034 pounds.

Veins.—Several veins strike N. 60°–80° E. and dip north. Few inches to 28 inches wide.

Wall rock.—Quartz monzonite.

Ore and sulfide minerals.—Pyrite, sphalerite, and galena.

Gangue minerals.—Quartz and ankerite.

Ore shoots.—Occur chiefly at the intersections of cross veins or at vein branches.

QUAIL

Production.—A few hundred tons.

Veins.—Quail: Strike, N. 40° W.; dip, nearly vertical; width, 3 inches to 3 feet; galena 3 to 16 inches wide.

Ore and sulfide minerals.—Chiefly galena but some pyrite and sphalerite.

Gangue minerals.—Quartz.

WHALE

Development.—Seven adits.

Production.—1877–1930: 836 tons. Silver, 44,108 ounces; lead, 265,404 pounds; gold, 939 ounces; copper, 10,790 pounds. Data are incomplete.

Veins.—Whale: Strike N. 75° E.; dip, 45°–60° N., average, 57° N.; width of ore seams, 1 to 36 inches; width of vein, 5 to 10 feet. Ore seam swells or pinches in short distances.

Wall rock.—Hornblende gneiss. Strike, N. 15° W.; dip, 80° W.; dacite porphyry dikes. Walls strongly sericitized and pyritized.

Ore minerals.—Chiefly chalcopyrite, galena, and gray copper but some malachite, azurite, and chalcanthite.

Gangue minerals.—Chiefly quartz but some barite.

Changes with depth.—Chalcopyrite more abundant at lower levels. Oxidized copper ore near surface.

[48] Lovering, T. S., Geology and ore deposits of the Montezuma quadrangle, Colorado: U. S. Geol. Survey Prof. Paper 178, pp. 68–116, 1935.

Ore shoots.—Localized by same strong northwesterly fault as in Missouri mine. Proportion of gray copper to galena greater in narrow parts of vein.

WINNING CARD

Production.—1882–1930: $35,000.
Vein.—Winning Card. Strike, northwest; dip, vertical; width, 2 to 6 inches.
Ore mineral.—Stromeyerite.
Gangue mineral.—Quartz.

ARGENTINE DISTRICT

The Argentine mining district straddles the Continental Divide between the Montezuma district and the Georgetown-Silver Plume district. It includes the headwaters of Peru Creek, Leavenworth Creek, and Stevens Creek. Peru Creek joins the Snake River just below Montezuma at an altitude of 9,800 feet, and its valley is separated from that of Leavenworth Creek by a mountain whose lowest altitude, at Argentine Pass, is 12,008 feet. The heavily glaciated head of Peru Gulch is known as The Shoe Basin or Horseshoe Basin. It is bordered on the west by Gray's Peak, which has an altitude of 14,276 feet, and is the highest peak in the Front Range. Northeast of Gray's Peak is Stevens Creek, which joins Clear Creek about 3 miles west of Silver Plume. Leavenworth Creek empties into Clear Creek at Georgetown. Wagon roads lead up all three gulches to within a short distance of the Continental Divide, but none of the passes could be traversed by wagons in 1945. Throughout most of the Argentine district snow comes early and lingers until midsummer, greatly increasing the difficulty of mine operation. In spite of the severity of the winters and the shortness of the summer season, many of the mines have had large outputs of gold, silver, lead, and copper ores.

GEOLOGY

The eastern border of the Montezuma quartz monzonite stock is just west of the Argentine district, and quartz monzonite dikes are abundant in the surrounding Idaho Springs formation, which is the predominant rock at the headwaters of both Leavenworth Creek and Peru Creek. Farther north along McClellan Mountain, and on Kelso Mountain, an irregular mass of Silver Plume granite extends northward to the Silver Plume-Georgetown district (pl. 2).

Pre-Cambrian rocks.—In the southern part of Horseshoe Basin the Idaho Springs formation includes a member containing a large amount of quartzose gneiss, and the same member occurs to the north and to the east of Argentine Pass. In most places, however, the Idaho Springs formation consists of coarse-grained biotite-sillimanite schist interlayered with much injection gneiss. The dip of the schist is steep in most places, and the regional strike is from north to northeast. Several isoclinal folds can be recognized in the steep ridges east of Gray's Peak, and it is probable that similar folds exist in other localities where the exposures are inadequate to permit detailed observation.

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Lenticular masses of gneissic diorite and quartz diorite occur near Argentine Pass and are probably related to the Boulder Creek granite batholith a few miles to the east. The central parts of the quartz diorite intrusive are nearly massive but are faintly orthogneissic. The edges show a prominent banded structure, with some evidence of granulation. The quartz diorite strongly resembles coarse-grained quartz gabbro and, as some augite is invariably present, those parts of the intrusive that are poor in quartz might properly be called gabbro. A few small masses of granite gneiss (the gneissic aplite facies of the Boulder Creek granite) occur in small lenticular masses in the Idaho Springs formation parallel to the foliation. This granite gneiss is the country rock of most of the Pennsylvania mine. It is a moderately fine-grained pinkish gneiss, showing some evidence of granulation, but much of the gneissic structure is primary.

The Silver Plume granite in the northern part of the Argentine district is continuous with the stock of the type locality. In the southern part of the irregular mass that extends into the district along McClellan Mountain, the granite is locally gneissic; this facies is especially conspicuous near the Stevens mine, in Stevens Gulch. Pegmatites and aplites are abundant throughout both the schist and the granite areas, and some of the pegmatite dikes reach a length of half a mile, though most of them are short and irregular.

Laramide intrusives.—The most abundant of the intrusive rocks of the Laramide revolution in the district is a quartz monzonite porphyry of group 6 (pl. 7 and fig. 12), related to the quartz monzonite porphyry stocks to the west. Many of the quartz monzonite porphyry dikes are much more sodic than the Montezuma stock, however. Monzonite porphyries of group 4, the most mafic of the Laramide intrusives in the district, are represented by relatively few dikes. Rhyolite and dacite porphyries of group 7 are also abundant throughout the Argentine district, in marked contrast to the Montezuma district to the southwest. Most of the dikes formed during the Laramide revolution strike northeast or east, but a few short dikes strike northwest. Nearly all the porphyry occurs in dikes, but a small chimney of rhyolite porphyry crops out at the crest of Kelso Mountain, and another irregular mass of monzonite porphyry occurs on the east side of Horseshoe Basin, a short distance west of Argentine Pass.

ORE DEPOSITS

Within the West Argentine district, as that part of the district lying west of the Continental Divide is known, the mineral belt is extremely narrow, and nearly all the veins occur in a zone less than a mile wide. (See pl. 3.) The belt trends about north-northeast, and its eastern side is marked by a series of strong veins that extend almost continuously north-northeast for 8 miles, from the Snake River 2 miles southeast of Montezuma into the headwaters of Leavenworth Creek. Within the Argentine district the Pennsylvania, Delaware, Peruvian, Santiago, and Independence veins occur in this zone and are the source of the bulk of the district's output. The Baker, the Josephine, and the Stevens mines, which lie on the northwestern edge of the mineralized belt, are less important than those on the veins mentioned above but have been productive. The angle of movement on the premineral faults was probably steep, ranging from 30° to 60°, and in those veins where the direction of movement was ascertained the horizontal component of movement was such that the left-hand wall moved ahead on both normal and reverse faults.

The ores are valuable chiefly for their lead, silver, and gold contents, but some zinc and copper are also present. As in the region to the west, quartz and ankerite are the common gangue minerals, but on Mount McClellan many of the veins contain fluorite. The predominant ore minerals are galena, pyrite, sphalerite, chalcopyrite (fig. 60, *B*) with some gray copper, silver sulfantimonides (chiefly dark ruby silver), and gold. The gold is generally associated with chalcopyrite or sphalerite and the silver minerals with galena and gray copper.

The most productive ore shoots in the Pennsylvania mine occurred at a split or branching in the main vein; the mineralized parts of the vein and the branches were largely limited to the places where the wall rocks were granite gneiss. The appearance of schist usually coincided with a decrease in ore. Many of the other productive veins, including the Santiago, Commonwealth, and Stevens, were productive between granite walls, but contained little ore where the walls were schist. The ore in these three mines as well as in the Baker, Josephine, and Kelso properties is close to a persistent northwesterly fault which locally is ore-bearing itself (pl. 3).

PENNSYLVANIA MINE

The Pennsylvania mine is on the northwest slope of Decatur Mountain a quarter of a mile south of Peru Creek and 3 miles east-northeast of Montezuma. It has been one of the most productive mines in the Montezuma quadrangle. Its total output is not known, but is probably not much in excess of the recorded output, which through 1930 totaled 31,142 tons of ore from which 2,858.58 ounces of gold, 761,020 ounces of silver, and 6,590,206 pounds of lead were recovered. The mine is easily accessible from Montezuma by a wagon road, which has steep grades following the valley of Peru Creek to the mine. The vein is opened by 6 levels, known as *A*, *B*, *C*, *D*, *E*, and *F*, between altitudes of 11,450 and 11,058 feet. The vein was discovered in 1879 and was slowly developed during the next decade. During the nineties it was most productive, but its output steadily diminished after 1900, and in 1908 no ore was shipped. Since that time an intermittent output has been credited to the mine, and the amount of ore milled at the property has varied, as much as 12,000 tons of ore being treated in some years and none in others.

The Pennsylvania vein strikes N. 20°–35° E., averaging about N. 30° E. It dips steeply west in most places, but locally overturns and dips about 80° E. The vein is chiefly in schistose rocks, 2,000 feet east of the Montezuma quartz monzonite stock (pl. 2). The common rocks in the lowest levels of the mine are quartz schist, quartz-biotite schist, injection gneiss, and granite gneiss. Locally thin dikes of Silver Plume granite are present. A dike of quartz monzonite is cut near the breast of the southwestern split of the vein on the *F* level. On the *C* level the prevailing wall rocks are granite gneiss, injection gneiss, and Silver Plume granite. The crosscut adit to the vein penetrates quartz monzonite porphyry and quartz-biotite schist. The wall rock of the vein has been strongly silicified and pyritized for a distance of 30 feet west of the vein, but to the east in the footwall silicification has been less intense, though pyrite is abundant 20 feet away.

On the *C* level the vein has been stoped for 800 feet, and the stopes are 6 to 14 feet wide. The largest stope is at the place where the vein divides into the "east and west slips." These two branches diverge at an angle of about 25° until they are nearly 50 feet apart; they then resume the general course of the main vein, continuing parallel as far as they have been explored. The ore in this level occurred in a strongly sheeted zone of granite gneiss. Between the walls of the sheeted zone numerous veins of galena, pyrite, chalcopyrite, and quartz seam the altered gneiss. Most of the minor veins are parallel to the walls, but several of them follow an irregular diagonal course across the sheeted zone. Galena is the most abundant mineral and occurs in seams 1 to 12 inches thick.

In the locality where the vein was seen by Lovering the zone was 12 feet wide, and about 30 inches of the sheeted zone consisted of galena, 8 inches of pyrite, and about 2 inches of chalcopyrite. The ore at the "split" is reported to have been 14 feet wide. It had less than 2 feet of waste and contained very little pyrite. Argentiferous gray copper ore was more abundant near the surface, and large amounts of copper sulfate were found near the outcrop of the vein when it was opened.

The walls of the vein and its branches on the *F* level have been intensely silicified and pyritized. The vein is smaller than on the *C* level, and the ore is commonly lean, pyritic, and thin, but in a few localities where good lead ore was found stoping has been done. About 1,800 feet south of the *F*-level crosscut, almost vertically below the "split" on the *C* level, the vein branches.

The west branch, which was followed 300 feet farther, is apparently the main vein, showing little change in the course followed to this point. The east branch has been followed about 200 feet. About 350 feet south of the main crosscut a lead ore shoot was found. The ore body is about 12 inches wide and 50 feet long, and, unlike the other ore shoots seen, dips steeply to the east. A short distance farther south, where the vein resumes its normal dip, the galena ore disappears, and the vein filling is pyritic. A second galena ore shoot was found 70 feet south of the first ore body. Here the vein was 3 to 5 feet wide and contained 12 to 30 inches of galena ore for a distance of 100 feet along the drift. At the place where the vein branches, many narrow veins and stringers occur in a sheeted zone about 7 feet wide but do not aggregate more than 12 inches of ore through the zone. Little ore is exposed until a point about 140 feet south of the "split" is reached, where an ore shoot containing both lead and copper was found, and some stoping has been done. The shoot is about 80 feet long on the *F* level and somewhat longer a short distance above it. The east branch contains very little galena but is heavily seamed with pyrite; it is 12 to 48 inches thick and in some places contains as much as 15 inches of pyrite.

Small veins striking parallel to the Pennsylvania vein occur east of it on the *C* and *F* levels but no ore has been mined from them. The meager evidence found in the mine suggests that the Pennsylvania vein follows a premineral fault the west wall of which moved relatively up and to the northeast.

The large body of ore found in the Pennsylvania vein occurred where it branches and in the part of the vein that had granite gneiss walls. The "split" in the vein is close to the south end of the wedge of granite gneiss and suggests the weakening of the vein as it passed into the incompetent schist. It is unlikely that an ore body will be found in the schist comparable to that found in the Pennsylvania mine between granite gneiss walls, but it is probable that chimneys of good ore can be found at "splits" in the vein and at other favorable places. The Pennsylvania vein extends to the southwest through the Delaware, Delaware Extension, and Sunrise claims, but little ore has been mined except from the Delaware. The Peruvian vein, northeast of the Pennsylvania, on the north slope of Peru Creek Valley, is probably a continuation of the same vein. The output of the Peruvian is unknown but is probably small.

OTHER MINES

Data on other representative mines are given briefly below. Detailed descriptions are given by Lovering in another report.[49]

BAKER

Development.—Original discovery 1865. 200-foot shaft with 4 levels. Independence vein cut several hundred feet below outcrop by drifts from Tobin and Waldorf mine.

Production.—1870: $27,567.97. 1871: $44,509. 1874: more than 1,000 ounces of silver.

Veins.—North Crevice: Strike, N. 72° E.; dip 65° N. South Crevice: Strike, N. 60° E.; dip 85° N.; average width, 16 inches; hanging wall and footwall 3 to 15 feet apart.

Wall rock.—Silver Plume granite, quartz-biotite schist, and injection gneiss.

Ore and sulfide minerals.—Silver minerals, chalcopyrite, argentiferous galena, stephanite, some sphalerite.

Gangue minerals.—Quartz and fluorite; fluorite abundant in three lower levels.

Ore shoots.—Ore shoot at junction of the two veins. Ore is 7 feet wide. Many small ore bodies, 20 inches to 20 feet wide.

Tenor.—Average ore yielded $6.11 in gold and $69 in silver to the ton.

JOSEPHINE

Development.—Original discovery 1876. Three adits driven south into mountain for 320 feet, 1,090 feet, and 960 feet.

Production.—1900–28: 2,059 tons. Gold, 228.06 ounces; silver 27,039 ounces; lead, 2,250,802 pounds; copper, 5,188 pounds; zinc, 24,053 pounds.

Veins.—Josephine: Strike, N. 12° E.; dip, 67° W.; width, 1 to 30 inches. Well defined. Several minor branches and cross veins. In sections between ore shoots chiefly quartz. Ore free from gangue.

Wall rock.—Silver Plume granite, schist and gneiss of the Idaho Springs formation.

Ore and sulfide minerals.—Galena, sphalerite, pyrite, and chalcopyrite.

Gangue minerals.—Quartz.

SANTIAGO-COMMONWEALTH-CENTENNIAL

Development.—5 levels. Underground shaft 300 feet deep on level 5. Commonwealth tunnel caved.

Production.—1901–27: Gold, 12,653.86 ounces; silver, 326,179 ounces; lead, 2,405,730 pounds; copper, 1,146,378 pounds.

Veins.—Santiago: Strike, N. 15°–35° E.; dip, 70°–85° W.; width, 2 to 8 feet. Vein filling is silicified and pyritized granite breccia. Commonwealth: Strike, N. 12°–25° E.; dip from 70° SE. to steeply northwest. Northward continuation of Santiago vein. Cut by Waldorf tunnel.

Wall rock.—Silver Plume granite, schist of the Idaho Springs formation, granite gneiss; schist more abundant to north.

Ore and sulfide minerals.—Galena, chalcopyrite, pyrite, and some sphalerite.

Gangue minerals.—Quartz and some ankerite.

Changes with depth.—Vein becomes narrower with depth. Galena, quartz, and chalcopyrite decrease and pyrite and sphalerite increase with depth. Gold content in lower levels is directly related to presence of rosin-jack sphalerite.

Ore shoots.—Southern part of Santiago vein is productive for a length of nearly 1 mile and a depth of 800 feet. One ore shoot has a stope length of 110 feet and a pitch length of 700 feet.

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[49] Lovering, T. S., Geology and ore deposits of the Montezuma quadrangle, Colorado: U. S. Geol. Survey Prof. Paper 178, pp. 69, 85, 104–105, 109–110, 1935.

In Commonwealth vein ore is of better grade, and vein is stoped where it swings to north.

STEVENS

Development.—Discovered in late sixties. Several adits; winzes sunk from some levels.

Production.—1873: Silver, 25,000 ounces; lead, 200,000 pounds. 1887: Gold, 54.12 ounces; silver, 12,947 ounces; lead, 390,698 pounds. 1892: Silver, 42,666 ounces; lead, 2,601,203 pounds.

Vein.—Stevens: Strike, north to northwest; dip, 60°–75° E.; series of branching fissures.

Wall rock.—Silver Plume granite.

Ore and sulfide minerals.—Sphalerite, galena, and some pyrite and chalcopyrite.

Gangue minerals.—Quartz and ankerite.

Changes with depth.—Decrease in lead and silver with depth.

Ore shoots.—Ore shoot stoped for length of 350 feet, 100 feet above tunnel. On tunnel level it splits into two shoots 120 and 200 feet long.

Tenor.—1872: Ore averaged 150 ounces of silver to the ton and a high percentage of lead. 1876: Ore averaged 80 to 100 ounces of silver to the ton and 65 percent of lead. 1888: 1.1 ounces of gold and 26 ounces of silver to the ton and 50 percent of lead.

SILVER PLUME-GEORGETOWN DISTRICT

LOCATION

The Silver Plume-Georgetown district [50] occupies an area of about 25 square miles in the west-central part of Clear Creek County, surrounding the towns of Silver Plume and Georgetown. Georgetown is situated at the junction of Clear Creek and South Clear Creek, and Silver Plume is on Clear Creek 2 miles southwest of Georgetown. The principal mines are on the south slope of Republican Mountain, just north of Silver Plume, but there are some important mines to the southwest, northeast, and northwest of Georgetown. The district is well watered by the drainage of Clear Creek and is very rugged, ranging from 8,400 to 12,400 feet in altitude. A paved highway down Clear Creek connects both towns with Idaho Springs and Denver.

HISTORY

Precious metals were first discovered in the district in 1859, when several lodes were located near Georgetown, at that time called Elizabethtown. The rich surface ores were worked chiefly for gold, although most of the veins in depth have since produced more silver than gold. Among the most prominent was one located on August 1, 1859, by George Griffith. In 1864 a rich silver vein, the "Belmont lode," was discovered in the Argentine district southwest of Silver Plume, and as silver at that time was worth $1.34 an ounce there was a rush of prospectors to the Silver Plume-Georgetown region seeking silver lodes. During 1865 and 1866, many silver-bearing veins were discovered near Georgetown and Silver Plume. In 1867 the Blackhawk smelter began to operate and greatly stimulated mining in the Front Range. In 1870 mining in the region was further helped by the completion of two railroads to Denver and one from Denver to Golden. The period of important silver-lead mining really commenced in 1872, reached its peak in 1894, and gradually declined thereafter.

The increased output during the eighties was due in part to the completion in 1877 of a narrow-gauge railroad to Georgetown and in part to the competition of foreign markets for the ores, beginning in 1875. As the silver-lead ores were opened at greater and greater depth the lower-grade zinciferous ores became prominent. About 1865 a small output of zinc began and increased slowly, reaching its maximum in 1917.

During World War I, in response to the greatly increased demand for zinc and lead, many of the old mines were reopened, and considerable amounts of these base metals were produced from old stopes, dumps, and blocks of ground left from the silver mining. In the postwar years, however, the silver-lead mines were largely idle, and most of the output of the district came from its few gold mines. Interest revived in the base metals of the district with the opening of World War II. During 1943 and 1944 the Pelican-Bismarck, Mendota, and Smuggler mines were reopened, and lead-silver-zinc ore was milled at two mills at Silver Plume and one at Georgetown.

The total output of the Silver Plume-Georgetown district has probably amounted to more than $30,000,000, but exact figures for many years are lacking. The output for the period 1907–42 has amounted to 27,616 ounces of gold, 3,203,448 ounces of silver, 324,592 pounds of copper, 22,447,925 pounds of lead, and 21,511,862 pounds of zinc, having a total value of $6,023,091.[51]

GENERAL GEOLOGY

Pre-Cambrian rocks.—The prevailing rocks are the Idaho Springs formation and the Silver Plume granite. Schists of the Idaho Springs formation are scattered throughout the district and make up about 40 percent of the rocks exposed.

The most abundant and widespread type of schist in the district is quartz-biotite schist (called granitic gneiss by Spurr and Garrey).[52] Biotite schist (called black biotitic gneiss by Spurr and Garrey) occurs in irregular lenses and bodies in the quartz-biotite schist. A facies of the quartz-biotite schist containing lens-shaped pebblelike masses of fibrolitic quartz was believed by Spurr to be a metamorphosed conglomerate. It occurs abundantly on Pendleton Mountain and on Brown Mountain in the southern and western parts of the district. Small masses are scattered through the district, and some are prominent just north of Silver Plume.

[50] Spurr, J. E., Garrey, G. H., and Ball, S. H., Economic geology of the Georgetown quadrangle (together with the Empire district), Colo.: U. S. Geol. Survey Prof. Paper 63, 1908.

[51] Data furnished by C. W. Henderson, U. S. Bureau of Mines.

[52] Spurr, J. E., Garrey, G. E., and Ball, S. H., op. cit., p. 177.

There is a suggestion that the masses on Brown Mountain and Pendleton Mountain are parts of the same bed or structural unit, separated by a mass of Silver Plume granite, and that the scattered areas of pebble conglomerate north of Silver Plume are parts of a narrower bed that has been warped into a northward-plunging syncline. The lime-silicate phase of the Idaho Springs formation occurs in numerous small lenses in the southeastern part of the district and in one northward-trending lens on Democrat Mountain northwest of Georgetown. The lime-silicate rocks include hornblende-diopside gneiss and massive aggregates of epidote, garnet, quartz, and magnetite, and of calcite, pyroxene, and brown garnet.

The Idaho Springs formation has been invaded by several pre-Cambrian igneous rocks. Hornblende gneiss forms both dikes and sheets in the Idaho Springs formation, and many small masses of it are included in the granites. It occupies small areas in the southern and east-central parts of the district.

The quartz monzonite described by Ball[53] as occurring in a large batholith in the central part of the Georgetown quadrangle is almost identical with the Boulder Creek granite of the Boulder quadrangle, which is a gneissic quartz monzonite in many places. The northern end of the batholith lies just east of the Silver Plume-Georgetown mineralized area; its related border facies, the quartz monzonite gneiss, gneissoid granite, and quartz diorite, are sparingly scattered through the district. In the south-central part is the northern end of a fairly large area of quartz monzonite gneiss (pl. 2), which is an early sheared border facies of the Boulder Creek granite, that is not exposed elsewhere in the district. The mass on Paine's Mountain, just south of the district, is the largest in the Georgetown quadrangle and is on the west border of the large mass of Boulder Creek granite that occupies the central part of the quadrangle. The well-developed primary gneissic structure has been intensified by crushing and was probably developed by shearing, which was due to the intrusion of the main mass of Boulder Creek granite. Small bodies of gneissoid granite, an aplitic phase of the Boulder Creek granite, are scattered through the eastern part of the district, and in this locality there are also a few small areas of quartz diorite and hornblendite that are also related to the Boulder Creek granite.

The Silver Plume district is the type locality of Silver Plume granite, which forms stocks, dikes, and irregular masses in the Idaho Springs formation and the other pre-Cambrian rocks. It makes up about half of the rock in the district. The Silver Plume granite has invaded the schist and earlier igneous rocks widely, and there is scarcely a square mile that does not contain an appreciable amount of it. In many places, especially northwest and south of Georgetown, this granite intimately injects the schist and includes numerous small lenses of the Idaho Springs formation within its own borders.

Dikes and small irregular masses of pegmatite and aplite occur throughout the area, but most of them are too small to be shown on the map. It is probable that pegmatites related to both the Boulder Creek granite and the Silver Plume granite are present, but in general they cannot be distinguished. They are particularly abundant just northwest of Silver Plume. In general they consist of coarse intergrowths of orthoclase or microcline, quartz, and biotite with or without muscovite. A light-gray acidic plagioclase is restricted to dikes in the Boulder Creek granite.

Laramide intrusives (*"porphyries"*).—Dacite of group 4 (pl. 7 and fig. 12), quartz monzonite porphyry of groups 5 and 6, and granite porphyry and alaskite of group 7 occur in the district both as stocks and dikes. The stocks do not occur in the main mineralized area but to the north and south of it. On Lincoln Mountain, in the northern part of the district, is a large stock of quartz monzonite porphyry about 1 mile long and three-fourths of a mile wide. Just south of the district, 1 mile southwest and 1½ miles southeast of Paines Mountain, respectively, there are small stocks of alaskite and of granite porphyry, each about a third of a mile in diameter. The dikes are confined chiefly to the mineralized area around Silver Plume and Georgetown. The most persistent have a northwest trend, but some occupy east-west and northeast fractures.

Dacite of group 4 is believed to be the earliest of the intrusives of the Laramide revolution in the district. It forms an eastward-trending dike 50 feet wide and 0.4 mile long between Clear Cleek and South Clear Creek, half a mile south of Georgetown. The dike includes large irregular fragments of pre-Cambrian rocks near its borders and small rounded ones toward the center and shows wavy flow lines close to its edges. It is a bluish-gray dense aphanitic rock consisting of small laths of plagioclase, prisms of black hornblende, and tiny rounded quartz grains in a felsitic to andesitic groundmass.

Quartz monzonite porphyries belonging to groups 5 and 6 are the most abundant porphyries in the district. Besides the large stock on Lincoln Mountain there are important dikes just northwest of Silver Plume that trend northwestward and a strong northeastward-trending dike just south of Silver Plume. The porphyry on Lincoln Mountain apparently grades into quartz monzonite, a fine-grained granular rock composed of orthoclase, oligoclase, augite, hornblende, and quartz.

Granite porphyry of group 7 forms a number of dikes as well as the stock south of Paines Mountain. Nu-

[53] Spurr, J. E., Garrey, G. E., and Ball, S. H., op. cit., pp. 51–54.

merous short dikes are found within a distance of 1½ miles south of Silver Plume, a strong dike cuts Brown Mountain northwest of Silver Plume, and several dikes occur on Lincoln Mountain in the vicinity of the quartz monzonite porphyry stock. Most of these dikes trend northeastward, but some trend northward and some eastward. Rhyolites and aporhyolites are closely associated with the granite porphyry and in places grade into them.

Alaskite porphyry, also belonging to group 7, forms numerous dikes in the vicinity of Silver Plume and on both sides of Clear Creek north of Georgetown, as well as in the two stocks southwest of Paines Mountain. The most extensive dikes trend northwestward, but some trend northeastward. In the Baltimore tunnel near Georgetown a dike of alaskite porphyry cuts one of quartz monzonite porphyry, and a surface exposure in the same general area shows that granite porphyry also cuts quartz monzonite porphyry. In general the distribution of the veins in the district coincides with the distribution of the porphyry dikes, but the stocks are outside the main mineralized area. The ore deposits seem to be most closely related to the alaskite porphyry dikes, and in places important veins follow along the walls of these dikes.

Quaternary deposits.—The district has been affected by two periods of glaciation, and remnants of the moraines are strewn along the valley slopes of Clear Creek, South Clear Creek, Bard Gulch, and Leavenworth Gulch. Boulder till of the earlier period, probably Kansan, occurs chiefly on the east side of Clear Creek and South Clear Creek, extending for about a mile from the present streams to an altitude of slightly more than 11,000 feet. There is a long narrow strip of the older till on the south side of Bard Gulch and another smaller remnant on the west side of Clear Creek opposite Georgetown. The terminal moraine of this period is at Dumont, at an altitude of about 7,900 feet. The later glaciation, probably Wisconsin, affected all the principal valleys, and fairly continuous moraines of this period are found along them except on Clear Creek north of Georgetown, where most of the material has been eroded. The terminal moraine of this period is near Empire Station, at an altitude of about 8,175 feet.

STRUCTURE

Pre-Cambrian structure.—The foliation in the Idaho Springs formation is rather irregular in the district. The general trend is north with a steep dip to the east. In the southern part of the district, west of Leavenworth Gulch and east of South Clear Creek, the prevailing strike is northeast. In the vicinity of Silver Plume it is nearly north-south, and northward it swings to the northwest and then back to the northeast, north of Bard Gulch. A northward-plunging syncline is probably present, with its axis passing just east of Silver Plume, but the data on the dips of the foliation are insufficient to determine the nature of this structure with certainty. The foliation in the quartz monzonite gneiss and gneissic granite is in general parallel to the foliation of the enclosing or bordering schist.

There is no evidence of pre-Cambrian faulting in the district other than that afforded by the fissures filled with cross-breaking pegmatite dikes.

Laramide structure.—During the Laramide revolution, fractures, faults, and fissures were formed over a period of time beginning before the intrusion of the earliest dikes and continuing after the deposition of the latest ores. The porphyry dikes were intruded at various epochs of a general period of volcanism, during which movements were renewed repeatedly along old planes or along new planes subparallel to the old ones. Individual fault zones were repeatedly opened and repeatedly cemented either by injections of molten rock or by the deposition of minerals from solution. Postmineral movement is indicated by open fissures along veins, by seams of postore gouge, and by postore friction breccia.

The fault fissures in general dip steeply but show great variation in strike and may be classified into three main systems. In the area between Silver Plume and Columbia Mountain the fissures belong mainly to two systems; in one the average trend is about N. 70° E., and in the other N. 70° W. There are also some fissures in this area belonging to a system in which the trend is N. 50° E., but they are subordinate in number and extent. Throughout the rest of the mineralized area the average trend of most of the fault fissures is about N. 50° E.

It is believed that fissures of the N. 70° W. system were formed earliest, as the majority of the dikes have this trend. In fact the Pelican-Bismarck fissure of this system was first opened in the breccia-reef period of faulting. The fissures of this system were apparently reopened at approximately the same time that those of the N. 70° E. system were developed, as important silver ores were deposited in fissures of both systems. The N. 50° E. system is apparently the latest, for practically all the pyritic gold veins have that general trend, and at Empire they are definitely later than the lead-zinc veins.

The fault fissures are usually of slight displacement. The grooves and slickensides on the walls range from horizontal to vertical. In the Silver Plume region the majority of the striae are nearly horizontal, in a few places steepening to as much as 30°. The pitch in different places may be in opposite directions. In the Colorado Central vein the striae dip about 20° southwest, and the maximum displacement is about 100 feet. In the pyritic gold veins the dip was in general steeper.

In the Centennial vein at Georgetown the striae dip 32° SW., and in the Anglo-Saxon mine they dip 65° NE.

ORE DEPOSITS

The chief metals produced in the Silver Plume-Georgetown district are silver, lead, gold, and zinc, but in general the gold occurs in separate areas. In the very productive area covering about 2 square miles just north of Silver Plume, the veins contain silver, lead, and zinc almost to the exclusion of gold, and this is also true of the veins on Republican Mountain and on Democrat Mountain, 1½ to 2½ miles north-northeast. In these areas veins of both northeast and northwest trend are prominent and important, but commonly the trends are nearer east-west than north. One and a half to 2 miles south of Georgetown is a smaller but important silver mining area—that of the Colorado Central group—the abundant ores of which are largely of high grade and very similar to those of the Silver Plume area. This silver belt is represented farther to the northeast by the Comet-Aetna and Magnet veins, about a mile east of Georgetown. In this belt the predominant strike of the veins is northeast.

Between the two silver belts is a narrow gold belt about three-fourths of a mile wide extending from Leavenworth Mountain, 1½ miles south of Georgetown, northeastward to Saxon Mountain. In this belt the important veins all trend northeastward. The gold-bearing veins commonly contain some silver, and at the northern end of the belt the value of the silver content is somewhat higher than that of the gold. On Lincoln Mountain, 3½ miles northwest of Georgetown, some veins are chiefly valuable for silver and others for gold.

Mineralogically the two groups of ores may be classified as (1) galena-sphalerite ores with some pyrite, chalcopyrite, gray copper, and polybasite, and (2) pyritic ores containing chiefly pyrite and chalcopyrite, with subordinate quantities of galena and sphalerite, and less commonly tetrahedrite.

In the Griffith mine near Georgetown both types of ore are present and prove to represent two different periods of mineralization. The fissure was first lined with a coating of comb quartz and then completely filled with solid sulfides consisting of galena, sphalerite, pyrite, and chalcopyrite, with practically no intermixed gangue. Subsequently the vein was reopened, fractured, and brecciated, and the openings were filled with ore consisting principally of pyrite and brown carbonates of iron, manganese, and magnesium, with some quartz and a little galena, sphalerite, chalcopyrite, and barite. In places quartz is more abundant than brown carbonate. The same relationship found in the Griffith mine was noted in several other mines, chiefly on the borders between an area of predominantly gold-bearing veins and an area of silver-bearing veins. In the Harrison mine on the east side of the Empire district, two east-west veins of lead-silver type are faulted by a vein of the pyritic gold type trending N. 10° E.

Silver-lead deposits.—The principal metallic minerals of the silver-lead ores are sphalerite and galena, with locally considerable pyrite. Both light-yellow and dark sphalerites are present. The galena and to a less extent the sphalerite are argentiferous, and the silver content of the ore ranges from very little to several hundred ounces per ton. The ores commonly contain less than 0.10 ounce of gold to the ton and in some places none at all. The chief silver minerals in the ore are polybasite, argentiferous tetrahedrite, argentite, pyrargyrite, and proustite, and locally there is considerable native silver. Stephanite has also been reported, and mercurial tetrahedrite has been identified in the Colorado Central mine at a depth of 1,050 feet. The chief gangue mineral in the lead-silver veins is quartz, but there are also considerable amounts of brown carbonate, including siderite, ankerite, rhodochrosite, magnesite, calcite, and dolomite; sericite, barite, cherty silica, and locally kaolinite are also common. Fluorite occurs rarely.

Galena and sphalerite are commonly contemporaneous, but in some veins galena is later than sphalerite. Both minerals were also among the last to crystallize, forming on free faces in vugs. In several places pyrite is later than both galena and sphalerite, although all three are more or less intergrown. Pyrite is present everywhere, but is not prominent; its period of formation lasted from the beginning to the end of mineral deposition. The primary silver minerals are all closely associated and were among the last minerals to be deposited; in many places they form free crystals in druses. Quartz, like pyrite, was deposited during the whole period of mineral formation, and the same is true of the brown carbonates, but most of the carbonates are late. Chalcedonic quartz in general belongs with the late minerals. Fluorite, barite, calcite, and kaolinite are among the last minerals to form and seem to have no close relationship to the metallic sulfides.

In general, then, the sequence of mineral deposition in the veins is as follows: (1) Quartz and some pyrite; (2) massive galena, sphalerite, and pyrite with some quartz; (3) brown carbonates and quartz; and (4) small amounts of all those named, together with fluorite, barite, calcite, and kaolin.

Spurr [54] believed that the silver minerals were the result of secondary enrichment, but apparently based his conclusion solely on the fact that the silver content decreased with depth. He observed that native silver and the soft black rich sulfide ores plainly of secondary origin extended downward only about 200 feet below the surface. Argentiferous tetrahedrite and ruby silver

[54] Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., p. 140.

were important constituents of the galena-sphalerite ore more than 1,500 feet below the outcrop, however, and it seems probable that most of these silver minerals were primary, certainly so below the upper levels.

The zone of complete oxidation commonly ranges in depth from 5 to 40 feet below the surface. The oxidized material is a brown clay, which is generally rich, containing several hundred ounces of silver to the ton. Below this zone and merging with the lower part of it is a zone of partly oxidized ore containing friable, locally powdery, black sulfides and bunches of (residual?) galena believed by Spurr to be secondary. The pulverulent sulfides contain relatively large quantities of silver, lead, and gold. They are found especially along cracks and water courses and have evidently been concentrated from leaner ores by descending waters. They occur to depths of 200 to 300 feet from the surface, but in decreasing quantity. From primary ore that assays 20 to 30 ounces of silver, secondary sulfides have formed that contain 200 to 300 ounces of silver. In many lodes pyrite and siderite are abundant in superficial parts of the vein, and they apparently have been deposited by descending waters.

Below the zone of soft supergene sulfides and irregularly overlapping it is the zone of such rich hypogene silver minerals as polybasite, tetrahedrite, and ruby silver. These minerals diminish in quantity as depth increases. In most veins the best ore was found in the uppermost 500 feet, but rich ore occurred to a depth of more than 800 feet in several lodes and was noted 1,550 feet and even 2,000 feet below the surface in the Pelican-Bismarck vein. The lower-grade galena-sphalerite ores in many of the strongest and most extensive veins, such as the Terrible and the Pelican-Bismarck proved fairly constant in amount and character to a depth of 1,200 to 1,800 feet. In other veins of smaller horizontal extent commercial ore is limited to the upper few hundred feet. In most of the mines on Republican and Democrat Mountains the known ore bodies are limited to the upper 200 to 400 feet.

Pyritic gold deposits.—The chief minerals in the pyritic gold deposits are pyrite, chalcopyrite, gold, small amounts of silver, and quartz. Galena and sphalerite are generally present in small amounts. Where galena is relatively abundant it usually contains considerable gold and silver. Some chalcopyrite is generally associated with the pyrite and locally is fairly abundant. Tetrahedrite and soft black chalcocite are common but not abundant. In the Griffith mine small quantities of hessite were found with argentite. Platinum and iridium having a value of $3 a ton were reported from the Centennial mine. Free gold visible to the naked eye is found in places, but native silver is rare. The gangue minerals besides quartz include small amounts of barite and brown carbonates of iron, manganese, magnesia, and lime. Fluorite is present in some of the veins of the auriferous belt and is abundant in the Big Chief vein near Georgetown.

The valuable metals in the ores are gold, silver, copper, and in places, lead. Copper is present in most veins, but in many there is not enough to be of value. The ratio of gold to silver varies considerably. In many veins it is about 1 to 2 ounces of gold to 20 to 40 ounces of silver. From these ores there is a transition on the one hand to those having very little silver and on the other to those where the silver is of greater value than the gold.

In many of the mines the age relations of the minerals in the veins are obscure, but in the Griffith mine the order of deposition of the pyritic part of the vein was as follows: (1) Pyrite, brown carbonates, and quartz; (2) chalcopyrite, quartz, galena and sphalerite, and tetrahedrite; and (3) barite and kaolinite. Locally tetrahedrite forms in cracks in the chalcopyrite. In the Centennial mine the gold occurs with the chalcopyrite. Sooty chalcocite is plainly the result of secondary enrichment. Fluorite in the Big Chief mine near Georgetown is later than the main period of mineralization, as it coats cavities in the older sulfides.

The zone of essentially complete oxidation in the pyritic veins corresponds to that in the silver-lead veins. In the Centennial mine it extends to a depth of 15 or 20 feet and is marked by the nearly complete oxidation of pyrite to limonite.

The principal products of alteration of the feldspars and biotite in the wall rocks are quartz, sericite, various carbonates, and pyrite. Fluorite is present locally. The alteration products of descending waters subsequent to vein deposition are principally kaolin and calcite.

Localization of ores.—In the Silver Plume-Georgetown district, as in so many other localities in the Front Range, the northwesterly premineral faults seem to be the master figures responsible for the localization of the district. This is particularly well exhibited in the highly productive area just north of Silver Plume, where the northwesterly Pelican-Bismarck vein, which can be traced far to the southeast of the area in which it was strongly mineralized, is believed to be the trunk channel along which the ore-bearing solutions moved from depths. Most of the productive vein systems in this locality either branch from or approach close to the Pelican-Bismarck vein, and nearly all the output has come from within half a mile of this strong lode. In the Diamond and Pelican tunnels red silicified breccia occurs along the walls in places, indicating that the fissure was first opened in the breccia-reef period of faulting. Elsewhere in the district the control of trunk channels is not so well exhibited, though there is a suggestion that other strong northwesterly veins, such as the Sunburst-Sceptre, may have exercised a similar control.

Many of the features controlling the localization of ore shoots in the veins of the porphyry belt are well illustrated in this district, and most of these features were recognized and described by Spurr and Garrey in 1903. As in the other mining districts located in the pre-Cambrian terrain, the ore shoots were localized in the most permeable part of premineral faults. Some of the ore shoots are plainly due to certain structural features of the fractures, such as change in course, change in dip, branches or splits in the vein, and intersections with other veins. Other ore shoots seem related to the structure of the wall rock, such as the relative angle made by the foliation with the vein, the plane of weakness made by a porphyry dike, or the impounding effect of a porphyry dike lying athwart the vein. The largest number of ore shoots, however, seem to be related to the kind of wall rock, for a vein may be weakly mineralized where it cuts schist and strongly mineralized where it enters a granite or porphyry mass, or it may be nearly barren in porphyry and productive as soon as it enters granite or pegmatite.

Although changes in course and dip were not recognized by Spurr and Garrey as influential in localizing ore, it seems apparent from the study of the mine maps of the Wide West, Pelican-Bismarck, Colorado Central, and other veins that a change in dip or in course affected the position and width of the ore. In the Wide West mine the larger ore masses were found on "flats," or places where the dip was much less than the average. In most places, the vein dipped from 65°–78°, but the ore bodies were broadest and richest where the dip was only 45°, suggesting a premineral reverse fault. The effect of a change of course on a vein is illustrated in the Pelican-Bismarck vein. There the right-hand wall moved ahead almost horizontally, tending to create openings where the course of the vein swung to the left, and as shown in plate 10, the ore shoots were found in these parts of the vein. On the Mendota vein, the left-hand wall moved ahead, and the principal ore shoots are found where the course of the vein has swung to the right. The Colorado Central vein has a general dip to the northwest, and the footwall apparently moved down and southwest at about 30°. The best ore occurred where the vein dipped northwest at about 60°, and those parts where the dip steepened greatly or the vein became slightly overturned to the southeast were much less productive places, as they would tend to be closed by the movement of the vein walls (fig. 52). The tendency of the ore to occur where the vein swings to the right is shown in figure 37. This vein also shows what Spurr called right-handed imbrication. As the main vein tends to die out it gives off a fracture to the right or is paralleled by an overlapping

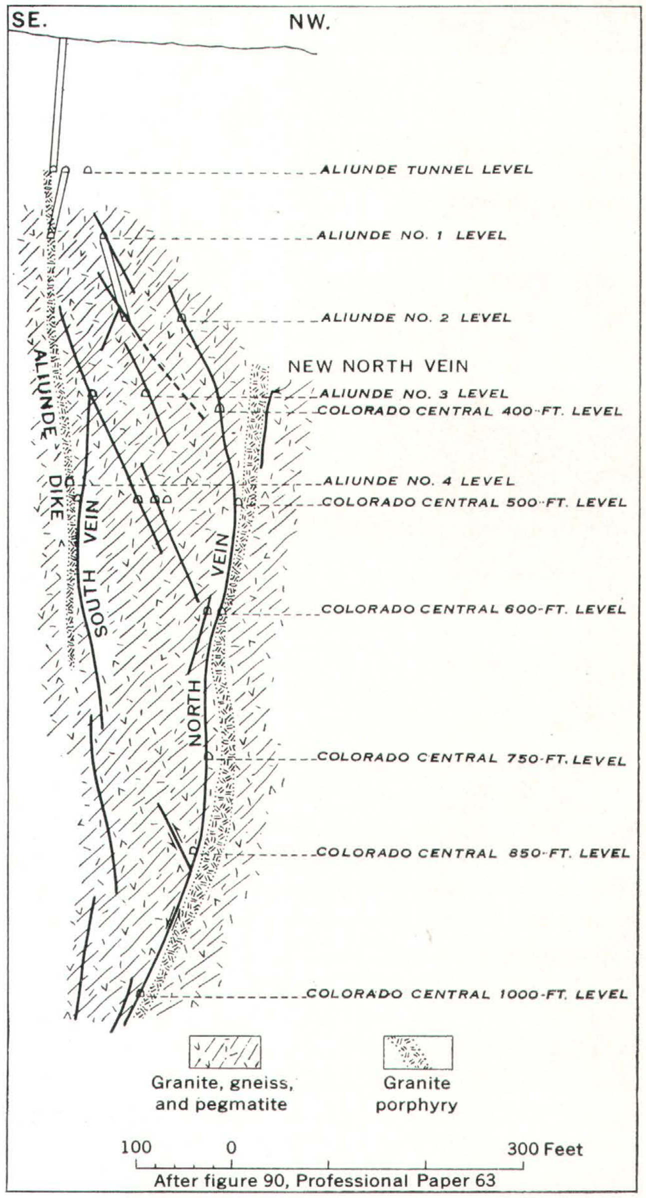


FIGURE 52.—Section of the Colorado Central lode, Georgetown district, showing the vertical imbrication and branching of the lode.

fracture that is present a short distance to the right of the person looking along the vein. Where the vein imbricates there is a tendency for the mineralization to die out along one vein and reappear on the overlapping vein nearby, continue on it for some distance, disappear, and reappear at about the same point on another parallel vein farther to the right, according to Spurr. The restriction of the ore to the part alongside the porphyry dike is a feature of this vein.

It has been common knowledge almost since mining started in the district that junctions of veins are likely to be the site of ore shoots. This type of control is well illustrated in the Kirtley vein, where almost every junction has meant a good ore shoot (fig. 53). At the junction of the Stranger and Kirtley veins and through a distance of 600 feet beyond the junction the main vein

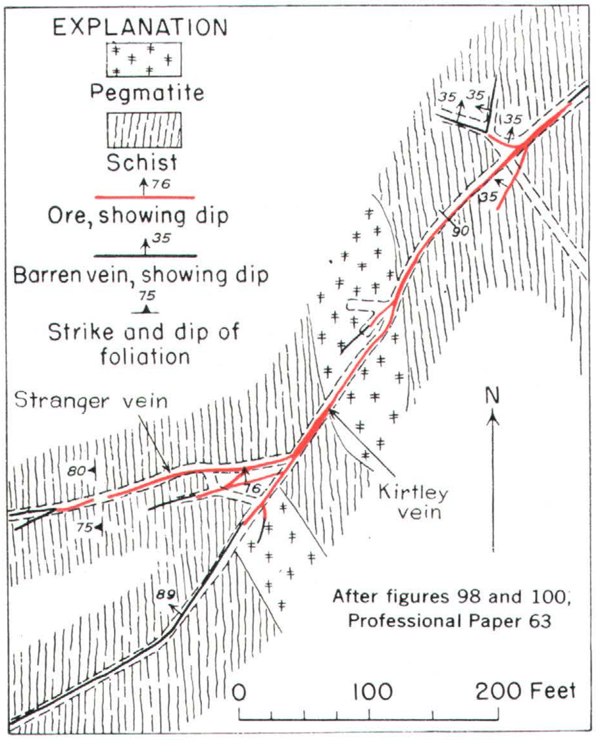


FIGURE 53.—Kirtley vein, Georgetown district, illustrating the occurrence of ore at the junctions of minor veins.

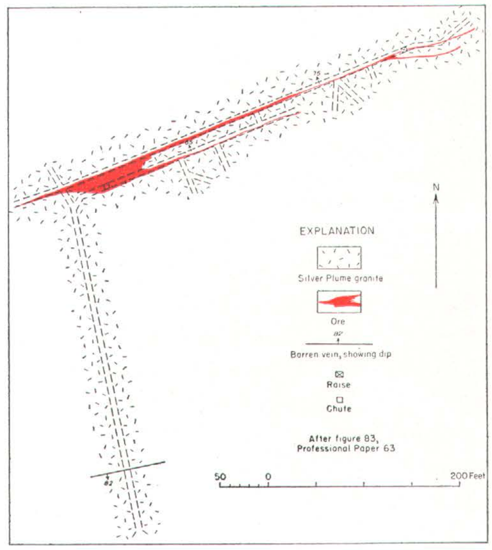


FIGURE 55.—Part of the Terrible vein, Silver Plume district, showing the occurrence of ore at a junction of subparallel fissures.

was well mineralized. The Stranger contained ore for a distance of 200 feet between the junction and a point where a small vein branched from the Stranger. Similarly, the Terrible vein in the numbers 1 and 4 Dunderberg workings shows the influence of intersecting fissure systems and the junction of two subparallel fissures. Both places are marked by important ore bodies, as shown in figures 54 and 55. The most productive ore shoot in the Pelican-Bismarck vein occurred

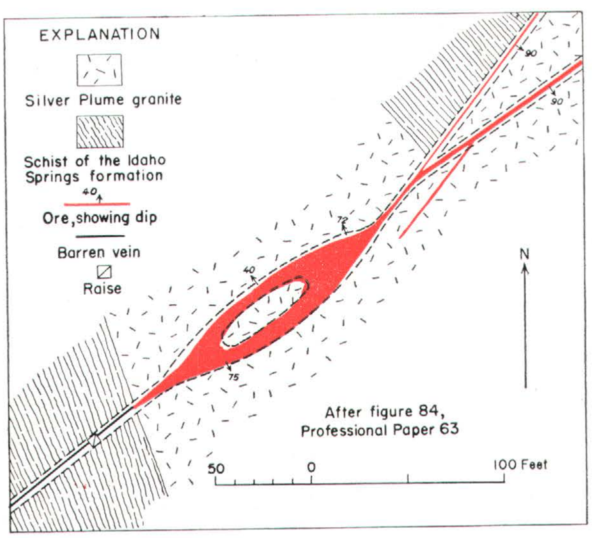


FIGURE 54.—Part of No. 1 level, Dunderberg mine, Silver Plume district, showing mineralization of fractured granite horse at the intersection of two fissure systems at an acute angle. On the level below, the entire horse is mineralized. Note relation of ore to granite and schist.

just south of its intersection with the Seven-thirty vein (fig. 56). Although the intersection of these two veins is not evident on the lower level of the mine, the location and pitch of the entire ore shoot are apparently determined by the intersection.

The relation of the wall rock to localization of ore is apparent in many of the mines. Granite makes one of the best wall rocks and schist of the Idaho Springs formation one of the poorest. In the Terrible mine the main veins are well mineralized in the granite and generally are fissure fillings of ore, but they change to barren seams of gouge or disappear entirely where they enter schist. (See fig. 26.) Near the northeast end of the Dunderberg workings a strong vein in granite passes into schist on the northeast and immediately "horsetails" and ends within a short distance. A little farther on, however, where a granite bar lies in the schist, the vein reappears and is well mineralized throughout the granite. On the upper or "A" level of the Dunderberg mine a strong shoot of ore in granite extends as far northeast as the contact with the schist and there ends abruptly. This shoot follows the granite contact but does not enter the schist, although the vein continues on as a poor, unmineralized fissure. Granite walls are also more favorable than porphyry in many places. On the Seven-thirty vein the fracture crosses a dike of alaskite porphyry and is weak and nearly unmineralized where the walls are porphyry, though productive on both sides in the granite (fig. 57.) Porphyry walls, however, are in general better than schist walls. In the Maine vein an ore shoot one to several feet wide occurred in the vein between porphyry walls but thinned markedly on entering the adjacent schist and soon disappeared. (See fig. 36.) Some of the porphyry dikes provided planes of weakness that were followed by the premineral fault and

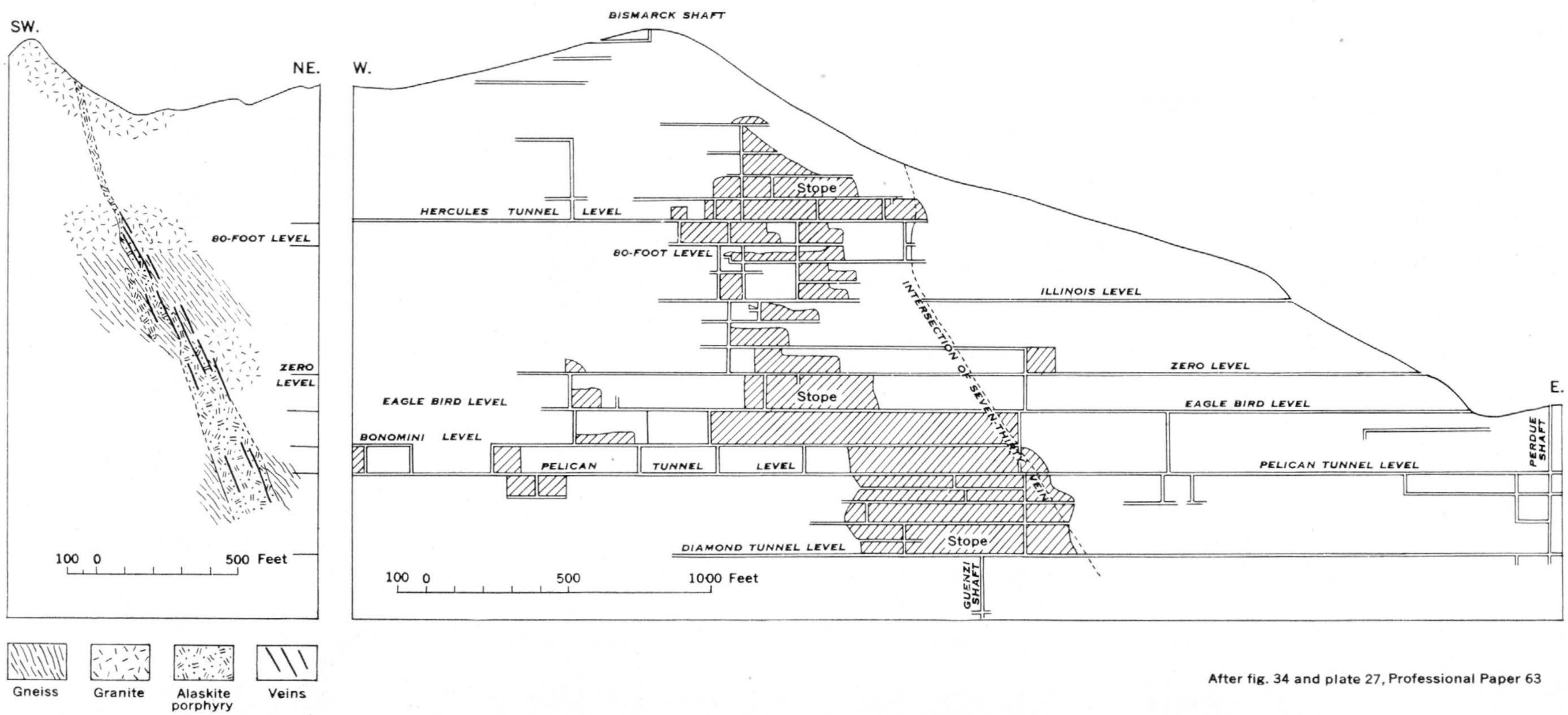


FIGURE 56.—Section and profile of the Pelican-Bismarck lode, Silver Plume district, showing vertical imbrication of vein and relation of ore shoots to the intersection of the Seven-thirty vein.

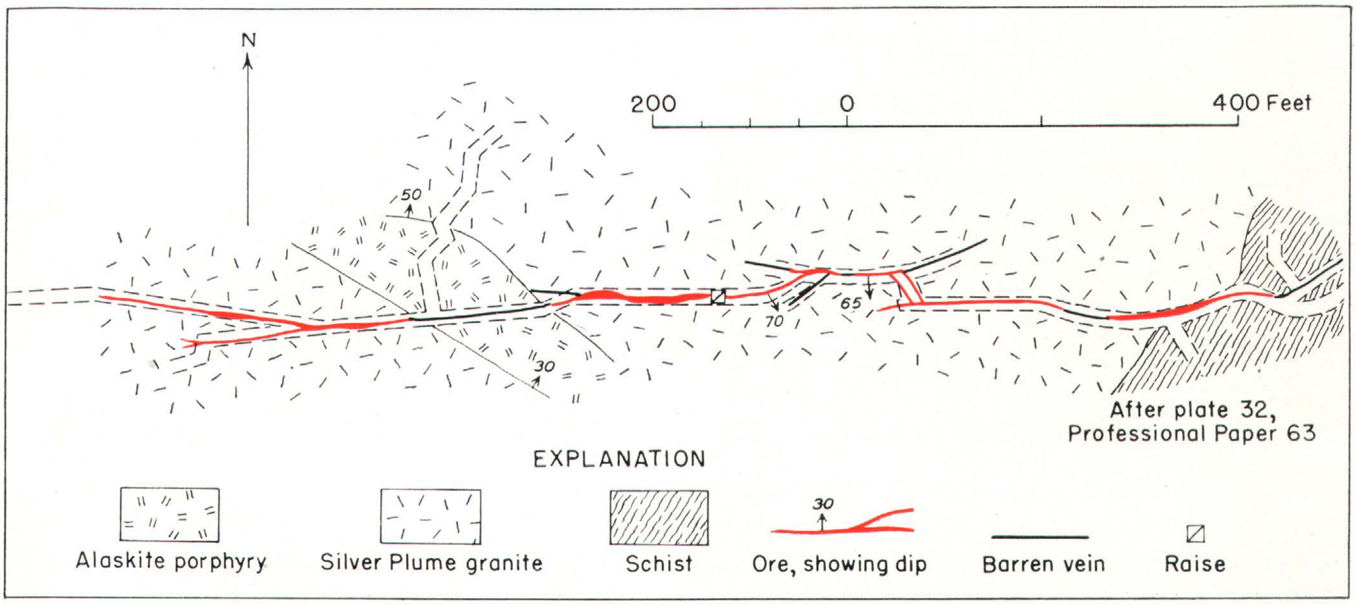


FIGURE 57.—Part of the 80-foot level of the Seven-thirty mine at Silver Plume, illustrating the preference of ore shoots for granite walls rather than alaskite porphyry and the widening of ore at junctions.

thus were instrumental in determining the location of the veins.

The most persistent vein in the Silver Plume district, the Pelican-Bismarck follows a north-northwesterly porphyry dike for more than half a mile. Similarly, the ore-bearing part of the Colorado Central vein follows a northeasterly dike of porphyry, though the vein is more persistent than the dike. The best ore in the Colorado Central vein, however, was near the porphyry dike and between walls of granite and pegmatite (fig. 37). In the Frostberg and Mendota veins gently dipping porphyry dikes cut by the veins apparently acted as guides for the rising mineralizing fluid and concentrated ore shoots in the wall rock immediately beneath the porphyry dike. The most productive ore shoots in the Frostberg mine occurred immediately under the porphyry dike; the ore persisted where the vein and dike coincided, but the vein became barren and unmineralized after it cut through the dike and entered the overlying schist. An ore shoot occurred beneath the same dike between granite walls in the Mendota vein, but the vein became barren as it crossed through the dike into overlying granite.

The beneficial effects arising from a combination of favorable wall rock and intersecting branch veins is well illustrated in the No. 1 Dunderberg level, where two branch veins unite in a granite mass and then enter the adjacent schist (fig. 54). The vein is nearly barren in the schist, but an extremely good ore shoot occurs at the intersection of the two fissures.

PELICAN-BISMARCK VEIN SYSTEM

The Pelican-Bismarck vein system [55] extends for more than a mile along the south slope of Sherman Mountain, from just north of Silver Plume to Brown Gulch, 1¼ miles to the northwest. The Bismarck lode was discovered in June 1866 and the Pelican in 1868. The Pelican claim was only 50 feet wide; the claims of both the Pelican Co. and the Dives Co. were so narrow that they failed to cover the lode. This led to almost interminable litigation, which did not end until 1880, when both claims were consolidated under the Pelican and Dives Mining Co.

The Pelican-Bismarck vein system, consisting of a main trunk vein with important branches at both ends, is perhaps the strongest vein system in the Silver Plume district. The trunk vein, called the Pelican-Bismarck, in general strikes N. 60° W. and has a moderate to steep northeast dip. The lode is complex, consisting in large part of overlapping, splitting, and reuniting or parallel veins occupying a narrow zone. The Seven-thirty vein splits off from the northwest part of the main trunk vein and strikes about S. 80° W.; the Wisconsin-Corry City vein splits off from the southeast part, and farther southeast the main vein splits into the Dives-Dunkirk and Baxter veins, which strike about S. 75° E. and S. 60° E., respectively. The Dives-Pelican is the principal mine that exploits the main trunk vein; it comprises about 15 miles of underground workings and develops the vein over a vertical range of about 2,020 feet.

The vein was formed along a strong fault that followed a preexisting dike of rhyolite porphyry of group 6 (see pl. 7 and fig. 12) for about half a mile and continued both to the northwest and southeast beyond the dike. It was most productive where it coincided with the dike. The dike in turn followed an earlier fault of the breccia-reef period; in places in the Diamond

[55] Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., pp. 185–186.

tunnel the reddish silicified sheared rock typical of the breccia reefs is visible on the hanging wall of the vein fissure, and at one place in the Pelican tunnel there is an inclusion of this material in the dike. Silver Plume granite is the chief wall rock other than porphyry dike along the main trunk vein, but it contains many lenses and blocks of schist, and schist and gneiss of the Idaho Springs formation predominates to the northwest and southeast. The porphyry has been faulted by the vein so that in places it is very thick and in other places is entirely absent. The various streaks that make up the vein may lie on one or both of the porphyry walls and within it; for example, on the Zero level there are two parallel veins, both in porphyry and lying about 70 feet apart. The northeast vein has been called the Bismarck and the southwest one the Pelican. In the Diamond tunnel the strongest vein lies on the northeast wall of the dike, but another productive vein lies partly on the footwall and partly within the dike.

The principal metallic minerals of the vein are sphalerite and galena with a considerable amount of pyrite in places. The chief gangue mineral is quartz, though barite, calcite, and, especially near the surface, siderite are present. The galena and sphalerite are both argentiferous, and the ore contains a little gold. In 1896 the average value of the ore shipped from the mine was $75 per ton. This ore contained 150 ounces of silver and 0.1 ounce of gold to the ton, 14 percent of lead, and 20 percent of zinc. Sulfides of silver, including argentite and polybasite, also occur, especially in the upper levels. Native silver was common near the surface. A specimen of ore from a depth of about 1,550 feet below the surface and 100 feet above the Pelican level, consists mainly of sphalerite, with some quartz, galena, tetrahedrite, polybasite, and a little dark-red ruby silver.

The aggregate length of workings along the main vein and its branches is about 7,200 feet. Most of the ore has come from a single shoot (fig. 56), which extended 500 to 800 feet along the vein and was continuous from the surface vertically down to the Bonomini level; from that level, with an offset to the southeast, it extended down to the lowest workings below the Diamond tunnel—a total vertical distance of approximately 1,500 feet. The upper part of this shoot coincides with the junction of the main vein with the Seven-Thirty vein. It would appear that the junction of the Seven-Thirty vein with the Pelican-Bismarck lode bears a causal relation to the principal ore shoot, but the junction is very weak, and the Seven-Thirty vein is not enriched near the junction. According to report, the intersection of the Wisconsin lode with the Pelican-Bismarck has a similar effect.

At the surface the ore of the principal Bismarck shoot consisted mainly of soft black silver sulfides, with much wire silver. From the surface to a depth of 40 feet oxidized ores having the appearance of brown clay are reported. These ores are said to have been the richest in the vein, containing several hundred ounces of silver to the ton. Mixed with the oxidized ores and extending downward for 200 to 300 feet, especially along watercourses, are soft black sulfide ores plainly of secondary origin. These ores consist chiefly of galena and sphalerite intermixed with sooty chalcocite and silver sulfantimonides and sulfarsenides, and contain several hundred ounces of silver to the ton. The ordinary ore of the vein consists of intercrystallized quartz, sphalerite, and galena with minor amounts of tetrahedrite. In many localities pyrite is scattered through the entirely altered porphyry of the vein. The best ore bodies are said to have been found at a depth of 300 feet, but good ore is also reported to have been found to a depth of 1,800 feet. The galena-sphalerite ore is much the same from the top to the bottom of the mine, but the sphalerite seems to be relatively more abundant in the lowest levels.

The porphyry along the vein has been largely decomposed to a soft white material, consisting of sericite, fine quartz, and iron carbonate. Near veins the wall rock is highly silicified. Small veinlets and oval cavities lined with quartz and filled with what appears to be kaolin are common. The kaolinitic material has been detected as far down as the Pelican level, about 1,500 feet below the surface.

Postmineral movement has been slight. Here and there, however, a few transverse faults, each with a displacement of a few feet, have been noted.

DIVES-DUNKIRK LODE [56]

In the neighborhood of Cherokee Gulch the Pelican-Bismarck lode splits into the Dives-Dunkirk and Baxter veins, the latter being in a direct line with the Pelican lode but weaker than the Dives-Dunkirk. Farther southeast both of these veins split repeatedly. In the Diamond tunnel the Baxter vein dips almost vertically, but the Dives, lying to the north, dips about 60° NE.; thus the two branches tend to diverge with depth. The Dives-Dunkirk vein has been followed continuously from its junction with the Pelican to the workings of the Dunkirk mine. In the Ashby tunnel workings the main Dives-Dunkirk vein is overlapped by a parallel vein about 100 feet farther north, which may be a branch from it, though the actual junction is not exposed in the accessible workings. The Dunkirk vein has not been traced southeast of the Ashby tunnel workings, but the Morning Star may be its southeasterly continuation.

The Dives-Dunkirk vein follows a strong fault, which has a general trend of N. 78° W. and a dip of 50°–80°

[56] Spurr, J. E., Garrey, G. H., and Ball, S. H., Economic geology of the Georgetown quadrangle (together with the Empire district), Colo.: U. S. Geol. Survey Prof. Paper 63, pp. 192–194, 1908.

NE. (pl. 10). Movement on the vein has been approximately horizontal, the northeast wall having moved northwest 5 to 12 feet. The effects of mineralization are rather irregular and bear no relation to the intensity of faulting. Some parts of the fault zone are quite unmineralized.

The wall rock of the Dives-Dunkirk vein is chiefly gneiss with some Silver Plume granite; no porphyry has been observed. The foliation of the gneiss has a general north-south trend. The ore consists of sphalerite, galena, and pyrite in various proportions, and the silver content may be as much as 300 ounces to the ton. In general the effects of mineralization grow gradually less with increasing distance from the Pelican vein. According to C. H. Morris, "the yield or production from the Dunkirk group since the discovery and location of the Dunkirk claim in 1868 has been some 200,000 ounces of fine silver." [57] This figure, however, does not include returns from large amounts of ore extracted from the west end of the vein between 1870 and 1880.

COLORADO CENTRAL VEIN [58]

The Colorado Central mine in Leavenworth Gulch, 1½ miles S. 20° W. of Georgetown, is one of the most famous in the region. It was discovered in 1872, and the estimated total value of its output exceeds $8,000,000. The strike of the Colorado Central vein or veins is about N. 45° E., and the dip is 60° NW. to vertical (figs. 37 and 52). The veins have been explored underground for three-quarters of a mile, and the workings reach to a depth of about 1,050 feet. The workings of the mine show a zone of parallel branching or overlapping veins. The main Colorado Central vein in its most productive parts skirts along the southeast contact of a granite porphyry dike that has a thickness of 8 to 40 feet. To the southwest the vein leaves the porphyry contact and finally splits, one branch swinging back to the porphyry contact and the other continuing the main trend of the vein. The northwestern branch is called the North vein and the southwestern branch the South vein. The junction pitches northeastward. On the Marshall tunnel and Aliunde No. 3 levels there is a series of imbricated veins between the North and the South veins, striking parallel to them and dipping 60° to 70° NW. (fig. 52). Where they parallel these veins the North and South veins become weak. Similar intermediate veins are found at greater depth, especially as the junction of these two veins is approached. In places the "flat" veins have a tendency to twist around, so that the general strike becomes somewhat oblique to the regular trend of the North and South veins. These discontinuous branching veins, which in places connect with the North and South veins, have produced considerable ore. The New North vein, a separate vein from those already described, skirts the northwest contact of the main porphyry dike. This vein trends parallel to the Central vein and diverges from the porphyry contact toward the northeast. On diverging it splits and has not been followed farther northeast.

These veins form a zone that is the core of a wider zone in which the rocks were sheeted and subsequently mineralized. Some of the veins thus formed have been very productive. The principal vein is the Kirkley, which lies a few hundred feet northwest of the Colorado Central vein. Another is the Munsill vein, which lies to the southeast. A noteworthy feature of all these veins is the tendency of the individual veins to be discontinuous and to overlap one another in an imbricate pattern. The veins overlapping to the north are offset to the west. On the 1,000-foot level, however, in the northeastern part of the workings, the overlapping is to the east. Foster [59] stated that depth seemed to have little effect on the metal content, although the mine was worked to a depth of 1,000 feet. He stated that rich and poor ore channels were found at all depths. It is reported that the richest ore shoot in the mine was worked more or less continuously from the surface down to the 500-foot level. This shoot between the 400- and the 500-foot levels contained the Carnahan stope, the richest in the mine. On the 1,000-foot level, the principal vein (North vein) is exposed for 1,700 feet, but only 17 percent of this developed extent of the vein is mineralized. On the 400-, 600-, 750-, and 850-foot levels, which also have long stretches of development, the percentages are about 55 to 71. It would appear that the entire vein is grading into an unmineralized fault lead at depth. High-grade polybasite and ruby silver ore were found on the 1,000-foot level, although miners stated that the ruby silver was more abundant in the upper than in the lower workings. Oxidation in general extended only a few feet downward from the surface, and the oxidized ore resembled a strongly iron-stained clay. It is reported to have contained 1,000 to 2,000 ounces of silver to the ton. No zonal distribution of the galena and sphalerite has been noticed in the mine.

The principal wall rocks in the Colorado Central vein are porphyry, gneiss, Silver Plume granite, and pegmatite (fig. 37). The gneiss is the most abundant, but it contains many dikes, lenses, and stringers of granite and pegmatite. Solid pegmatite occurs in the wall rock to a greater extent than in most other mines of the region. Granite porphyry in many places forms one of the walls of the main lode but rarely forms both walls. Two distinct dikes of granite porphyry are associated with the Colorado Central vein. They are

[57] Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., p. 194.
[58] Idem, pp. 245–264.

[59] Foster, E. L., The Colorado Central lode, a paradox of the mining law: Colorado Sci. Soc. Proc., vol. 7, p. 48, 1902.

parallel and 100 to 150 feet apart. The northwestern dike is followed by the Central and North veins. On the 400-foot level it is exposed for a distance of 2,000 feet and ranges in width from 20 to 40 feet, but on the other levels it is only 4 to 15 feet wide. The northeast dike pinches out, and the North vein continues for long distances in granite and gneiss. The southeastern dike is called the Aliunde dike.

The wall rock most favorable for strong persistent veins is granite or pegmatite. Hard gray granitic gneiss mixed with pegmatite and granite is an abundant wall rock in the central part of the mine, and in it the veins are strong and productive. In the eastern part of the mine workings soft black gneiss is prevalent and is characteristically weak and unmineralized. The gneiss strikes north or west of north diagonally across the vein. In soft gneiss the vein is likely to break up into overlapping parallel lodes where the foliation is nearly parallel to the vein. The most productive parts of the Colorado veins were near the Central porphyry dike. The porphyry contact afforded a plane of weakness, which made a single strong and persistent circulation channel. The wall rocks throughout are more or less altered to sericite, quartz, and siderite.

The pitch of the striations on the walls of the veins ranges from zero to 45° SW. The striations indicate that the southeast wall moved southwest at an average pitch of 20°. On the North vein in the Ocean Wave tunnel the horizontal displacement is approximately 100 feet. The main faults have been reopened several times. After the deposition of the porphyry dikes the faults were reopened and vein material was deposited. Post-porphyry faulting was renewed several times, and successive mineral assemblages were deposited. Post-mineral faulting has been of minor importance. In a few places the northerly or northwesterly faults have displaced the veins for short distances, the maximum being about 12 feet.

The most abundant metallic minerals of the Colorado Central veins are galena and light-yellow sphalerite with small amounts of pyrite. The galena contains a relatively small amount of silver. Most of the silver is contained in polybasite, argentite, pyrargyrite, stephanite, proustite, and tetrahedrite. Polybasite appears to be the most abundant silver mineral; it occurs in massive form and in crystals lining vugs. Next, but much less abundant, is ruby silver, chiefly pyrargyrite. Native silver is occasionally observed. Only the richer ore characterized by these silver-bearing minerals has been worked. According to Foster,[60] the average silver content of the ore mined over a 16-year period was 200 ounces to the ton. Very little gold was present, and only one lot of the ore mined contained enough gold to be paid for by the smelter; this lot consisted of concentrates that yielded 0.25 ounce of gold to the ton. According to a miner, only one pocket in the mine, the MacCarey stope on the 850-foot level, contained as much as 0.1 ounce of gold to the ton. Hematite in aggregates of small crystals was found in the lowest part of the mine, the 1,050-foot level, but the vein was barren of ore. The principal gangue mineral is quartz, both coarsely crystalline and chalcedonic, and it is locally abundant. Siderite and ankerite are also common. Calcite occurs in and near the veins, very commonly in the barren parts.

Quartz was continually deposited from the beginning to the end of the process of ore deposition. Siderite and ankerite also were deposited over a long period. Barite and kaolinite are apparently characteristic of the later period of deposition, although barite has been reported as one of the earliest minerals in the vein on the 1,050-foot level. Pyrite, although in small quantities is as widely distributed as quartz. Deposition of galena and sphalerite commonly began slightly after that of the first quartz and pyrite but was repeated subsequently. Polybasite, tetrahedrite, pyrargyrite, proustite, and argentite appear to have been deposited in the later stages, subsequent to the bulk of the older vein minerals. Hematite has been observed to be contemporaneous with quartz, sphalerite, and pyrite but also in a later formation with siderite, ankerite, galena, and pyrite. Specimens from the 500-foot level showed the following succession: (1) Medium-grained to coarse-grained intercrystallized galena, sphalerite, and jaspery quartz and (2) kaolin, barite, and polybasite in irregular geodes. A specimen from the 1,000-foot level shows (1) comb quartz with a little pyrite, (2) coarse-grained galena and sphalerite, (3) a thin coating of pyrite or chalcopyrite, and (4) finely crystalline calcite. One specimen from the 1,050-foot level showed a gangue of massive quartz and barite, in vugs of which parargyrite, galena, and sphalerite were deposited. A characteristic specimen from the dump showed (1) a lining of comb quartz and some pyrite, (2) coarse-grained galena and sphalerite, (3) barite, (4) a thin film of pyrite, and (5) ankerite or siderite.

All the pay ore contained polybasite and ruby silver. Where these minerals were absent the silver content rarely exceeded 25 ounces to the ton. Much of the first-class ore after sorting, averaged 700 to 800 ounces of silver. Second-class ore averaged 200 to 300 ounces. The ores were found in irregular shoots, which commonly pitched westward. A stope on the North vein extending 200 feet southwest of the junction and 100 feet above and below the 400-foot level contained the richest ore in the mine and yielded about $1,000,000. In the Carnahan stope below the 400-foot level ore worth $500,000 is said to have been extracted from a body 100 feet long and 50 feet high. The location of

[60] Foster, E. L., op. cit., p. 48.

these and other bonanzas indicated that the junctions of the veins may have been important in determining ore deposition.

GRIFFITH LODE [61]

The Griffith is a strong lode on the west slope of Griffith Mountain, about half a mile northeast of Georgetown. It has a general strike of N. 50° E. and a vertical dip. The Griffith mine exploits the southwestern part of the vein and the Annette mine the northeastern part. The vein is chiefly developed by a series of tunnels up the mountainside, and the Annette No. 1 level follows it for 1,900 feet. In places the vein branches and on the Annette No. 1 level it forks and reunites. The east end of the Griffith lode shows only a weakly mineralized slip. Near the southwest end of the developed lode, a branch, called the Sonora vein, diverges from the south side, opening out to the east. It strikes southeast and dips 70° NE. On the surface some high-grade ore containing 700 to 800 ounces of silver to the ton is said to have been taken from this vein, but where it joins the Griffith it shows only a small streak of pyrite.

The wall rock consists chiefly of gneiss of several varieties, but also of some pegmatite, alaskite, and hornblendite. In most places the rocks are well mingled. The vein shows two distinct periods of ore deposition, and its character therefore varies widely from place to place. Considering the vein as a whole, the ore minerals include galena, sphalerite, pyrite, and chalcopyrite, and the chief gangue minerals are brown carbonates, including siderite, rhodochrosite, and magnesite. Kaolin occurs in many places and is locally abundant. A silver telluride containing some gold is locally present in small quantities, associated with pyrite, galena, and chalcopyrite in a matrix containing a little magnesite. Dr. Pearce [62] gives an analysis of the mineral and concludes that it is a mixture of hessite and argentite. A specimen of this telluride ore assayed 17.5 ounces of silver and 1.97 ounces of gold to the ton, with 13.75 percent of lead and 5.8 percent of copper. The telluride ore occurred in a shoot that extended from the surface downward almost vertically.

In general the ores of the mine can be divided into two classes: The galena ores, which contain galena, sphalerite, chalcopyrite, and some pyrite, and the carbonate-pyrite ores, which contain carbonates, pyrite, and some barite. These two classes of ore were deposited at distinctly different periods.

Most of the output of the lode has come from the galena ores, though in general they are subordinate in quantity to the carbonate-pyrite ores. In the galena ores of the Griffith mine the metals in the order of value are lead, silver, and gold. In the Annette mine it is reported that the value of the ore is due more to gold, silver, and copper and less to lead. The galena ores are reported to contain an average of about 40 ounces of silver and 0.4 to 0.45 ounce of gold to the ton. The carbonate-pyrite ore, for the most part, could not be profitably mined; its average grade was about 0.10 to 0.15 ounce of gold and 10 to 12 ounces of silver to the ton, with little or no lead. However, one stope of carbonate-pyrite ore is reported to have yielded 20 to 25 ounces of silver and 0.3 to 0.5 ounce of gold to the ton. An assay of a specimen of this ore collected by Spurr yielded 0.16 ounce of gold and 63 ounces of silver to the ton. In many places the two classes of ores are mixed. On the Annette No. 1 level this mixed ore yielded 20 ounces of silver and 0.05 to 0.10 ounce of gold to the ton. On the Griffith No. 1 level a small body of rich ore in a low-grade vein contained 300 ounces of silver and 0.10 to 0.15 ounce of gold to the ton and some copper. This ore contained a sulfantimonide of silver, either tetrahedrite or polybasite.

The sequence of the vein formation is as follows:

1. The opening of a strong fissure.
2. The deposition of comb quartz and then the filling of the vein fissure with sulfides, comprising galena, sphalerite, pyrite, and chalcopyrite; tetrahedrite was noted along cracks in chalcopyrite.
3. Reopening of the vein with the formation of much larger openings. In some places this reopening split the older vein in the middle, in others the older vein was brecciated, and in still other places the new fissure departed locally or completely from the course of the original one.
4. The deposition of abundant carbonate and pyrite with very small amounts of chalcopyrite, galena, and sphalerite. The carbonate is apparently a mixed carbonate of iron, magnesium, manganese, and lime and probably includes siderite, magnesite, and ferriferous rhodochrosite. In places small crystals of quartz are scattered through the carbonates, but for the most part the deposition of quartz persisted longer than that of the carbonates. Barite, commonly found lining druses, was the last mineral deposited.

The surface ores were very rich and, according to Raymond,[63] contained sufficient gold to repay sluicing. It is reported that the upper levels contained more silver, gold, and copper and less galena than did the lower and that on the upper levels much of the carbonate-pyrite ore was rich enough to yield a profit.

On the Griffith No. 1 level, 100 feet from the portal, the Griffith vein is cut by a transverse fault striking N. 43° W. and dipping 76° NE., which offsets its

[61] Abstracted from Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., pp. 285–290.

[62] Pearce, Richard, Notes on the occurrence of a rich silver and gold mineral containing tellurium in the Griffith lode near Georgetown, Clear Creek County, Colo.: Colorado Sci. Soc. Proc., vol. 5, pp. 242–243, 1898.

[63] Raymond, R. W., Mines and mining west of the Rocky Mountains: 41st Cong., 2d sess., H. Ex. Doc. 207, p. 368, 1870.

northern part about 10 feet to the northwest. This fault is later than both periods of mineralization.

DEMOCRAT MOUNTAIN GROUP[64]

The Democrat Mountain group of veins occupies an area a few thousand feet in diameter on the very summit of Democrat Mountain, 2 miles northwest of Georgetown. As shown in figure 58, the zone of veins has an easterly trend, but the veins themselves belong to two sets, one having a northeasterly trend and the other a northwesterly. There was considerable activity in the district in the seventies, but for many years mining operations have been unimportant. The approximate value of the output has been about $2,000,000.

The veins of northwest strike include the Emma-Galie, the Polar Star-Junction, and the Fletcher-Silver Cloud; those of northeast strike include the Rogers and Cliff. Veins having strikes transverse to one another may join without crossing or may cross. Where they cross there has been no appreciable displacement. Some of the weaker lodes have an irregular or curved trend, more or less wavering between the two principal strikes. This is typical of the Nyanza and Silver Glance lodes. The vein filling is similar in both systems, indicating a contemporaneous mineralization of the vein zones. In the Buckeye mine postmineral movement was indicated by angular fragments of the ore cemented by silicified country rock.

The chief wall rock of the veins is biotite gneiss with considerable granite and some pegmatite and diorite. A single dike of porphyry, about 30 feet wide, was noted in the Queen tunnel. It has a northeast strike, is at right angles to the Queen of the West vein, and seems to have no important relation to the vein. The wall rocks are somewhat sericitized along the vein.

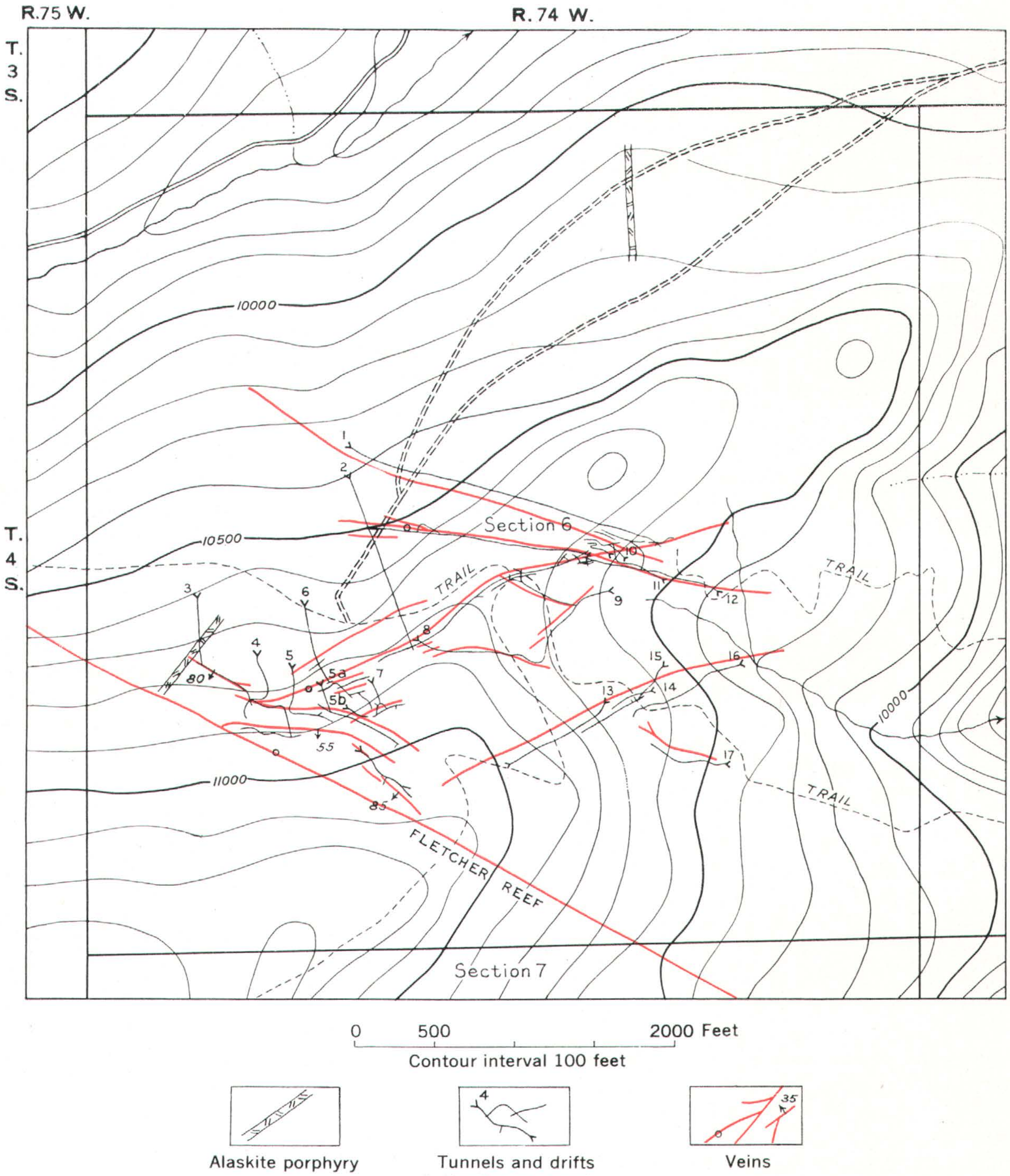
Porphyritic granite, or "corn rock," because of its greater rigidity, is more favorable to mineralization than the gneiss. In several places lodes passing from granite into gneiss show a tendency to split and break up. Galena is the chief sulfide present in the veins, but sphalerite also occurs, especially along the east slope of the mountain. Pyrite is rarely present, but locally there is some chalcopyrite.

Quartz is the chief gangue mineral; it occurs in both a distinctly crystalline and a fine cherty state. In places fragments of the crystalline quartz are cemented by the chert. In the Cliff mine iron and manganese carbonates were noted. The most characteristic ores of the group are high-grade silver ores, which contain no gold, and less iron, lead, and zinc than the ores of the Republican Mountain mines. The best ore contains several hundred ounces of silver to the ton; the amount of low-grade ore is not very great. Native silver has been found in several places. The quartz and carbonates are earlier than the galena and other sulfides. In some of the mines the sulfide ore has been brecciated and cemented by cherty silica.

In general the ore bodies of this group have been few in proportion to the amount of exploration, but they have commonly been high grade. Apart from the ore bodies the vein fissures show little mineralization. According to reports, the chief ore body of the group occurred in the vicinity of the principal crossing of the strong northeastward-trending Rogers vein with the northwestward-trending Polar Star and Emma veins. It is reported that around this junction, within a horizontal area of several hundred feet, $1,000,000 worth of ore was extracted. Apparently nearly all the intersecting lodes had ore shoots; however, in most places the ore did not occur at the junction but a short distance from it. It is reported that the ore shoots on the east side of the mountain dip east and those on the west side dip west. The ore bodies of this district are charteristically shallow, most of the ore coming from within 200 feet of the surface. Locally ore has been found to a depth of 400 feet or more, but the lower workings commonly have encountered chiefly barren and soft unmineralized lodes.

The Emma-Galie lode trends N. 70° W. and appears to cross the Rogers lode, which trends N. 75° E. A high-grade ore shoot is said to have occurred on the Emma vein where a minor diagonal lode intersected the main vein and coincided with it for some little distance before crossing. The Polar Star-Junction vein trends about N. 78° W. and crosses the Rogers. It has been developed along the strike for about 2,200 feet. To the west this vein forks; the northern fork is the Polar Star vein and the southern the Jordan. A small body of ore was found on the Jordan, not far from the junction. The Buckeye vein has a general strike of N. 85° W. and a dip of 60° to 80° S. It is opened by two tunnels. The country rock is gneiss with a little pegmatite. The vein tends to break up toward the east into a number of branches. On the main vein, near the junction with the main branch, the chief body of ore was found. The Queen of the West lode strikes about N. 58° W. and dips steeply southeast. It is a fairly strong vein and contains a little ore. The Silver Glance is a curving, oblique vein, having an average trend of about N. 85° W., and a dip of about 55° S. It is developed by a shaft and six levels, and considerable ore has been taken from small scattered shoots along it. The northeast system of lodes is represented chiefly by the Rogers and Cliff veins, which trend about N. 60° E. and are nearly 1,000 feet apart. Minor veins of the same system include the White Metal, Premium, and La Plata. The Rogers is the strongest and most mineralized lode of the region and crosses the chief veins of the north-

[64] Abstracted from Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., pp. 303–309.



LIST OF MINES

1. Matthews tunnel
2. Bonanza tunnel
3. Queen tunnel
4. Ramshorn tunnel
5. Silver Glance tunnel (No. 3 level)
5a. Silver Glance tunnel (No. 2 level)
5b. Silver Glance tunnel (No. 1 level)
6. White Pine tunnel
7. La Plata tunnel
8. Nyanza tunnel
9. Edgar tunnel
10. Lathrop level
11. Upper Junction adit
12. Lower Junction adit
13. Cliff mine (No. 1 level)
14. Cliff mine (No. 2 level)
15. Cliff mine (No. 3 level)
16. Cliff mine (No. 4 level)
17. Buckeye tunnel

FIGURE 58.—Sketch map of the Democrat Mountain group of veins. After figure 114 and plate 60, Professional Paper 63.

westerly system. It is opened up by the Edgar, Bonanza, and White Pine tunnels.

The Cliff mine was actively worked as early as 1857. According to Burchard's mint reports the output up to 1883 was $60,000. The mine is developed by four tunnels aggregating 2,500 feet in length. A number of small branches that leave the main vein appear to have had important influence on ore deposition.

OTHER MINES

Data on other mines of the district are given briefly below. Detailed descriptions have been given by Spurr, Garrey, and Ball.[65]

ANGLO-SAXON

Development.—Discovered 1867. Four levels, numerous cross cuts and shafts.

Production.—Prior to 1883, $700,000.

Vein.—Anglo-Saxon: Strike, N. 70° E.; dip, steep to vertical; irregular branching seams of oxidized material on surface.

Wall rock.—At surface altered granite and pegmatite with some gneiss striking N. 40° W., and dipping 20° NE.

Ore and sulfide minerals.—Argentite and galena.

Gangue minerals.—Quartz.

Changes with depth.—High-grade ore in oxidized zone.

Tenor.—High-grade ore, 1,000 to several thousand ounces of silver per ton.

ANGLO-SAXON EXTENSION

Development.—Tunnels aggregate 2,500 feet; seven levels, lowest 825 feet long in 1905.

Production.—1889: $2,016. Gold, $880; silver, $768; lead, $250; copper, $118. 1890: $3,955. Gold, $1,100; silver, $2,246; lead, $609.

Veins.—Anglo-Saxon Extension: Strike, N. 73° E.; dip, flatly northwest; slickensides pitch 65° NE.

Wall rock.—Lowest level is in gneiss striking northwest.

Ore and sulfide minerals.—Chiefly galena but some malachite, azurite, and cerussite in oxidized zone.

Gangue minerals.—Quartz.

Ore shoots.—Mostly pitch northeast. Most of the ore is between Blacksmith Shop level and Seventh level 225 feet apart.

Tenor.—Lean ore yielding $10 to $18 per ton.

BAXTER LODE

Development.—Exposed in Diamond and Ashby tunnels and in inaccessible upper levels.

Production.—Total to 1880, $360,000.

Vein.—Baxter: Strike, N. 60° W.; dip, steeply northeast to vertical. Is a southeast branch of the Pelican-Bismarck vein.

Wall rock.—Silver Plume granite.

Ore and sulfide minerals.—Galena and sphalerite.

CENTENNIAL GROUP

Development.—Burrel and Big Indian veins explored laterally ½ mile and Centennial for 1,400 feet. Centennial shaft is 600 feet deep.

Production.—Centennial about $300,000; Burrel about $17,000.

Veins.—Centennial: Strike, N. 40° E.; dip vertical. Vein branches and weakens at both ends. Branches at southwest end are parallel and strike S. 60°–70° W. Form zone several hundred yards wide. Burrel, chief branch of Centennial; Big Indian and Big Chief are also branches of Centennial.

Wall rock.—Biotite gneiss with some pegmatite. Southwest extensions in Silver Plume granite.

Ore and sulfide minerals.—Chiefly pyrite, chalcopyrite, tetrahedrite, galena, sphalerite, and pyrite. Gold is associated with chalcopyrite, and silver with tetrahedrite.

Gangue minerals.—Quartz; some postore fluorite in Big Chief vein.

Changes with depth.—Oxidation to depth of 10 to 20 feet. Sulfides occur locally at surface. On 600-foot level vein is strong but assays only $6 to $10.

Ore shoots.—Shoot from surface to below fifth level. On 500-foot level, shoot is due to junction of two branches converging to southwest. Maximum width of ore here is 10 to 14 feet.

Tenor.—Ore contains: Silver, 20 to 30 ounces per ton; gold, 1.0 to 1.5 ounces per ton; copper, 4 to 8 percent; average value, 300- to 500-foot levels, $18.60 per ton, three-quarters gold. One assay on 500-foot level, 522 ounces of gold per ton. Small amounts of platinum and iridium on 600-foot level. In Big Chief vein ore about $10 per ton.

COMET-AETNA LODE

Development.—Original discovery, 1867. Comet mine, 3 shafts and tunnels; Aetna mine, 3 tunnels.

Production.—$60,000 from one ore shoot.

Vein.—Comet-Aetna: Strike, N. 55° E., dip, 70° NW. About 5 to 8 feet of vein in places; few feet of ore at maximum. Fills strong fracture. May be extension of Colorado Central. Soft and difficult to drift. Zone 100 to 200 feet wide contains numerous quartz stringers.

Wall rock.—Altered pegmatite and granite with granite and micaceous gneiss. Gneiss strikes N. 80° W., dips 45° NE.

Ore and sulfide minerals.—Galena and sphalerite and some pyrite and a little chalcopyrite.

Gangue minerals.—Chiefly quartz but some siderite and ankerite; ore in cavities lined with drusy quartz.

Tenor.—Ore in Comet mine low grade. Ore in Aetna mine 35 to 300 ounces of silver per ton. Some assays as high as 1,600 ounces.

KIRTLEY GROUP

Development.—Kirtley vein opened 1,200 feet in Kirtley tunnel, 250 feet on Marshall tunnel level of Colorado Central mine. Minor workings on other veins.

Production.—Kirtley mine: To April 1880, $250,000.

Veins.—Argentine: Strike, N. 75° E.; dip, 75° SE.; imbricates Kirtley on northeast. Creole: Strike, N. 78° E.; branch of Argentine. Equator: Strike, N. 25°–40° E. Gates: Strike, N. 32° E.; dip, 55° NW. Hidden Treasure; Strike, N. 25°–40° E. Kirtley: Strike, N. 45° E.; dip, northwest in upper levels, vertical in Kirtley tunnel, southeast in lower levels; smaller veins branch laterally and vertically. O. K.: Strike, N. 55°–78° E.; dip, 30°–35° NW.; joins Kirtley 300 feet northeast of Stranger junction. Stranger: Strike, S. 85° W.; dip, vertical; main branch of Kirtley, turns northeast at junction. Tilden: Strike, N. 87° W.; dip, 70° N., may join both Kirtley and O. K. Veins are an inch to 8 feet wide. Movement along veins was slight.

Wall rock.—In southwest part of mine, gneiss striking N. 15°–25° E., and dipping 70°–80° NW. In east part, granite gneiss with pegmatite.

Ore and sulfide minerals.—Galena, sphalerite, polybasite, tetrahedrite, chalcopyrite, pyrargyrite, proustite, and gold.

Gangue minerals.—Quartz, comb and chalcedonic.

Changes with depth.—In O. K. and Tilden veins high-grade oxidized near surface.

[65] Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., pp. 185–311.

Ore shoots.—Abundant ore at junction of Kirtley and Stranger veins; extends 500 feet to northeast along Kirtley and 200 feet along Stranger. Best ore 20 to 30 feet from junction.

Tenor.—Fine-grained or fibrous galena contains more silver than ordinary galena. Low-grade ores commonly are higher in sphalerite. Kirtley ore contained 100 to 600 or more ounces of silver per ton. The Argentine and Creole veins contained much lead, less than 100 ounces of silver per ton, some zinc, and 0.1 ounce of gold per ton. In the O. K. and Tilden veins oxidized ore contained 100 to 1,200 ounces of silver per ton. Best ore is usually at junctions.

LEBANON GROUP

Development.—Lebanon tunnel 1,082 feet long; 2,500-foot tunnel on Edinburgh vein.

Production.—$500,000 or more.

Veins.—Network of branching and crossing lodes with general northeast trend. Most branches open to east. Alhambra: Strike, N. 55° E.; dip, 60° NW.; branch of Morning Star; intersections usually enriched, slickensides horizontal. Edinburgh: Parallel to Elija Hise vein. At junction with Scott vein, Edinburgh is a 6- to 8-inch quartz seam. Elija Hise: Strike, N. 75° W.; joins Alhambra. Everett: Strike, N. 65° E.; branch of Alhambra. Morning Star: Strike, N. 80° E., dip, 50°–65° NW.; eastern extension is East Peru lode; unites with Alhambra to west. Number 9: Extension of Peru. Peru: strike, west; dip, vertical. Scott: northeast extension of Alhambra.

Wall rock.—Gneiss having northeast trend. Morning Star vein is partly on contact of Silver Plume granite and porphyry dike. Silver Plume granite along Scott vein.

Ore and sulfide minerals.—Chiefly galena, sphalerite, and tetrahedrite but some chalcopyrite and pyrite. Also iron oxides in Edinburgh vein and some barite in Peru vein.

Gangue minerals.—Quartz.

Ore shoots.—Rich shoots at junction of Alhambra with Morning Star vein; stoped 100 feet above tunnel level.

Tenor.—At junction of Alhambra with Morning Star: 100 to 125 ounces of silver per ton, 26 percent of zinc, and 19 percent of lead. Sorted shipment contained 26 percent of lead, 14 percent of zinc, 42 ounces of silver per ton, 0.1 ounce of gold per ton.

MAGNET LODE

Development.—Shallow shaft and 5 tunnels, lowest 500 feet; aggregate, 6,000 feet of workings.

Production.—Prior to 1875, more than $50,000.

Veins.—Magnet: Strike, N. 45°–77° E.; dip, 45°–75° NW. Vein follows strong fault with branching minor fractures. Slickensides pitch 30°–63° SW. Vein varies from single seam to zone of stringers. On east two mineralized veins converge and join Magnet; one strikes S. 57° W., the other S. 28° W. Vein is cut by De Meli lode, which is unmineralized fault. Sequel: Strike, northeast, dip, northwest.

Wall rock.—Chiefly porphyritic biotite gneiss. To northeast pegmatite and injection gneiss; farther northeast soft biotite gneiss. Much alteration in places.

Ore and sulfide minerals.—Galena, polybasite, sphalerite, and tetrahedrite; some chalcopyrite and pyrite.

Gangue minerals.—Quartz and some barite.

Ore shoots.—Main ore bodies confined to hard rock. Junctions and flattening of dip influenced ore. Tunnel No. 1: Ore body 250 feet along tunnel, from surface to 235 feet below, shoot pitches 60° E. Body east of De Meli lode 40 feet long, steep pitch; extended between levels 2 and 3.

Tenor.—Average gold content, 0.05 ounce per ton. Silver, 35 to 700 ounces per ton, some as high as 1,400 ounces; average, 150 to 300 ounces per ton. Silver content usually greater where zinc is less. Ratio of zinc to lead is 2:1.

PAYROCK LODE

Development.—Discovered 1872. Vein developed 2,700 feet along strike, workings aggregate about 5 miles; lowest level (Ashby tunnel) 1,000 to 1,500 feet below surface.

Production.—To 1880, $450,000. 1889: Silver, $135,757.56; lead, $3,952. 1890: Silver, $35,203; lead, $517. 1892: Silver, $217,479; lead, $6,107. Total estimated, about $2,000,000.

Vein.—Payrock: Strike, N. 50° E.; dip, about vertical. Best ore at junction of veins. Payrock entirely cut off by Silver Point dike.

Wall rock.—Hard gneiss (strike, due north) with pegmatite and granite porphyry dike (Silver Point "lode").

Ore and sulfide minerals.—Chiefly galena, some polybasite (?), pyrite, and sphalerite.

Gangue minerals.—Chiefly quartz but some calcite and siderite.

Changes with depth.—Carbonates more abundant near surface. Richest and longest ore bodies near surface. Secondary sulfides reported 50 feet below surface. Good ore to maximum of 1,200 feet below surface.

SEVEN-THIRTY LODE

Development.—Original location, 1870. Hercules tunnel. Shaft with eleven levels, from Hercules level to depth of 975 feet. Above Hercules level 5 tunnels driven west, 3 east. Workings aggregate 5 to 6 miles.

Production.—To 1896, $1,868,720.97. Not much since 1896.

Vein.—Seven-thirty: Strike, east to N. 50° E.; dip, from 80° N. to 55° S., average 80° S. Is a branch of Pelican-Bismarck, but junction is inconspicuous. Slickensides are horizontal to 25° E.; left-hand wall moved ahead, but movement was small. Vein is largely replacement of wall rock; commonly no definite walls.

Wall rock.—Silver Plume granite, gneiss, pegmatite, and quartz monzonite porphyry dike 50 to 80 feet wide, which dips flatly east to northeast.

Ore and sulfide minerals.—Galena, sphalerite, polybasite, tetrahedrite, and a little pyrite. Native silver, argentite, and pyrargyrite are also reported.

Gangue minerals.—Chiefly quartz but a little barite and late calcite.

Changes with depth.—Oxidized ore extends to about 40 feet below surface, richest in mine. Ore said to be good down to sixth or seventh level; below, it consists of sphalerite and pyrite ores poor in lead and silver. On Burleigh tunnel level, 1,800 feet below Hercules tunnel, supposed Seven-Thirty vein is very weak and very lean.

Ore shoots.—Most favorable ground is where vein bends to more easterly course and is between granite walls. West of shaft is a fairly continuous ore shoot from surface, 1,000 feet in pitch length and 900 feet in stope length. East of shaft are scattered stopes over horizontal distance of 1,750 feet and vertical distance of 400 feet.

Tenor.—1887–95 ore averaged 154 ounces of silver per ton, 11.5 percent of lead, and 0.1 ounce of gold per ton; value, $113.17 per ton. Some ore contained 1,400 to 1,500 ounces of silver per ton.

SNOWDRIFT LODE

Development.—Two shafts and 4,500 feet of workings. Vein explored nearly 1,000 feet horizontally and 400 feet vertically; some stoping.

Production.—1870: $96,316.80.

Vein.—Snowdrift: Strike, N. 85° W.; dip, about vertical. Vein branches repeatedly in gneiss.

Wall rock.—Soft gneiss with patches of granite porphyry.

Ore and sulfide minerals.—Galena, gray copper, decomposed sulfides (sooty chalcocite?), and sphalerite.

Gangue minerals.—Quartz (chalcedonic).

Changes with depth.—Ore extends down 300 feet. Better near surface. Upper bodies rich in silver.

SUNBURST AND SCEPTRE LODE

Development.—Sceptre tunnel follows vein 2,300 feet. Two tunnels on Sunburst vein, upper 132 feet above lower and 1,000 feet long. Lower, 225-foot crosscut and 900-foot drift on vein.

Veins.—Sceptre: Strike, N. 73° W.; dip, 70° SW. Sunburst: Strike, N. 70° W.; dip, 70° SW.; is western extension of Sceptre. Minor veins parallel to main vein. Vein of ore, or mixed ore, quartz, and brecciated country rocks as much as 5 feet wide bordered by zone of dense clay and crushed rock on hanging wall and gray jaspery quartz on footwall.

Wall rock.—Chiefly gneiss and pegmatite. Local bodies of Silver Plume granite. Alaskite dike 15 to 18 feet wide along southwest side of vein.

Ore and sulfide minerals.—Chiefly galena and sphalerite but some pyrite, chalcopyrite, polybasite, and tetrahedrite. Some native silver within 200 feet of surface in Sunburst mine.

Gangue minerals.—Quartz, ferruginous rhodochrosite and siderite. Also wall-rock fragments.

Changes with depth.—Ore in upper parts of shoots commonly a little higher grade than in lower.

Ore shoots.—Main ore body in Sceptre mine, 1,250 feet northwest of portal of tunnel. It was 320 feet long and pitched 16° southeast. Another body about 150 feet long, 1,700 feet from tunnel portal. In Sunburst mine, one ore body extended from 125 to 325 feet from portal of upper tunnel and from surface to lower level; vertical to steep westerly pitch. Second ore body, 490 feet southeast of upper tunnel portal, was 275 feet in stope length and extended from 115 feet above upper level to lowest level; pitched northwest.

Tenor.—Ore mostly low grade. Sceptre ore contained 30 to 300 ounces of silver and 0.08 to 0.12 ounce of gold per ton, 3 to 5 percent of galena, and 5 to 12 percent of sphalerite. Sunburst ore averages 100 ounces silver and 0.08 to 0.10 ounce of gold per ton, 4 to 5 percent of lead, and 8 to 10 percent of zinc.

TERRIBLE VEIN GROUP

(Includes Terrible, Dunderberg, Frostberg, Mendota, Smuggler, Mammoth-Brown, West Terrible, and Baltimore mines.)

Development.—Many miles of workings, many shafts. Developed at depths by Burleigh, Mendota, and other crosscut tunnels.

Production.—Probably several million dollars. 1890: Silver, $19,368; gold, $1,950.

Veins.—Three master veins roughly parallel and about 500 feet apart: Mendota, Terrible, Fenton-Mammoth. Veins have general trend of N. 70° E.; form zone 5,009 feet long and 1,000 feet wide; many branches. On master veins and others of northeast trend, southeast wall moved southwest. Where veins are parallel to strike of gneiss they are barren. Postmineral faulting unimportant. In northeast part, all veins cut strong northwestward-trending quartz monzonite porphyry dike. Baltimore vein: Strike, east-west; dip, 60° N.; branch on northeast side of Fenton vein. Blaine vein: Branch of Fenton, may be western extension of Silver Ore; junction of Blaine and Fenton pitches flatly to west. Brown vein: Strike, east-west; Brown and other minor east-west veins cut main Fenton-Mammoth vein. Bush vein: Strike, east-west; dip, 70° N.–85° S.; branch of Mendota vein in east. Cascade vein: Strike, east-northeast: dip, 40°–60° N.; irregular branch on south side of Terrible vein. Cashier vein: Strike, northeast; dip, 68°–88° SE.; eastern extension of Cascade. Dunderberg vein: Strike, northeast; dip 70° SE. to vertical; main lode called Dunderberg northeast of where Terrible vein splits; Dunderberg branches to northeast and cuts northwestward-trending quartz monzonite porphyry dike. Elephant vein: Central branch of Terrible vein. Fenton vein: Strike, northeast; dip, steeply north to vertical; southwest end of Fenton-Mammoth; junction of Blaine and Fenton pitches flatly to west. Fenton-Mammoth vein: Strike, northeast; dip, steeply north to vertical; splits at intersection with quartz monzonite porphyry dike, joins Terrible vein on northeast and southwest; few inches to 3 feet wide on Burleigh tunnel level. Frostberg vein: Strike, east to east-southeast; dip. 50°–80° N.; east branch of Dunderberg: cuts quartz monzonite porphyry dike; few inches to 5 feet wide; splits at depth into north and south Frostberg veins; worked 1,100 to 1,200 feet along strike. Gunboat vein: north branch of Terrible. Mammoth vein: Strike, northeast; dip, nearly vertical; main vein northeast of intersection with Brown; cuts quartz monzonite dike. Mendota vein: Strike, northeast; dip, from 85° NW. to 72° SE.: splits on northeast into Bush and Tishomingo veins; fraction of foot to 4½ feet wide. Maine vein: Strike, northwest; dip, 40°–60° NE.; few inches to 2½ feet wide; eastern extension of Terrible-Dunderberg system. Queen vein: Strike, east-west; dip, 55°–70° N.; branch of Fenton. Silver Ore vein: South branch of Terrible; may be eastern extension of Fenton. Smuggler vein: Strike, northeast; dip, steeply south; southwest extension of Mendota. Terrible vein: Strike, N. 60° E.; dip, 60°–65° NW.; joins Fenton-Mammoth on northeast and southwest; splits at intersection with quartz monzonite porphyry dike; reunites farther east to form Maine vein; Terrible splits into branches (Gunboat, Elephant, and Silver Ore). Tishomingo vein: Strike, west to northwest; dip, 70°–89° N.; main branch of Mendota.

Wall rock.—Chiefly schist, gneiss, and Silver Plume granite, both separate and mixed. Veins strongest in granite and weak in gneiss and schist. Quartz monzonite porphyry dike trends northwest. Other smaller dikes. Walls invariably altered.

Ore and sulfide minerals.—Galena, sphalerite, and pyrite. Some polybasite, chalcopyrite, tetrahedrite, and ruby silver.

Gangue minerals.—Chiefly quartz but some siderite and barite.

Changes with depth.—Ruby silver and polybasite most abundant in upper levels. Silver content decreases with depth. Sulfide fairly constant to 1,250 feet. In Mendota vein, 15 feet below surface oxidized ores 5 to 10 feet thick, in places oxidized zone went down 150 feet; lower down, less lead, more zinc; silver decreases with depth; heavy pyritic ore in places near surface.

Ore shoots.—Ore shoots localized by junctions, by granite wall rock, and in eastward-trending parts of veins. Large amount of stoping on master veins. On Mendota vein, much stoping for length of more than 2,100 feet and from surface to depths of 600 to 900 feet.

Tenor.—In general, ore contained from 20 to several hundred ounces of silver per ton, 2 to 50 percent of lead, 4 to 40 percent of zinc, and 0.01 to 0.22 ounce of gold per ton. High-grade ore from Terrible vein contained 100 to 800 ounces of silver per ton. Most of Mendota ore contained 20 to 40 ounces of silver per ton. Considerable high-grade ore from Baltimore vein contained 200 to 500 ounces of silver per ton. Smuggler ore, 1893–1900, contained 15 to 156 ounces of silver per ton, 2 to 49.85 percent of lead, 4 to 40 percent of zinc, and 0.06 to 0.22 ounce of gold per ton. South Frostberg vein, 200 to 400 ounces of silver per ton in upper levels, 10 to 15 ounces on Mendota level.

WIDE WEST LODE

Development.—Original discovery, 1881. Tunnels, shafts, and other workings aggregate 8,500 feet.

Production.—Several hundred thousand dollars.

Vein.—Wide West: Strike, N. 82° E.; dip, 60° to 75° NW.; few inches to 12 feet wide. Vein at right angles to foliation of gneiss. On lowest level lode composed of two parallel veins 10 to 20 feet apart. On No. 4 level main lode splits into 3 veins.

Wall rock.—Alternating bodies of pegmatite and granite gneiss. Silver Plume granite in east end of lowest level.

Ore and sulfide minerals.—Galena, polybasite, tetrahedrite, and pyrite and some chalcopyrite and sphalerite.

Gangue minerals.—Chiefly gray quartz, barite, siderite, and calcite.

Changes with depth.—Siderite and calcite common at surface. Richest and largest ore bodies between 3d and 5th levels. Good ore as low as 600 feet.

Ore shoots.—Ore bodies localized in the flatter parts of the vein. Rich body on south branch of lode was 200 feet long and 300 feet high and pitched slightly east. Both the main vein and the two branches contained ore bodies about 75 feet from the junction.

Tenor.—Some mill runs yielded 1,000 to 2,000 ounces of silver per ton. Mill run in 1905: Silver, 236 ounces per ton; lead, 8 percent; zinc, 4 percent. Highest silver content in fine-grained galena.

WISCONSIN-CORRY CITY LODE

Development.—Corry City shaft, 850 feet deep on incline, with 10 levels; connects with Diamond tunnel at bottom. Upper and lower Wisconsin tunnel above shaft collar to west. Workings aggregate more than 17,500 feet.

Vein.—Wisconsin-Corry City: Strike, west to northwest; dip, 50°–60° N.; follows strong fault zone, in places several feet wide. Slickensides nearly horizontal. Ore along thin seams in fault zone.

Wall rock.—Alaskite porphyry (altered), gneiss, and Silver Plume granite.

Ore and sulfide minerals.—Galena, sphalerite, and pyrite, and some tetrahedrite or polybasite.

Gangue minerals.—Ankerite and other carbonates and some quartz.

Changes with depth.—Most of ore taken out from surface to depth of 300 to 500 feet. On Diamond tunnel level, lowest level in vein, lode is poorly mineralized.

Ore shoots.—Corry City ore shoot about 1,000 feet in pitch length and 500 feet in breadth. Two Wisconsin ore shoots, one about 500 feet in pitch length and 300 feet in breadth and the other 450 feet in length and 200 feet in breadth.

Tenor.—Ores have good silver content; the best ore contains several hundred ounces.

EMPIRE DISTRICT

The Empire mining district[66] occupies an area of about 8 square miles in the vicinity of Empire, in the southwestern part of the Central City quadrangle. It ranges in altitude from 8,500 to 11,500 feet.

The first activity in the Empire district was the discovery of the oxidized part of the Silver Mountain ore zone in 1862. This gossan was washed in sluices and treated in the same way as placer gravels, yielding a good profit, and for several years the district was very prosperous. Water was brought in a ditch from Mill Creek, 3½ miles away, and most of the surface material was sluiced. These operations decreased in importance after 1875 but continued in a small way for many years. The total gold recovered by this method amounts to a little more than 75,500 ounces. Lode mining has been intermittently productive since the seventies. After several years of desultory output the district recently assumed an important place with the development of the Crown Prince-Atlantic group by Minnesota Mines, Inc., from 1934 to 1943, when the mine was shut down, owing to World War II.

GEOLOGY

The pre-Cambrian rocks of the district include the Idaho Springs formation, Swandyke hornblende gneiss, granite gneiss, Boulder Creek granite, Silver Plume granite, and pegmatite. Boulder Creek granite occupies the greater part of the area. Silver Plume granite is present in the southern part and is also prominent just to the north of Mill Creek. (See pl. 2.) A moderately large area of schist borders the western part of the district, and small lenses and masses of schist, hornblende gneiss, and gneissoid granite are found scattered irregularly through the district itself. The largest of these lenticular masses is a northward-trending body of schist about a mile long and a thousand feet wide in the valley of North Empire Creek. The foliation in general trends northeast but in places trends nearly due north.

Within the district there are many porphyry dikes and stocks of the Laramide revolution (pl. 2) that are similar lithologically to those of the Silver Plume-Georgetown district. A stock of monzonite of group 4 (see pl. 7 and fig. 12), 1½ miles in diameter, occupies the western part of the district, and a small mass crops out east of Miller Creek near its mouth. The intrusion of the small stock that lies between Lion and North Empire Creeks probably had an important part in forming the fractures that surround it, which are so extensively mineralized. These fractures include those of the productive Minnesota mine and the Silver Mountain ore zone (fig. 59). In various parts of the area surrounding Empire there are dikes of quartz diorite and andesitic rocks, also of group 4. Quartz diorite dikes of closely related character were found in the Aorta tunnel of the Gold Dirt mine and in the Silver Mountain mine. One mass in the Aorta tunnel is probably an independent intrusive body that does not reach the surface. That in the Silver Mountain mine may be an offshoot from the mass between Lion and North Empire Creeks. Dikes of quartz monzonite porphyry of group 5 are limited to Douglas and Lincoln Mountains, the valley of Miller Creek, and the ridge between Lion and North Empire Creeks. In the Empire tunnel are dikes of quartz diorite porphyry that appear to be related. A few dikes of granite porphyry and of alaskitic quartz monzonite porphyry, both of group

[66] Spurr, J. E., Garrey, G. H., and Ball, S. H., Economic geology of the Georgetown quadrangle (together with the Empire district), Colo.: U. S. Geol. Survey Prof. Paper 63, pp. 383–410, 1908.

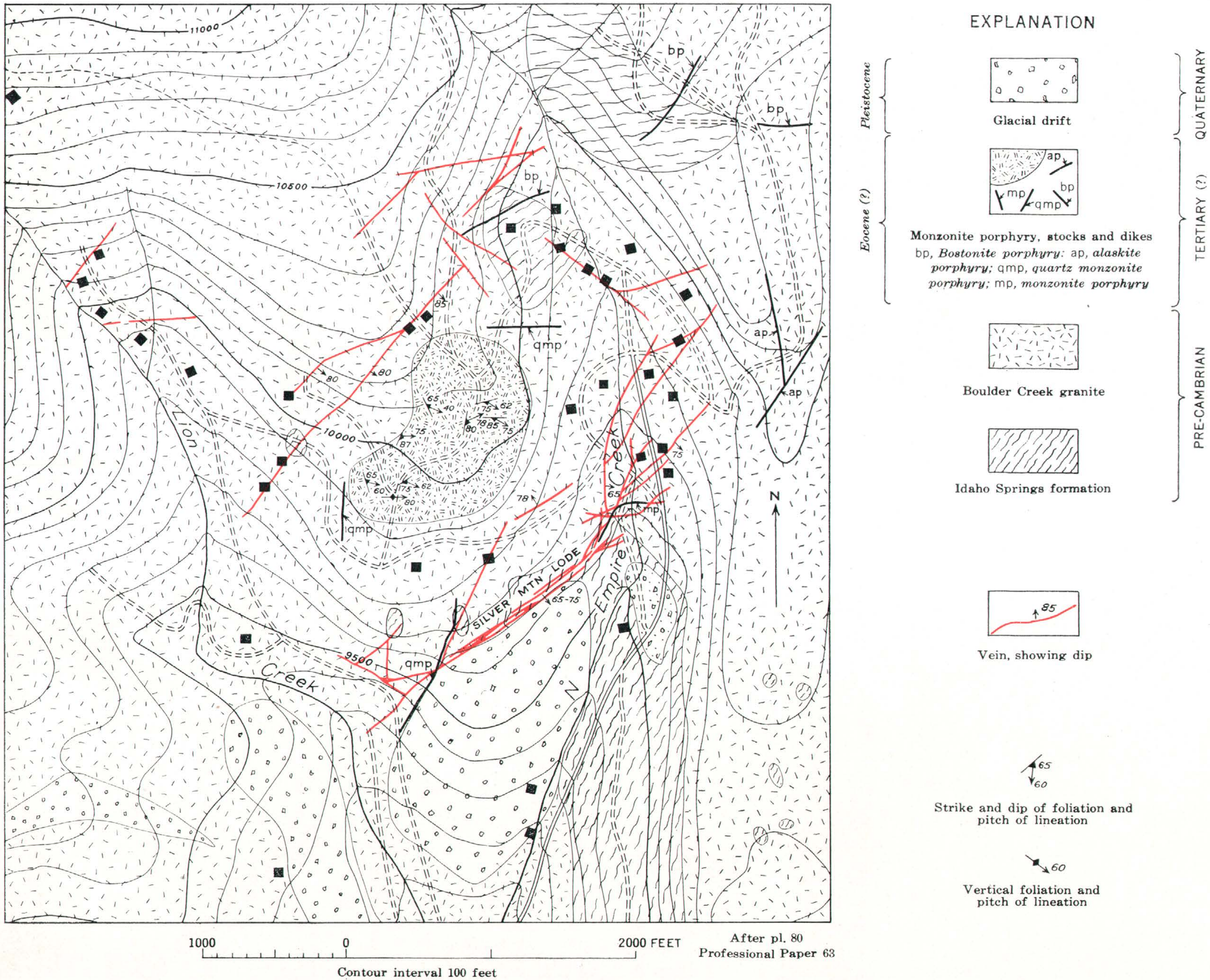


FIGURE 59.—Map showing relationship of veins to porphyry stock in the Empire district.

7, are found underground in some of the mines. Alaskite porphyry forms a stock six-tenths of a mile long a mile west of Empire, also dikes on the ridge east of North Empire Creek and on the divide between North Empire and Mill Creeks. The stock appears to cut the monzonite. Alaskite porphyry was also found underground in a number of the workings. A number of dikes of bostonite and bostonite porphyry of group 9 occur in the northern part of the Empire district and also near the south end of the ridge east of Lion Creek about half a mile north of Empire. A dike of bostonite was found underground in the Golden Chariot mine, and a dike of biotite latite of group 11, 2½ feet wide, was cut by the Elizabeth tunnel.

The Pleistocene deposits of the district include drift of the earlier glacial epoch; drift, moraines, and outwash gravels of the later glacial epoch; and recent alluvium.

ORE DEPOSITS

The ore deposits of the Empire district are almost entirely of the pyritic gold type. The chief metal produced is gold, although in places there is sufficient copper to be of value. The chief minerals of the veins are pyrite, chalcopyrite, and quartz. Rarely there are small amounts of sphalerite and galena. The veins have a general northeasterly trend and a steep dip to the southeast; they are chiefly limited to a narrow belt surrounding the quartz monzonite porphyry stock 1½ miles due north of Empire and to the area just northeast of the town.

Most of the veins are fissure fillings and occur both as simple fractures and as complex lodes. A mile and a quarter north of Empire is the strong zone of fracturing and alteration, about 3,500 feet long and several hundred feet wide, called the Silver Mountain ore zone. This zone is impregnated with pyrite throughout and contains irregular bodies of ore along certain fractures. It lies a few hundred feet southeast of a small stock of monzonite, which is elongated in a northeast direction. A similar complex lode, in the Comet-Little Johnny group, parallels it to the northwest. Where these lodes end northwesterly cross lodes occur in the area between them. It seems probable that this encircling zone was formed by the stresses related to the intrusion of the porphyry stock and probably reflects the collapse of the roof when some of the underlying magma was withdrawn following a late stage in the consolidation of the stock. The most important mines in the district are found in the northeast parts of this zone. Just north of Empire several short veins follow a northeasterly zone of porphyry dikes.

In general the individual veins are not persistent, though they may be wide, strong, heavily mineralized shear zones. Few have been traced for more than 1,000 feet, and most of them have not been explored to depths greater than 500 feet. Spurr believed that the gold content decreased with depth, but below the shallow zone of superficial enrichment there is no definite evidence of further impoverishment. Some of the vein zones maintain widths of as much as 15 feet for distances of more than a hundred feet, as in the Minnesota mine, but in most places the veins are less than 5 feet wide, and the veins northeast of Empire are rarely more than 2 feet wide. In most of the mines the country rock is Boulder Creek granite, but in places the veins cut schist and gneiss. The wall rocks along the veins are partly altered to sericite and quartz; in the Silver Mountain and Little Johnny zones the alteration has been very intense in places. Locally there appears to have been a kaolinitic alteration of some of the porphyry dikes.

Residual enrichment seems to have taken place in many of the veins down to a depth of 40 to 50 feet through the removal of the massive pyrite by oxidation. It is possible that the leaf gold found in the Hidden Treasure lode is due to secondary enrichment.

The gold seems to be chiefly associated with the chalcopyrite. The tenor of the ore in the district ranges from about 0.2 to 0.4 ounce of gold, although small lots have contained as much as 7 ounces to the ton. In much of the ore the silver content is only a few ounces to the ton, but in some shipments it is as high as 20 ounces to the ton. The copper content is generally only a few percent. Some lots contain as much as 12.5 percent of copper, and others contain so little copper that the smelter does not pay for it.

MINNESOTA MINE

The Minnesota mine is on the east side of Lion Creek, 1½ miles N. 12° W. of Empire, at an altitude of about 9,850 feet. The mine is developed by more than 7,000 feet of workings (pl. 13), which comprise a main-tunnel level aggregating 4,200 feet and two other main levels, one 100 feet above and the other 100 feet below the tunnel level. They are connected by raises, winzes, and a shaft, the collar of which is at the portal of the tunnel. In 1936, at the time of the writers' visit, the lowest workings were 130 feet below the tunnel level and about 550 feet below the highest outcrops of the veins. The ore was treated in a 120-ton mill, near the portal of the tunnel.

The Minnesota mine comprises the Crown Prince, Atlantic, Comet, and Comet Extension properties, which were formerly operated as separate mines. The individual mines have been described by Spurr.[67] In 1934 the properties were taken over by the D. A. Odell Mines Co., and extensive development work was begun.[68] The ore was milled in the 100-ton Gold Dirt flotation mill. In 1935 a 100-ton cyanide plant was built near

[67] Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., pp. 406–408.

[68] Henderson, C. W., Gold, silver, copper, lead, and zinc in Colorado: Minerals Yearbook, U. S. Bur. Mines, p. 215, 1935.

the portal of the main tunnel, and the mine became the largest contributor of gold ore in Clear Creek County.[69] On January 1, 1936, the name of the company was changed to Minnesota Mines, Inc. Data as to the output of the mine are not available, but since 1934 the mine has been by far the most productive in the Empire district. The output of gold in the district jumped from 1,661.18 ounces in 1934 to 4,578.80 ounces in 1935 and to 11,571.11 ounces in 1936.[70] The rapid increase was almost entirely due to the output of the Minnesota mine.

The veins of the Minnesota mine are in Boulder Creek granite on the northwest side of a stock of monzonite porphyry about 1,000 feet in diameter. Dikes of fine-grained gneiss or gneissic aplite occur as wall rock in places, and to the northwest of the veins schist is exposed in a crosscut from the main tunnel. In places the Comet vein borders or lies within dikes of monzonite porphyry (pl. 13), and in one stope on this vein a small dike of bostonite porphyry was noted. At several places in the Atlantic vein there are thin irregular seams of intrusive breccia 6 to 12 inches wide. The veins seem to be within the zone of hydrothermal alteration surrounding the porphyry stock (fig. 59), for the granite between the veins and for more than 50 feet southeast of the Comet vein is sericitized and contains small amounts of disseminated pyrite. The alteration effects extend for about 3 feet northwest of the Atlantic vein, but beyond that the rock is nearly fresh.

The relations of the various veins to one another are shown on plate 13. The two main veins are the Atlantic and the Comet, which extend approximately parallel to each other about 200 feet apart, the Atlantic being to the northwest. Both strike about N. 40° E. and dip steeply to the southeast. Southwestward the Atlantic vein splits into the E vein, which strikes about N. 65° E., the Fault vein, which strikes about N. 55° E., and a strong but relatively barren fault fissure, which strikes about N. 30° E. For the most part the veins dip steeply to the southeast, but locally they steepen to vertical or even turn over to a steep northwest dip.

The Comet vein is very irregular in width. At the southwest end of the tunnel drift it is only about 5 feet wide, but to the northeast it widens to as much as 8 feet and finally spreads out into a mineralized shear zone 30 to 50 feet wide. The Atlantic vein averages about 5 feet in width for much of its length, but near the junction of the "E" vein and Fault vein it widens to as much as 25 feet. The Fault vein is 5 to 12 feet wide but locally widens to as much as 20 feet. The "E" vein and "B" vein are small veins 2½ to 3 feet wide.

There have been at least two periods of strong movement along the veins; the ore is strongly sheared and is broken by gouge seams throughout the veins. Grooves on the walls of the Atlantic vein pitch 38°–40° SW. Some found near the breast of the tunnel seem to be preore and to indicate that the northwest wall moved down. Others in the stope near where the vein splits are on the wall of a gouge seam that cuts a small pyrite vein, and they appear to indicate that the southeast wall moved down. On the Comet vein, grooves on the walls of a narrow vein containing sheared pyrite indicate that the southeast wall moved southwest and down at 60°. Though this evidence is far from conclusive it suggests that in the early movement the northwest walls of the veins moved down to the southwest at about 40° and that the postore movement was in the reverse direction. The amount of displacement due to these movements could not be determined. The veins seem to be related to a fracture system concentric to the porphyry stock, and it is likely that the intrusion of the stock had much to do with the formation of these fissures.

The veins throughout the mine are made up of sheared and sericitized granite containing abundant irregular seams of gouge, horn quartz, and pyrite, a fraction of an inch to 15 inches wide, and abundant disseminated pyrite. (See pl. 13.) Thin irregular pyrite veins commonly extend into the walls. Most of the pyrite seams are less than 3 inches wide, but locally they widen to 15 inches. The wider seams show evidence of having been formed by replacement of the granite. Most of the pyrite is fine-grained; its granular texture apparently resulted from fine crushing during postore movement, as in places there are fragments and fragmental seams of coarse-grained pyrite. Small amounts of chalcopyrite and galena are found. The chief valuable metal in the ore is gold, and the best ore is that in which the fine-grained pyrite is most abundant. The silver content of the ore is uniformly low.

The tenor of the ore ranges from 0.18 to more than 1 ounce of gold to the ton but averages about 0.3 ounce, according to Joe Messick, the mine superintendent. Ore from the B vein averaged about 0.4 ounce, but that from the Fault vein contained only 0.18 to 0.20 ounce to the ton. The tenor of the Atlantic ore ranged from 0.3 to 0.6 ounce to the ton, and where the Comet vein was first cut in the bottom level it averaged 0.8 ounce of gold to the ton through a width of 30 feet.

The ore shoots in the Minnesota mine are very extensive. On the tunnel level there is a continuous stope on the Atlantic vein for 925 feet, and it is almost continuous along the Fault vein and B vein for another 875 feet, making a stope length of about 1,800 feet. The stope also extends for 550 feet along the E vein. These stopes extend upward for 30 to 70 feet above the tunnel level, and a few pockets of ore have been found still higher. The ore appears to be continuous downward

[69] Henderson, C. W., and Martin, A. J., op. cit., 1936, pp. 253–254.
[70] Henderson, C. W., op. cit., 1936, pp. 36, 37.

for at least 100 feet below the tunnel level, though stoping below the tunnel had not progressed very far at the time of the writer's visit. On the Comet vein there is a nearly continuous stope 200 feet long, which extends for about 70 feet above the tunnel level and appears to have followed a junction of two or more veins. The best and widest ore on the Atlantic vein came from near the junction of the Fault and E vein, and the best and most extensive ore bodies on the Comet vein seems to be close to where the vein splits into numerous branches.

OTHER MINES

Data on other representative mines are given briefly below. Detailed descriptions may be found in Professional Paper 63.[71]

CASHIER

Development.—Tunnel with 450 feet of workings; shaft with several drifts.

Veins.—Cashier: Strike, N. 50° E., dip, 70° SE.; breaks up into several smaller veins to northeast.

Wall rock.—Granite, cut in places by seams of pegmatite. In places, granite is highly altered.

Ore and sulfide minerals.—Pyrite, chalcopyrite, and gold.

Gangue minerals.—Quartz.

Tenor.—Some of ore contained as high as 3½ to 6 ounces of gold per ton.

CONQUEROR

Development.—Crosscut tunnel 1,100 feet long and 2,000 feet of drifting. Shaft connects with tunnel level.

Production.—Considerable.

Veins.—Conqueror: Strike, N. 70° E.; dip, 75° NW.; several feet wide. Zone of clay and crushed rock. Patsy: Strike, N. 23° E., dip, 80° SW.; faulted by Conqueror vein. General Harrison and Rosencrans, both faulted by Conqueror vein.

Wall rock.—Silver Plume granite with some gneiss and pegmatite. Dikes of alaskitic quartz monzonite porphyry on northwest wall in places. Walls impregnated by pyrite and quartz.

Ore and sulfide minerals.—Pyrite, gold, and some chalcopyrite.

Gangue minerals.—Clay and quartz.

Changes with depth.—Ore decreased in value above and below tunnel level.

Ore shoots.—Highest grade and largest body of ore obtained at point where two branches of Conqueror vein came together near shaft; stope 250 feet long, 5 feet wide, and 125 feet high.

Tenor.—Ore in Conqueror vein in stope near shaft averaged 3 to 4 ounces of gold per ton. Best ore contained 5 ounces of gold per ton. In northeast drift patches of ore gave assays of 3 ounces of gold and 3 to 4 ounces of silver per ton. Average throughout mine much lower. Patsy vein was low grade and produced little ore. Other veins have not yielded ore.

EMPIRE CITY

Development.—Tunnel follows vein for more than 650 feet.

Veins.—Empire City: Strike, N. 43° E.; dip, 70° NW. to 80° SE.; narrow, made up of clay and crushed gneiss. Vein 60 feet southeast of Empire City strikes N. 36° E.

Wall rock.—Soft biotitic gneiss containing patches of pegmatite.

Ore and sulfide minerals.—Pyrite, chalcopyrite, and gold.

Gangue minerals.—Clay and quartz.

Ore shoots.—Mineralized streaks generally so narrow that mine has not been highly productive.

Tenor.—Reported as high as 8 ounces of gold per ton in places. Small tongue of altered alaskite porphyry at breast of mine assayed as high as 8 ounces of silver and 0.15 to 0.20 ounce of gold per ton.

EMPIRE TUNNEL

Development.—More than 3,000 feet long. Planned to cut important veins of district at depth. Intersects Empire City-Gold Bug group of veins.

Veins.—Small unimportant lodes cut by tunnel. Veinlets of pyritiferous quartz abundant.

Wall rock.—Silver Plume granite and gneiss of the Idaho Springs formation. Also masses of gneissoid granite and dikes and irregular masses of dioritic rock; a few dikes of granite porphyry and bostonite porphyry.

Ore and sulfide minerals.—Pyrite, galena, sphalerite, and magnetite.

Gangue minerals.—Quartz.

GOLD BUG

Development.—Tunnel along vein.

Vein.—Gold Bug: Strikes N. 40° E.; dips 80° SE. Pyrite and quartz streaks few inches in width and small stringers of pyrite forming network several feet wide in granite.

Wall rock.—Hanging wall mostly granite; footwall mostly alaskitic quartz monzonite porphyry.

Ore and sulfide minerals.—Pyrite.

Gangue minerals.—Quartz.

GOLDEN CHARIOT

Development.—500-foot crosscut tunnel and a 200-foot drift on vein.

Veins.—Golden Chariot: Strike, N. 50° E.; dip, 75° NW.; crushed rock lead, 1 to 3 feet wide.

Wall rock.—Hanging wall, bostonite and some gneiss; footwall, gneiss and some pegmatite and alaskite.

Ore and sulfide minerals.—Pyrite and chalcopyrite.

Gangue minerals.—Clay and quartz.

HARRISON

Development.—Tunnel 400 feet long.

Vein.—Harrison: Strike, N. 10° E.; dip, 70° E.; 4 to 10 inches wide. Other veins: Strike N. 80° E.: dip 73° N.; strike N. 58°–65° E.; and N. 52° E.; 3 to 8 inches wide. History of vein formation: Development of east-west fissures; filling by sphalerite-pyrite ore; brecciation of sphalerite ore; filling of new fractures by quartz and pyrite; formation of north-south fractures faulting east-west veins; filling of north-south veins by quartz and pyrite; formation of new set of east-west fractures that fault north-south veins.

Ore and sulfide minerals.—Pyrite, sphalerite, and galena.

Gangue minerals.—Clay and quartz.

HIDDEN TREASURE

Development.—Two tunnels, one 700 feet above the other.

Vein.—Hidden Treasure: Strike, N. 78° E., angular fragments of granite, quartz, and granite gneiss in massive pyrite-chalcopyrite ore found on dump.

Ore and sulfide minerals.—Gold, pyrite, chalcopyrite, and some galena and sphalerite.

Gangue minerals.—Quartz.

Changes with depth.—Lower tunnel cut only a barren fault.

Tenor.—Mine produced largest and finest free gold in district, leaf gold and small irregular masses. Upper tunnel produced ore of exceptionally high grade.

[71] Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., pp. 386–411.

JACKPOT

Vein.—Jackpot: Broad soft lode impregnated with pyrite in places; in other places, quartz-pyrite-chalcopyrite stringers.

Wall rock.—Granite.

Ore and sulfide minerals.—Pyrite and some chalcopyrite.

Gangue minerals.—Quartz.

MINT

Development.—500-foot tunnel and a drift 150 feet below tunnel level, connecting with crosscut from Cashier workings. Two shafts from tunnel level to depths of 50 and 80 feet.

Vein.—Mint: Strike, N. 20° E.; breaks into several smaller veins to northeast.

Wall rock.—Granite, cut in places by seams of pegmatite. In places granite is highly altered.

Ore and sulfide minerals.—Pyrite, chalcopyrite, gold, galena, and some sphalerite.

Gangue minerals.—Quartz.

Changes with depth.—Gold-bearing and silver-bearing pyrite-chalcopyrite ore of upper levels changes to galena-chalcopyrite-pyrite ore with less gold and more silver in lower levels.

Tenor.—Near surface and for some distance below tunnel level, pyrite-chalcopyrite ore contained 3½ to 4½ ounces of gold and 14 to 18 ounces of silver per ton. To depth of 150 feet below tunnel, galena-chalcopyrite-pyrite ore contained 2½ ounces of gold and 23 ounces of silver per ton.

ORO CASH

Development.—Tunnel more than 300 feet long.

Vein.—Oro Cash: Strike N. 22° E.; contains pyrite and quartz in clay and crushed rock.

Wall rock.—Chiefly granite; near breast 3 dikes of different kinds of porphyry.

GOLD FISSURE, GOLD DIRT, AND SILVER MOUNTAIN

(Silver Mountain ore zone)

Development.—Three shafts with 3 to 6 levels each. Aorta crosscut tunnel passes under Silver Mountain and Gold Dirt mines and forms 6th level of latter. In zone southwest of mines Bay State tunnel is on about the same level.

Veins.—Silver Mountain ore zone: Strike, northeast; fractured and altered zone 3,500 feet long and several hundred feet wide; made up of many slips and fractures intricately branching and crossing; includes Gold Fissure vein, which branches into Gold Dirt and Tenth Legion veins, and Silver Mountain lode, which strikes northeast, branches to northeast and in places is 60 to 70 feet wide of crushed and altered gneiss.

Wall rock.—Gneissoid granite and biotitic gneiss. Numerous dikes and a few larger intrusives of dark dioritic rock. Wall rocks largely altered to sericite and quartz, pyrite abundantly disseminated throughout.

Ore and sulfide minerals.—Pyrite, chalcopyrite, black copper sulfides, and gold.

Gangue minerals.—Quartz, sericite, and some siderite.

Changes with depth.—Lodes stronger in upper levels than in Aorta level. Some veins, strong in upper levels, are mere slips in lower levels. Chalcopyrite and black copper sulfides more abundant in upper level. Veins entirely oxidized to depths of 40 feet. In Gold Fissure vein best ore extended for 25 to 150 feet beneath the surface.

Ore shoots.—Lodes formed along slips or zones of intense crushing; best ore along veins, but in places wall rock sufficiently mineralized to be ore. Some of largest and most persistent ore bodies consist of irregular impregnations of country rock by sulfides (filling microscopic fissures) on either side of small fis sures. Ore bodies seem to have no relation to junctions or splits.

Tenor.—Oxidized ore sluiced and passed through stamp mill yielded $70 to $85 per ton in gold; residual parts contained $2.50 to $70 per ton in gold. Highest grade ore contained several ounces of gold per ton. Sulfides yielded about 80 percent of values; rest was free gold. Large masses of low-grade ore. In Gold Fissure vein best ore assayed 10 ounces of gold per ton. In Gold Dirt smelting ore averaged 3 ounces of gold per ton. In Tenth Legion vein ore carried as high as 12½ percent of copper, 7 ounces of gold, and 20 ounces of silver per ton; 2 feet of ore on 125-foot level yielded $45 to $50 per ton. Surface ore yielded $35 per ton.

LAWSON-DUMONT DISTRICT

The Lawson-Dumont district [72] occupies about 10 square miles in the south-central part of the Central City quadrangle. It lies along Clear Creek between the Idaho Springs and Empire districts, includes the towns of Lawson and Dumont, and extends for about 1 mile south and 2 miles north of the creek. (See pl. 4.)

GEOLOGY

The rocks of the district include the Idaho Springs formation, granite gneiss, gneissic quartz diorite, Silver Plume granite, pegmatite, and porphyries of the Laramide revolution. Schists of the Idaho Springs formation occupy most of the eastern part of the district. The general trend of the foliation is northeasterly, and the dip is approximately 40° NW. Fingers and lenses of granite gneiss and pegmatite of northeasterly trend are scattered through this schist area. The western part of the district is chiefly occupied by granite gneiss, which is probably an aplitic facies of the Boulder Creek granite. Many lenses and irregular masses of schist are present in the granite gneiss. In the northern part of the district there is a strong bifurcating northeasterly dike of gneissic quartz diorite also related to the Boulder Creek granite. West of Lawson several irregular masses of Silver Plume granite cut the granite gneiss.

The intrusives of the Laramide revolution in the district include monzonite porphyry of group 4, quartz monzonite porphyry of group 5, and bostonite of group 9. (See pl. 7 and fig. 12.) The monzonites occur as northwestward-trending dikes, chiefly in the central and northeastern parts of the district. An east-west system of bostonite dikes associated with a small stock occurs in the southeastern part of the district, and a strong northward-trending dike of bostonite cuts the granite gneiss in the northwestern part of the district (pl. 2).

STRUCTURE

The pre-Cambrian structure of the district appears to have had consderable influence on the structures formed during the Laramide revolution. The foliation in the Idaho Springs formation has a general

[72] Bastin, E. S., and Hill, J. M., Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colo.: U. S. Geol. Survey Prof. Paper 94, 1917.

northeasterly trend averaging about N. 50° E. and a dip ranging from 35° to 50° NW. The foliation in the granite gneiss has approximately the same trend, and the granite gneiss tends to finger into the schist along the planes of foliation. The earliest Laramide fissures in the district are those occupied by the monzonite dikes. They also are chiefly of northeasterly trend, but some of them trend northwest and east-west. Apparently the next tectonic stage was the opening of the east-west fissures filled by the bostonite dikes. The fault fissures followed by the veins are of two distinct sets. One of predominantly northeastward-trending fissures, confined largely to the western part of the district, contains lead-silver ores; the other, chiefly of eastward-trending fissures contains pyritic gold ores. As evidence in the nearby Empire district indicates that the lead-silver veins are earlier than the pyritic gold veins, the same relationship is believed to hold in the Lawson-Dumont district.

ORE DEPOSITS

The ore deposits of the Lawson-Dumont district are of the two above-named types, lead-silver and pyritic gold. The lead-silver ores are very similar to those of the Georgetown-Silver Plume district, and the pyritic gold ores resemble closely those of the Central City-Idaho Springs district; both show the same general mineral content and paragenesis. The lead-silver veins have a general northeasterly trend and are found chiefly in the western part of the district. A few lead-silver veins of various trends also occur near Dumont. The pyritic gold veins are limited to the eastern part of the district in the vicinity of Dumont. The majority of the veins have an east-west trend, but some strike northeast and some northwest. In a few of the pyritic veins some lead-silver ore also is found, but such occurrences are rare.

The chief minerals of the lead-silver veins are galena, sphalerite, and pyrite. Silver minerals, such as proustite, pearcite, and polybasite, occur in varying amounts, and are abundant in the high-grade silver ores. These ores in general range in tenor from about 50 to 1,000 ounces of silver to the ton, from a few percent to 50 percent of lead, and from a few percent to 20 percent of zinc. Their gold content is generally very low, commonly a few hundredths of an ounce. Quartz is the chief gangue mineral, although some siderite is usually present. Chalcopyrite is found in some of the ores but is rarely abundant enough to be of commercial importance. In general the sequence of mineral deposition is (1) the massive sulfides comprising galena, sphalerite, and pyrite, with some chalcopyrite, (2) the silver minerals, such as polybasite, proustite and pearcite, and (3) very small amounts of chalcopyrite, galena, and sphalerite.

The chief constituents of the pyritic gold ores are pyrite and quartz. Chalcopyrite is generally present and in places is abundant enough to be of commercial interest. Gold seems to be contained chiefly in the chalcopyrite, though in places it is associated with fine-grained pyrite. The gold content of this ore is commonly 1 to 10 ounces to the ton, but the silver content is generally low, ranging from a few ounces to 16 ounces to the ton. Galena and sphalerite are present in a few places but are usually unimportant. In general the veins of the Lawson-Dumont district have had a relatively small output compared with those of the Silver Plume-Georgetown district or the Central City-Idaho Springs district, but a few, such as the Jo Reynolds and the veins of the Red Elephant group, have had an output of more than a million dollars.

BLUE RIDGE AND SENATOR MINE

The Blue Ridge and Senator mine is about a mile southwest of Dumont, on the south side of Clear Creek, at an altitude of 9,000 feet. Two veins are developed in the mine, the Senator, which strikes about N. 45° E. and dips 47°–75° NW., and the Blue Ridge, which strikes N. 60° W. and dips about 60° NE. The veins are developed by three tunnels—the upper west, the middle west, and the lower east—and a main shaft. The Senator is the productive vein of the mine and has been stoped for much of its length. On the middle tunnel level, about 300 feet northeast of the shaft, it is joined by the Blue Ridge vein, which has not been found beyond this junction. The wall rock of the veins is principally granite gneiss, but schist is exposed in places, especially in the eastern part of the mine. For the northern 700 feet of its exposure in the mine workings the Senator vein is nearly parallel to a wide dike of bostonite porphyry; it follows either wall or both walls of the dike, and finally leaves it entirely. North of its junction with the Blue Ridge vein the Senator vein is in the porphyry dike and is practically barren. A smaller dike of bostonite 1 to 5 feet wide trends nearly parallel to the larger dike.

Abundant gouge is common along the Senator vein. The most heavily mineralized part of the vein is in the southwest part of the mine, 350 to 1,200 feet southwest of the main shaft. As exposed in a raise above the middle west tunnel level southwest of the main shaft, the Senator vein consists of 4 to 8 feet of fractured granite gneiss traversed by numerous slips and sulfide veinlets. Sulfides also occur in irregular masses, which grade into granite gneiss. The Blue Ridge vein in most places is barren or feebly metalized; in only a few places were veinlets of galena and sphalerite noted by Bastin. In the upper west tunnel the Blue Ridge vein is locally 4½ feet wide and has been stoped for about 100 feet.

The ore of the Senator vein consists of sphalerite and galena with a little local chalcopyrite and pyrite in a gangue of quartz, calcite, and some barite. Oxidized ore is almost limited to the upper tunnel, the ore consisting of remnants of galena and sphalerite in a porous iron-stained matrix of cerussite. Ore from the middle west tunnel contains crystals of proustite and polybasite in fractures in massive sulfide ore and on crystals of quartz in vugs. They are associated with small crystals of chalcopyrite and galena. In places chalcopyrite coats the silver minerals. Microscopic study of polished specimens of the ore shows that polybasite not only occurs in fractures in the ore but has been developed by metasomatic replacement of galena along its contact with the sphalerite. Secondary chalcopyrite is partly contemporaneous with the polybasite and partly later, replacing polybasite along fractures. Sphalerite has apparently been wholly immune to replacement.

Two assays of the massive galena ore were made. One showed 0.03 ounce of gold, 7.17 ounces of silver, 0.2 percent of copper, 76.5 percent of lead, and 1.2 percent of zinc; the other showed 0.08 ounce of gold, 3.10 ounces of silver, and 51 percent of lead. A shipment of 22½ tons of ore from a raise above the middle west tunnel contained 0.08 ounce of gold and 47.5 ounces of silver to the ton and 22.9 percent of lead. This ore came from a depth of about 500 to 600 feet below the surface. Silver minerals were noted at a depth of 600 feet in another part of the Senator vein. The very rich silver ore came from a depth not greater than 450 feet. Some of the oxidized ore near the surface contained several ounces of gold and only a few ounces of silver. The gold content of most of the ore mined from the Senator vein ranged from a trace to 0.2 ounce, and the silver content generally exceeded 50 ounces and in many shipments exceeded 100 ounces. Ore shipped from 1891 to 1893 contained a trace to 0.10 ounce of gold and 45.50 to 91.50 ounces of silver to the ton, 10.15 to 34 percent of lead, and 5 to 11 percent of zinc. The total value of ore shipped from the property is said to have been about $250,000.

OTHER MINES

Data on other representative mines are given briefly below. Detailed descriptions have been given by Bastin and Hill.[73]

ALBRO

Development.—Several shafts and drift tunnels. In 1912 main shaft was 185 feet deep with 3 levels.

Production.—$500,000.

Vein.—Albro: Strike, east-west; dip, 30°–50° N.; about 3 feet wide in stope at east end of 150-foot level; average 8–12 inches with 3-inch sulfide seams.

Ore and sulfide minerals.—Chalcopyrite and galena; some pyrite and sphalerite.

Gangue minerals.—Silicified schist.

Tenor.—Stope on 150-foot level contained 2½ to 3 ounces of gold and 12 to 14 ounces of silver per ton and 7 to 8 percent of copper, 160 tons of ore in 1909 contained 0.39 to 1.02 ounces of gold and 7.6 to 21 ounces of silver per ton and 3 to 10.2 percent of copper. 202½ tons of ore in 1908 averaged 0.54 ounce of gold and 5.65 ounces of silver per ton and 2.4 to 17 percent of copper.

AMERICAN SISTERS

Development.—Shaft and series of drift tunnels.

Vein.—American Sisters: Strike, N. 50°–75° E.; dip, 65°–70° NW.

Wall rock.—Granite gneiss, considerably altered.

Ore and sulfide minerals.—Chiefly galena and sphalerite but some chalcopyrite, pyrite (disseminated), proustite, and pearcite.

Gangue minerals.—Quartz, some siderite and sericite.

Tenor.—Specimen of galena ore: 6.24 ounces of silver per ton, 0.35 percent of copper, 61 percent of lead, 2.10 percent of zinc. Specimen of sphalerite ore: Trace of gold, 79.20 ounces of silver per ton, 0.25 percent of copper, 9 percent of lead, 46.60 percent of zinc. Ore 1893–98: 0.08 to 0.4 ounce of gold, 33.5 to 367.2 ounces of silver per ton, 2 to 14.5 percent of lead, 6 to 13 percent of zinc.

BELLEVUE-HUDSON AND ALAMOSA

Development.—Original discovery 1886. 3 tunnels. Explored vertically more than 1,000 feet. Bellevue-Hudson tunnel, 1,080 feet long.

Vein.—Bellevue-Hudson vein system: Three parallel veins in zone 60 feet wide; south branch consists of 2½ feet of schist and 2 inches of galena.

Wall rock.—Schist.

Ore and sulfide minerals.—Galena and some sphalerite.

Gangue minerals.—Quartz.

Ore shoots.—Most of ore within 500 feet of surface.

Tenor.—Ore, 1890–91: 25.85 to 565.00 ounces of silver per ton, 1.52 percent of lead, very little gold. Ore from lower levels, 1908: 0.03 to 0.2 ounce of gold and 12.6 to 54.2 ounces of silver per ton, 4 to 31.6 percent of lead, 3 to 14 percent of zinc.

GOLCONDA

Development.—Crosscut tunnel 1,665 feet long intersects vein at depth of 835 feet.

Production.—$4,500.

Vein.—Golconda: Strike, N. 43° W.; dip, 64°–65° NE., 4 to 8 inches wide in stope 300 feet west of tunnel.

Wall rock.—Idaho Springs formation.

Ore and sulfide minerals.—Chalcopyrite, pyrite, and tennantite, some galena, and sphalerite.

Gangue minerals.—Quartz.

Ore shoots.—Shoot extends 250 feet along tunnel level and pitches 75° NW.

Tenor.—1909, better ore: 11.78 ounces of gold and 98.50 ounces of silver per ton, 8.6 percent of copper. 1910, average: 1.25 ounces of gold and 9 ounces of silver per ton, 1.07 percent of copper.

JO REYNOLDS

Development.—Original discovery 1865. 2 tunnels connected by winze and 2 shafts. 9 levels 200 to 1,500 feet in length.

Production.—$1,462,500.

Vein.—Jo Reynolds: Strike, N. 65° E.; dip, 70° NW.

Ore and sulfide minerals.—Chiefly galena, pyrite, and sphalerite, some chalcopyrite, gray copper, polybasite, pearcite, proustite, argentite, and native silver.

Gangue minerals.—Quartz.

[73] Bastin, E. S., and Hill, J. M., op. cit., Prof. Paper 94, pp. 330–341, 1917.

Changes with depth.—Native silver found as deep as 9th level.

Ore shoots.—Small block of ore above 3d level produced $80,000. Contained 800 to 1,000 ounces of silver per ton.

Tenor.—Average gold content, 0.05 to 0.15 ounce per ton; average silver content, 28 to 357 ounces per ton. One assay, 1,208 ounces of silver per ton. Average below 3d level: 0.1 ounce of gold and 100 ounces of silver per ton, 10 percent of lead, 12 percent of zinc.

RED ELEPHANT GROUP

(Boulder Nest, Free American, St. James, Tabor, and White mines)

Development.—5 shafts, 230 to 700 feet deep with 3 to 13 levels. Commodore tunnel 3,460 feet long.

Production.—Free American: $100,000 in 1877 and $80,000 in 1878. Boulder Nest: $110,000 in 1877 and $230,000 in 1878. Tabor: $70,000. Estimated total, $1,500,000.

Veins.—Boulder Nest-Free American: Strike, N. 80° E. Tabor: Strike, southeast; dip, northeast. White: Strike, east; dip, 50°–75° N.; 3-foot to 4-foot fracture zone on 13th level of Schwartz shaft. St. James: Strike, east to northeast; dip, 55°–65° N.

Wall rock.—Idaho Springs formation and granite gneiss.

Ore and sulfide minerals.—Chiefly galena and pyrite, some chalcopyrite, bornite, gray copper, pearcite, and sphalerite.

Gangue minerals.—Chiefly quartz, some barite, and siderite.

Tenor.—Free American, average ore: 1877, 37.5 ounces of silver per ton; 1878, 250 ounces of silver per ton. Boulder Nest: 38–150 ounces of silver per ton and small amounts of gold. White vein: 0.00 to 0.05 ounce of gold and 49.50 to 202 ounces of silver per ton, 11.50 to 30 percent of lead, and 4 to 12 percent of zinc.

SILENT FRIEND

Development.—Two tunnels, 172 feet apart vertically; lower, 1,000 feet long, upper more than 700 feet.

Production.—About $22,000.

Veins.—Silent Friend: Strike, N. 45° W.; dip, 35°–64° NE.; 2 inches to 3 feet of fractured material containing quartz and pyrite; offset by several faults of northeast trend. Fault vein: Strike, north; dip, 35° to 40° W.; 3 to 4 feet of fractured material with quartz and pyrite; offsets Silent Friend vein 20 feet.

Wall rock.—Schist and altered bostonite porphyry.

Ore and sulfide minerals.—Pyrite, gold, chalcopyrite, galena, sphalerite, and tennantite.

Gangue minerals.—Quartz and some calcite.

Ore shoots.—Rich pocket in lower tunnel, 40 feet below junction of Silent Friend and Fault vein contained free gold in white quartz.

Tenor.—6 tons of ore assayed 0.08 to 0.2 ounce of gold and 2.1 to 62.9 ounces of silver per ton.

ALICE-YANKEE HILL DISTRICT

The Alice-Yankee Hill district [74] is in the north-central part of Clear Creek County and the southwest part of Gilpin County, about 7 miles N. 75° W. of Central City. It ranges in altitude from 10,000 to 11,500 feet, but the productive mines are easily accessible by automobile roads. The most noteworthy ore deposit of the district is the great pyritic stockwork of the Alice mine, which was first worked in the early eighties by hydraulic methods but was abandoned for many years after the rich ore near the surface had been removed. With the increased price of gold in 1933 the lower part of the supergene sulfide zone, which had previously been noncommercial, became of sufficient value to warrant exploitation, and a considerable output was made in the next few years.

The ores of the Alice-Yankee Hill district are chiefly of the pyritic type, but a few veins, such as the Stonewall, Ninety-Four, Cumberland, and Lombard veins, contain galena and sphalerite. The pyritic ores contain little silver and are mined for their gold content. They are relatively rich near the surface in the oxidized zone, but the unaltered sulfides are generally too low-grade to be worked. As a result, the individual pyritic deposits have not been long-lived.

The chief rock of the district is schist of the Idaho Springs formation, and it occupies nearly all the area between Alice and Yankee Hill. On the east side of Yankee Hill a north-south body of granite gneiss a quarter to a half a mile wide crops out. It fingers into the schist to the north but joins larger masses of granite gneiss to the south and to the northeast. Alice is on a narrow northerly tongue of medium-grained Boulder Creek granite, one of several that interfinger with schist and granite gneiss and merge southward into a small stock. Three-quarters of a mile southwest of Alice the quartz monzonite porphyry stock (group 5, see pl. 7 and fig. 12) that contains the Alice ore body is exposed. It is about half a mile long and a quarter of a mile wide. The schist in the district has a general northwesterly trend and a northeasterly dip.

ORE DEPOSITS

In three parts of the district—the ridge south of Fall River 2 miles southwest of Alice, the vicinity of Silver Lake, and Yankee Hill—there are many northeastward-trending veins, but none of them have been very productive. Most of them are of the pyritic gold type and consist chiefly of quartz and pyrite. The oxidized ore near the surface is said to have contained as much as 7 ounces of gold to the ton, although the average tenor of the better class of surface ore was approximately 1 to 2½ ounces. The unoxidized ore, consisting of quartz and pyrite, has been in general too low grade to be worked.

The depth of supergene enrichment probably varies slightly with the nature of the wall rock and to a somewhat greater extent with the position of the deposits relative to ancient erosion surfaces. At the Alice mine the oxidized zone was very shallow, and slightly oxidized sulfide ore was found at the surface at several places. The writers observed supergene sooty chalcocite on the main adit level about 100 feet below the surface but found none on the sublevel 40 feet deeper. The grade of the ore was directly related to the amount

[74] Bastin, E. S., and Hill, J. M., op. cit.

of supergene copper sulfide present. Specimens rich in the secondary sulfides would assay more than an ounce of gold to the ton, but the primary pyrite in the sublevel directly beneath the large bodies of enriched ore assayed only 0.03 ounce per ton or less. The better grade of ore sent to the mill from stopes on the main adit level averaged about 0.20 ounce of gold to the ton, less than an ounce of silver, and about 0.5 percent of copper, suggesting that the gold content of the supergene ore is about seven times that of the primary sulfides.

The many veins in the ridge south of Fall River were not being worked when the writers mapped this area, and nothing was learned concerning their output. Many had been extensively stoped near the surface, and the ore on the dumps suggested that they belonged to the pyritic gold group. The strike of the veins and their strength and number suggest that many similar blind veins exist under the extensive glacial cover that occupies the broad valley of Mill Creek just to the southwest.

ALICE MINE [75]

The Alice mine is about three-quarters of a mile west-southwest of Alice at an altitude of about 10,300 feet. The deposit is a large, irregular body of unevenly mineralized rock, which has been developed by an open pit and by irregular underground workings. (See pl. 14.) This mineralized body is in a quartz monzonite stock, which is about half a mile long in a north-south direction and about a sixth of a mile wide and is surrounded by pre-Cambrian schist. (See pl. 2.) The porphyry of the stock grades from intermediate quartz-biotite monzonite porphyry at the borders to porphyry of the Lincoln type, having a pinkish cast, at the center. The rock is cut by dikes of light-gray to nearly white porphyry, which is commonly an alaskite of group 6, but has been considerably altered to sericite and contains disseminated pyrite. Two observations on the structure of the porphyry taken in the underground workings showed a primary foliation striking N. 20° E. and dipping 75° NW. and a lineation pitching 70° due west.

The mineralized area is about 300 feet long in a north-south direction and about 150 to 200 feet wide. A vertical alaskite dike about 60 feet wide, striking north-south, forms the west wall of the ore body. The porphyry throughout the ore body is strongly sericitized and pyritized and locally silicified. The ore minerals are disseminated throughout, being more or less localized by abundant minute fractures throughout the porphyry mass (pl. 14.) The maximum alteration took place where two or more fractures intersected and here nests of ore minerals 3 inches or less across are common (fig. 60, *C*). In places cavities occurred at such intersections and were partly filled with ore minerals. Some of these cavities are as much as a foot in diameter and were probably formed by the solvent action of solutions. Other open spaces were formed by movement between porphyry fragments.

On the tunnel level, about 60 feet below the surface where oxidation has been slight, abundant pyrite and considerable chalcopyrite are present, with sooty chalcocite and bornite conspicuous locally. Rarely, arsenopyrite is found and is later than chalcopyrite and pyrite. Quartz and brown siderite are the principal gangue minerals. Bastin describes a sulfide of bismuth very rich in silver, which in places is associated with the chalcopyrite. Many of the cavities in the ore are lined with small quartz crystals, which are coated with pyrite cubes; some cavities contain chalcopyrite and sooty chalcocite. (See fig. 60, *C*.)

The ore is said to average between 0.13 and 0.18 ounce of gold throughout the ore body. Local pockets of ore containing 0.23 to 0.43 ounce to the ton may yield 30 tons or more. Locally small seams of chalcocite ore contain as much as 5 ounces of gold to the ton. The Alice ore body is similar in character to the Commercial Union mine nearby and to The Patch near Nevadaville.

The Alice property was first worked as a placer with the aid of hydraulic giants, and $60,000 worth of gold is said to have been recovered by these methods. Later a stamp mill was erected and was operated at a profit for three seasons, until the free-milling oxidized ore was exhausted. Subsequent attempts to treat the unoxidized ore by concentration have met with indifferent success. Concentrates shipped do not appear to have exceeded $10,000 in total value. Samples of 587 tons treated in the mill had an average tenor of 0.167 ounce of gold, 0.82 ounce of silver, and 0.38 percent of copper. Gold assays on 57 samples taken by Mr. E. E. Chase from various parts of the mine showed a maximum of 0.98 ounce, with an average of 0.225 ounce. Silver determined on 39 of these samples amounted to as much as 10.3 ounces with an average of 1.21 ounces. Bastin states that the amount of primary sulfide ore available is large and can reasonably be expected to exist with little change in value for several hundred feet below the present workings, and this is also the opinion of the writers. Another mineralized area similar to that already exploited was discovered by geophysical methods about half a mile to the south, underneath the gravels, but drill samples showed little oxidized ore, and the deposit has not been developed.

OTHER MINES

Data on other representative mines of the district

[75] Taken in part from Bastin, E. S., and Hill, J. M., op. cit., p. 323, and in part from data collected by the writers, July 1935.

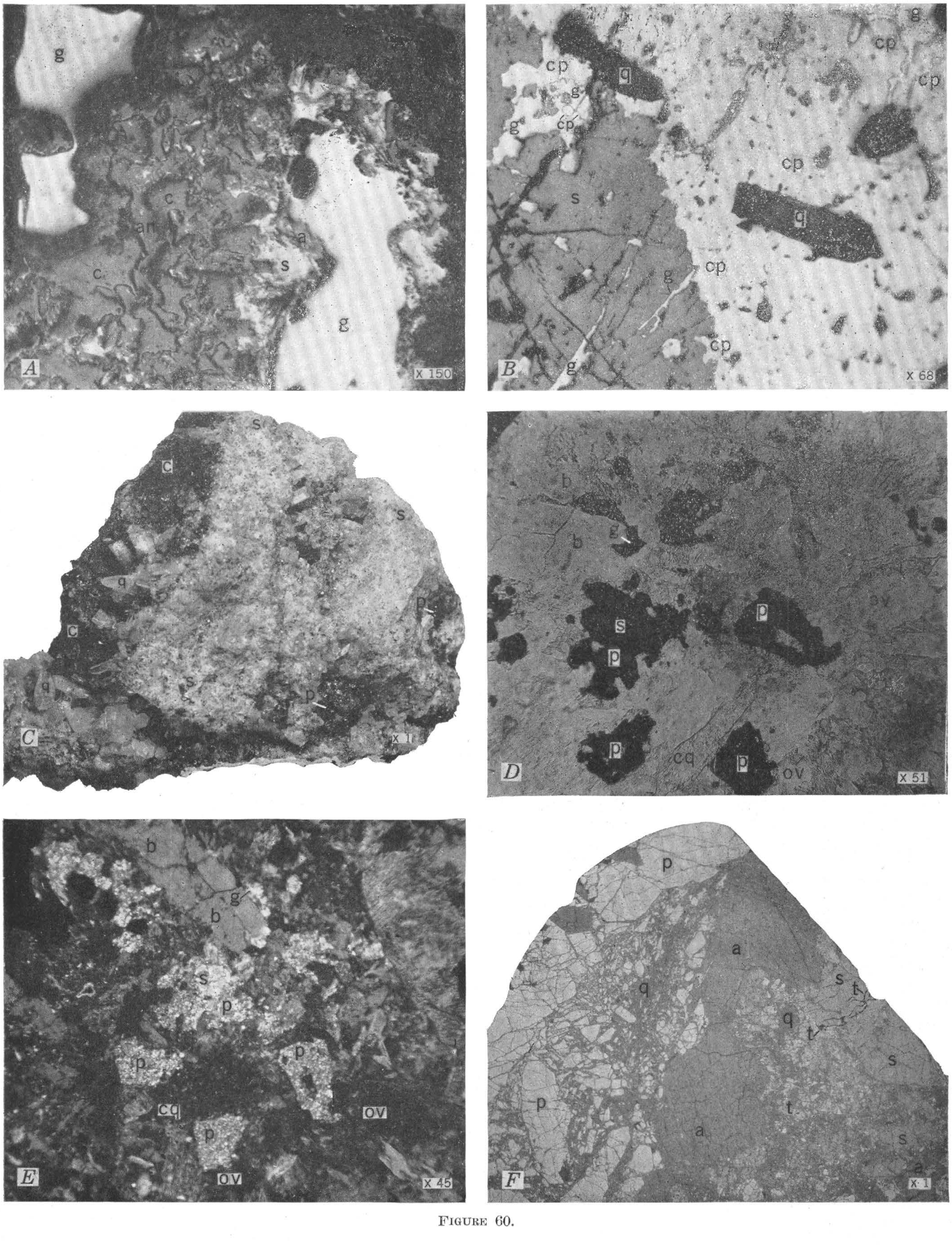


FIGURE 60.

are given below. Detailed descriptions have been given by Bastin and Hill.[76]

NINETY-FOUR TUNNEL

Development.—Tunnel more than 2,000 feet long, shaft 300 feet deep (caved) on Stonewall vein.

Veins.—Stonewall: Strike, N. 70° W.; dip, 50°–70° NE.; 1½ inches to 2 feet wide. Yankee Centennial: Strike, east; dip, 50°–77° N.; 1 to 10 inches wide. Enterprise: Strike, N. 10°–60° E.; dip, 75° NW.; 1 to 12 inches wide. Last Chance: Strike, N. 75°–85° E.; dip, 75° SE.; narrow. Hidden Treasure: Strike, N. 47° E.; dip, southeast; only feebly mineralized.

Wall rock.—Schist with lenses of pegmatite.

Ore and sulfide minerals.—Pyrite, galena, sphalerite, and some chalcopyrite.

Gangue minerals.—Quartz and crushed wall rock.

Ore shoots.—Most of stoping was on Stonewall vein.

Tenor.—Stonewall vein averaged about 1 ounce of gold and 10 to 12 ounces of silver per ton. Yankee Centennial, 50 tons averaged about 3 ounces of gold per ton, very little silver Hidden Treasure averaged $4 to $5 in gold.

NORTH STAR-MANN

Development.—North Star shaft 300 feet deep with 4 levels; drift tunnel 1,070 feet long on 115-foot level. Mann shaft 100 feet deep.

Production.—Prior to 1916: $100,00. 1916: $16,000.

Veins and fissures.—North Star-Mann: Strike, N. 65° W.; dip, about vertical; few inches to 5 feet wide, of crushed silicified wall rock with quartz-sulfide stringers. Two northeastward-trending barren faults; one is earlier than the vein and the other cuts the vein without noticeable displacement.

Wall rock.—Schist, granite gneiss, and large pegmatite lens.

Ore and sulfide minerals.—Chalcopyrite, gold, and pyrite.

Gangue minerals.—Quartz and some siderite.

Ore shoots.—Three found. One extends from tunnel portal to 230 feet west; the second extends westward from shaft for 200 feet; and the third extends along the last 80 feet of the 115-foot level. All appear to pitch steeply west.

Tenor.—Unoxidized ore averaged 0.4 to 0.5 ounce of gold per ton. Very rich oxidized ore taken from Mann shaft and surface trenches.

CENTRAL CITY-IDAHO SPRINGS DISTRICT

The Central City-Idaho Springs district[77] is about 30 miles west of Denver in the southeast part of the Central City quadrangle and the northeast part of the Georgetown quadrangle; it includes parts of Gilpin and Clear Creek Counties. The district has an area of about 25 square miles. Its principal towns are Central City, Blackhawk, and Idaho Springs. As shown on plates 3 and 4, the area southwest of Idaho Springs, which is known as the Freeland-Lamartine area,[78] is regarded in this report as part of the Central City-Idaho Springs district, because there is no definite break between the two either in the type of rock or the character and extent of the ore deposits.

The district ranges in altitude from 7,600 to 10,600 feet, and in places it is rugged. The physiography of the district is that of a dissected rolling upland. Much of the area just south of Central City is on the Overland Mountain erosion surface, and supergene enrichment has been especially evident in the upper parts of the veins in this area (fig. 62). A few mountains north of Clear Creek rise to a height of 10,000 feet and are probably monadnocks rising to the level of the Green Ridge surface. In the southwestern part of the district high spurs from the Continental Divide rise to heights of more than 11,000 feet.

Both Central City and Idaho Springs are connected with Denver and Leadville by good automobile roads. Practically all the important mines can be reached by automobile and trucks throughout the year. In the early days there was a good supply of native timber, but most of it has been removed by mining operations and forest fires. The district is well watered by Clear Creek, Fall River, North Clear Creek, and their various branches.

HISTORY

In the winter of 1858 George A. Jackson, of Missouri, discovered the hot soda springs near the present site of Idaho Springs, and on January 7, 1859, he washed gold from the "Idaho bar" near the mouth of Chicago Creek. This was the first placer of commercial grade to be found in Colorado, and its discovery led to a rush of prospectors to that region. On May 6, 1859, John H. Gregory made the first lode discovery in the Rockies when he found rich oxidized gold ore along the outcrop

[76] Bastin, E. S., and Hill, J. M., Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colo.: U. S. Geol. Survey Prof. Paper 94, pp. 321–322, 329, 1917.

[77] Bastin, E. S., and Hill, J. M., op. cit.

[78] Spurr, J. E., Garrey, G. H., and Ball, S. H., Economic Geology of the Georgetown quadrangle: U. S. Geol. Survey Prof. Paper 63, 1908.

EXPLANATION OF FIGURE 60

A, Photomicrograph of oxidized lead-silver ore from 1st level of Detroit-Hicks mine, Breckenridge district. Galena (*g*) is replaced by argentite (*a*), which in turn is replaced by native silver (*s*). The galena alters to anglesite (*an*), most of which has been converted to cerussite (*c*).

B, Photomicrograph of copper-lead-zinc ore from Stevens mine, Argentine district. Chalcopyrite (*cp*) replaces sphalerite (*s*), and both are replaced by galena (*g*). *q*, Quartz.

C, Specimen typical of better-grade ore from Alice mine. Original monzonite porphyry completely converted to coarse-grained sericite (*s*) and cut by open interlacing fractures partly filled with clear quartz on which rest clumps of pyrite (*p*) and chalcopyrite. Supergene sooty chalcocite (*c*) incrusts the chalcopyrite and assays high in gold. *q*, Quartz.

D, Photomicrograph showing part of area on *E*. Ore and fragments of sericitized schist in fine-grained vuggy quartz. Explanation of symbols is the same as for *E*. Crossed nicols and oblique illumination combined.

E, Photomicrograph of high-grade gold-telluride ore from Jewelry Shop mine, Idaho Springs. Note vugs lined with opal (*ov*). *b*, Barite; *cq*, chalcedonic quartz; *g*, gold; *p*, petzite; *s*, sylvanite. Transmitted light.

F, Ore from Shaffer vein, Freeland mine, McClelland tunnel level, 35 feet east of Shaffer raise, 1,325 feet below surface. Ankerite (*a*) and pyrite (*p*) broken and cemented by dark fine-grained quartz (*q*). Sphalerite (*s*) seamed by tetrahedrite (*t*), which is closely associated with the dark quartz (*q*).

of the Gregory vein just east of the site of Central City. During the summer of 1859 many other lode discoveries were made, and before winter 100 sluices were at work in the vicinity of Gregory's discovery, washing oxidized lode ore and the rich placer ground nearby. The rich oxidized ores were soon removed from the lodes, and by 1864 much of the gold mined was mixed with sulfides and was not amenable to amalgamation. In 1865 J. E. Lyon built the first smelting works in Colorado at Blackhawk and within a short time was successfully treating the sulfide ores so recalcitrant to amalgamation. The district had been nearly at a standstill during the Civil War because of lack of men and the low recovery of gold from the ores, but with the satisfactory smelting of the sulfides in 1866 the district began a long period of continued development and increased production from lode ores. Although the first silver vein found in Colorado was discovered near Montezuma in 1864 by Coley, it was not until 1877 or 1878 that the silver veins of Silver Hill, near Blackhawk, were discovered.

Mining was greatly stimulated in Colorado by the completion in 1870 of the Denver Pacific line, which connected Denver with the Union Pacific Railroad at Cheyenne, and further impetus was given to mining in the district in 1872 when a narrow-gauge railroad connected Blackhawk with Denver. In January 1904 the 4½-mile Argo tunnel was begun, with the object of intersecting many of the largest veins in the district at depth. In most of the veins, however, the ore was of low grade where cut by the tunnel 1,200 to 1,600 feet below the outcrop, and, although several profitable ore shoots were found by laterals from the tunnel, the general feeling grew, and still persists, that the tunnel proved the veins to be disappointing at depth. Activity in the district declined slowly until 1918, when with the end of World War I there was a very marked decline in output. The sudden increase in the price of gold in October 1933 stimulated new activity and led to a marked increase in output. Although substantial amounts of silver, lead, and zinc, and some copper have been produced, most of the ore shipped has been valued chiefly for its gold. (See tables, pp. 12, 13.)

GEOLOGY

Schist and granite gneiss are the most abundant rocks in the district. As shown on plate 2, Central City is on the axis of a northeasterly anticline that exposes a core of granite gneiss about 2 miles wide, which contains numerous stringers and lenses of schist and is bordered on both sides by schist. Schist predominates in the Idaho Springs region but includes numerous lenses of granite gneiss and pegmatite. The schist has a predominant northeast strike and dips 45°–75° NW. Scattered through the district are numerous dikes, sills, and irregular bodies of pegmatite, a few small masses of Silver Plume granite and hornblende gneiss, and lenses of lime-silicate rocks of the Idaho Springs formation.

Intrusives of the Laramide revolution are abundant in the mineralized area. The porphyries occur in numerous dikes and small irregular stocks, the largest of which is only half a mile in diameter. The majority of the dikes strike northeast, but some strike northwest, and a few short ones strike east.

Pre-Cambrian rocks.—In the mineralized district the predominant rocks of the Idaho Springs formation are light-gray to dark-gray quartz-biotite schists and gneisses, which in places grade into feldspathic injection gneiss. With these rocks are associated some lenticular layers of biotite-sillimanite schist, and lime-silicate rocks that represent metamorphosed limestones. South of Idaho Springs, on Vance Peak and Chief Mountain, quartz schist and gneiss are found immediately under-

Gross metal content of certain pyritic gold and lead-zinc-silver ores shipped from the Idaho Springs-Central City district 1888–1910 [1]

Mine	Year	Quantity (short tons)	Gold (ounces per ton)			Silver (ounces per ton)			Copper (maximum percent)	Lead (maximum percent)	Zinc (maximum percent)
			Maximum	Minimum	Average	Maximum	Minimum	Average			
Lead-zinc-silver ores:											
Concrete	(?)	307	-----	-----	1.03	-----	-----	8.00	-----	23.8	10.6
Crystal	1883–1910	35	3.00	0.15	.76	95.00	5.50	37.40	3.00	3-17	6–16
Hubert	1888-1909	131	5.80	.74	2.39	17.60	2.00	13.16	6.50	37	32
Hubert	1910	72	1.70	1.04	1.38	15.90	8.00	14.00	-----	30	-----
Ivanhoe	1898–1902	11	.90	.10	.59	21.40	7.62	13.95	-----	10.9–54.10	8–18
Owatonna	1897–1910	117	.50	.12	.23	58.80	5.70	27.57	-----	36	25
Santa Fe	1888–1904	91	4.00	.25	-----	38.00	2.70	-----	2.30	20	5
Seaton	1902–1910	202	2.35	.12	1.13	105.00	7.50	39.66	2.55	26.4	24
Windsor Castle	1897–1909	30	.68	.08	-----	23.00	8.40	-----	2.80	4–16	5–16
Pyritic gold ores:											
Carr	1893–1910	400	9.06	.72	2.88	21.20	2.00	7.62	11.7	-----	-----
Chase	1893–1908	193	8.20	.29	1.98	28.40	1.90	6.53	1.5 usually	-----	-----
O. K.	1893–1908	185	4.28	.30	1.13	10.20	3.40	5.59	2–10.25	-----	-----
O'Neal	1897–1908	48	12.00	.60	3.10	11.45	3.14	7.13	1.80–8.18	-----	-----
Perigo	1901–1909	42.5	3.16	.44	1.23	4.70	1.20	1.26	-----	-----	-----
Pittsburgh	1894–1909	243	12.72	.45	2.37	18.30	1.50	7.52	16.6	-----	-----
Pittsburgh	1910	435	25.35	.52	5.77	22.65	2.00	8.93	0.3–16.3, av. 6.65	-----	-----
San Juan	1888–1909	117	12.20	Tr.	2.09	34.00	2.15	6.81	9	-----	-----
Saratoga	1893–1909	1,019	8.41	.12	.90	13.90	1.00	2.32	1.5 usually	-----	-----
Specie Payment	(?)	506	7.09	.32	1.88	37.00	.70	5.80	7	-----	-----

[1] Bastin, E. S., and Hill, J. M., Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colo.: U. S. Geol. Survey Prof. Paper 94, pp. 109, 112, 1917.

Gold and silver content, in ounces per ton, of various minerals in representative Gilpin County veins [1]

	Gold		Silver	
	Average [2]	High-grade [3]	Average [2]	High-grade [3]
Pyrite	0.47	5.74	1.94	7.1
Chalcopyrite	.91	4.61	8.4	31.5
Gray copper	2.33	4.57	29.7	67.1
Galena	.45	.21	21.3	31.2
Sphalerite	1.16	1.10	7.0	16.3
Sooty sulfides	1.83	1.28	25.4	--------
Dark flinty quartz	.08	--------	11.5	--------
Clean quartzose gangue	.10	1.42	5.6	--------

[1] Bastin, E. S., and Hill, J. M., Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colo.: U. S. Geol. Survey Prof. Paper 94, pp. 117, 118, 1917.
[2] Average of data from 14 mines.
[3] Ore from Clark-Gardner mine.

lying hornblende gneiss. As shown on plate 2, the largest area of hornblende gneiss is in the eastern part of the district, where it occurs in a sharp syncline plunging northeastward along the eastern side of the Chicago Creek-Junction Ranch shear zone. It is associated with many concordant intrusive masses of granite gneiss or gneissic aplite.

The granite gneiss described by Bastin and Hill [79] is very similar in lithologic character and age relations to the gneissic aplite of Boulder County and to the gneissoid granite of the Georgetown quadrangle, and it is believed to be contemporaneous with them. It occurs in elongate, irregular areas, which have a general northeasterly trend parallel to the prevailing trend of the surrounding schist.

The many sill-like masses of granite gneiss that follow the axis of the northeastward-plunging syncline of hornblende gneiss gather together about 1½ miles north of Idaho Springs to form a mass striking east-northeast. This mass dips 50° NNW. in Seaton Mountain and underlies the syncline of Idaho Springs formation just to the northwest. With the reversal of dip that occurs in Russell Gulch, the granite gneiss reappears at the surface and forms the core of the northeasterly anticline on which Central City is situated. This is one of the largest bodies of granite gneiss known in the Front Range, and because of its competency it has been an important factor in determining the position of the veins and ore shoots of the district. (See pl. 2.)

The rock is a fine-grained primary gneiss composed of white to pink feldspar, quartz, and biotite; it is light gray on the fresh surface and buff or brown on the weathered surface.

The Silver Plume granite, though widely distributed throughout the Central City quadrangle, occurs very sparingly in the Central City-Idaho Springs district. Its outcrops trend northeastward, parallel to the structure in the adjoining schist and granite gneiss.

[79] Bastin, E. S., and Hill, J. M., op. cit., pp. 30–32.

Pegmatites in irregular lenses and dikes are abundant in the schist throughout the district. Many of the ore shoots in veins in the schist areas are apparently localized by walls of pegmatite. Most of the pegmatites are parallel to the prevailing structure in the schist. Many of them seem genetically related to the granite gneiss, but some are definitely later and are probably related to the Silver Plume granite. They are composed chiefly of potash feldspar, quartz, biotite, and muscovite, but they are exceedingly variable in texture and occurrence. The largest pegmatites are irregular masses that grade into granite gneiss or intimately inject the schist and grade into injection gneiss, but moderately persistent clean-cut dikes also occur.

Laramide intrusives.—Dikes and stocks of porphyries formed during the Laramide revolution are abundant throughout the district. Although few ore shoots of importance are found in the larger bodies of porphyry, some of the most persistent shoots occur in veins that follow porphyry dikes. Sodic monzonite and quartz monzonite porphyry of groups 4 and 5 (pl. 7 and fig. 12) are the most abundant rocks and occur in dikes and stocks largely limited to the eastern and south-central parts of the district. Dikes of quartz monzonite porphyry of group 6 and alaskite porphyry of group 7 are present in small amount. Dikes of bostonite and bostonite porphyry of group 8 are abundant in the western part of the district, and three small dikes of granite porphyry of group 7 occur half a mile north of Idaho Springs. In the southwest part of the district several short dikes of biotite latite (fig. 13, *F*) crop out just northwest of Chicago Creek in a narrow zone about 3 miles long trending N. 55° E. Most of the quartz monzonite dikes and many of the bostonite dikes have a northeasterly trend, but important bostonite dikes trend east-west and northwest.

The porphyrytic quartz monzonite, which is the most abundant type, is characterized by phenocrysts of pink orthoclase 2 to 10 millimeters in diameter and of light-gray plagioclase (oligoclase-andesine) 2 to 8 millimeters in diameter in a dark-gray aphanitic groundmass. Prisms of green hornblende as much as 3 millimeters long and of magnetite and titanite as much as 1 millimeter long are also visible. The groundmass is finely microgranular and consists of quartz, orthoclase, some plagioclase, and abundant magnetite. The quartz monzonite in the small stock near Fall River, three-fourths of a mile above the mouth of York Gulch, consists of orthoclase, andesine, biotite, quartz, and magnetite.

A quartz monzonite porphyry on the southwest slope of Seaton Mountain near Idaho Springs appears to belong to group 6. It is characterized by large feldspar phenocrysts as much as 1½ centimeters long, though most are less than 3 millimeters long.

The granite porphyry consists of sparsely scattered phenocrysts of gray and pink feldspar less than 3 millimeters in diameter and light-gray quartz nearly 1 centimeter in diameter in a finely crystalline pale-pink groundmass of quartz and orthoclase. Very small flakes of biotite and grains of muscovite occur in small amounts.

The bostonites are typically gray to lilac-colored or reddish-brown microcrystalline rocks composed of alkalic feldspar with only small amounts of quartz. The bostonite porphyries have phenocrysts of alkalic or alkali-calcic feldspar, or of pyroxene, or both (fig. 13, *E*). These rocks form dikes, which locally expand into lens-shaped masses as much as an eighth of a mile across. Some of the dikes are as much as 4½ miles long. The dikes between Russell Gulch and Nevadaville show a noteworthy radiation from a center near the Topeka mine. A bostonite dike cuts quartz monzonite in the northwest part of Central City, indicating that here as elsewhere in the Front Range the bostonite dikes are younger than the quartz monzonite dikes. The age relations of the porphyries are shown in figure 12.

STRUCTURE

Pre-Cambrian structure has had considerable influence on the distribution of structural features formed during the Laramide revolution. Many dikes and premineral fault fissures follow pre-Cambrian contacts or trends of foliation. The foliation in the granite gneiss parallels that of the surrounding schist in most places but locally cuts directly across it. The main elements of the regional structure reflect the doming of the schists by the Boulder Creek granite batholith south of Idaho Springs with the development of a transverse northeasterly flexure in the regional monocline. (See pl. 2.) A strong northeasterly shear zone extends along the northwest side of a large body of hornblende gneiss in the eastern part of the district. This shear zone existed in early pre-Cambrian time and strongly influenced the intrusions of Boulder Creek granite and gneissic aplite, but some movement occurred along the zone after the intrusion of these rocks that resulted in strong secondary foliation here. South of Justice Hill the zone merges with the steep south limb of the Russell Gulch syncline. Farther southwest its course has not been definitely ascertained, but it is believed that it continues southwestward, joining with the northeasterly shear zone that is prominent in the Boulder Creek granite near the junction of Ute Creek and Chicago Creek (pl. 2).

Faulting occurred both before and after the intrusion of the porphyries. The earliest fractures of the Laramide are strong northwesterly faults, some of which can be traced for miles beyond the limits of the district. (See pl. 9.) The later faults strike from east to northeast and contain most of the veins of the district. Both sets dip steeply. The northeasterly faults are much more numerous but far less extensive than the northwesterly faults. During the Laramide revolution the intrusion of igneous rocks began after both sets of fractures were present, and distribution of the porphyries was influenced by these planes of weakness. Later faulting along the early fractures displaced the porphyries and created channels for ore deposits. South of Russell Gulch the northeasterly faults correspond in trend with the foliation of the pre-Cambrian rocks, but to the north most of the veins strike more to the east than does the foliation. In a few places displacement has been measured on the northwesterly faults. In the Little Mattie mine postporphyry movement along three northwesterly faults has been consistent, the left-hand wall moving ahead almost horizontally a few feet.[80] On the main Blackhawk fault the northeast wall moved up and northwest at 60°, and the total displacement is several hundred feet where it crosses Fourmile Gulch. The displacement on the premineral faults that formed the northeasterly vein system has been little studied, but in most places the movement was probably small, rarely exceeding 20 feet.

ORE DEPOSITS

Gold, silver, copper, lead, zinc, and uranium ores occur in the Central City-Idaho Springs district, but shipments have owed their value mainly to gold and silver. The ore deposits are veins and stockworks formed during the Laramide revolution and are genetically related to porphyritic intrusive rocks. The district is on the southeast side of the main porphyry belt at a place where the eastern edge of the mineralized part swings from east-northeast to north. The ores are of two main types—one consisting mainly of pyrite, chalcopyrite, and quartz and the other of galena, sphalerite, chalycopyrite and subordinate pyrite. A zonal arrangement of the ores is shown in plate 9.

Subsequent to the primary mineralization, faulting occurred in many parts of the district. Many of these late faults were formed for a part or all of their length along veins and brecciated the ores. Other faults cut across and displaced mineral veins, but the displacements commonly do not exceed a few feet or tens of feet. This fracturing has been followed in places by the deposition of cherty white or gray quartz, probably from ascending thermal waters. This quartz is very similar to the "horn" quartz of the telluride veins of Boulder County; it was noted more frequently in the region just southeast of Central City than elsewhere, and it is worthy of note that it coincides with the north end of the telluride zone. Locally quartz and siderite have cemented brecciated ore and formed coatings on ore minerals in vugs. Etching of galena crystals in the Hayseed mine appears to have been contemporaneous

[80] Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit. pp. 360–362.

with the deposition of this quartz and siderite. Although the postmineral fracturing along the veins was slight and local, it facilitated the descent of meteoric waters along parts of the veins and thereby greatly increased the amount of downward enrichment.

The bulk of the ore of the district occurs in veins that follow zones of minor faulting, but a few important ore bodies occur in chimneylike zones of brecciation better classed as stockworks. The abundance of veins in different localities appears to be dependent primarily on the amount and character of the fracturing, which was to a very large degree determined by the physical character of the rocks. The distribution of the veins north of Idaho Springs and near Central City shows a close relation to areas of granite gneiss, pegmatite, and porphyry dikes. The absence of veins in certain areas seems to be due to the presence of the Idaho Springs formation, which is less suited to the development of large persistent fractures. In the schist area southwest of Idaho Springs the more productive veins cut or follow dikes of porphyry or pegmatite or break across the foliation of the schist.

The strike of nearly all the veins lies between east and N. 45° E., but in some it is northwesterly and in a very few it is in still other directions. If examined in detail, the veins are found to be parts of a complicated network composed of master veins connected by oblique cross veins, each fracture having its smaller branches and spur veins. In cross section the pattern is similar, for vertical branching is no less characteristic than the splitting shown in a horizontal plane. Few of the veins can be definitely followed as individual fractures for more than 3,000 feet. The longest northeasterly vein, the California-Mammoth just south of Central City, is traceable on the surface almost continuously for about 2 miles. The west-northwesterly Gem vein, a mile north of Idaho Springs, is more extensive but less continuously mineralized. Many of the smaller veins pinch out at moderate depths, but several of the large veins have been mined successfully to depths of 1,000 to 1,500 feet. The California shaft is 2,200 feet deep along the vein and when first sunk was one of the deepest gold mines in the world.

Most of the veins have steep dips, generally more than 60°. In the vicinity of Idaho Springs the prevailing dip is to the north and northwest; in the vicinity of Central City the dips are steeper and almost evenly divided between northwest and southeast. Changes of dip or strike, or both, amounting to as much as 20° are uncommon along a single vein. The width of the workable veins ranges from half an inch or even less in the telluride veins to about 40 feet in a few broad mineralized shear zones. The common widths of commercial ore are 1 to 5 feet. Most of the veins are not simple fissure fillings but the results of mineralization along a fracture zone the walls of which underwent repeated movement before and during mineralization.

The stockworks are pipes or chimneys of irregularly fractured and brecciated rock that have been cemented by ore minerals. The most noteworthy of these is The Patch, about a mile southwest of Central City. The Patch in surface outline is oval, having a diameter of about 750 feet in a northeasterly direction and about 400 feet in a northwesterly direction. The pipe of mineralized breccia extends from the surface down to the Argo tunnel, a distance of 1,600 feet, without decrease in size but with a marked decrease in mineralization. (See fig. 61.) In places the rock is merely cut by an irregular network of fractures, but elsewhere it has been broken into fragments that have been moved with respect to one another and in places rounded. The Patch is on the California-Mammoth lode, and Bastin regarded it as localized where a number of large fracture zones approach one another closely and where the shearing movement, instead of being limited to the zones, became distributed through all the intervening rock. Brecciation reached a maximum along several northeasterly zones that in some places are alined with the California-Mammoth lode. Although fracturing in The Patch may have been produced by the same forces as those that produced the neighboring vein fissures, its similarity to pipes of explosion breccia of igneous origin is so great that the present writers believe its origin is to be found in the upward punch of an underlying igneous pipe following an earlier shear zone. Some parts of The Patch are barren, others are heavily mineralized. The zones of maximum brecciation are in general also zones of maximum mineralization. The ore minerals fill fractures and angular cavities between fragments and also replace silicates of the rock. The chief output has been pyrite-chalcopyrite-gold ore from well above the Argo tunnel level.

Another stockwork, very similar to certain parts of The Patch, is opened by a large stope on the 850-foot level of the Hubert mine a third of a mile north of The Patch. It has a known width of about 35 feet but a vertical extent of only about 150 feet. It was developed at the angle of the wedge formed by the junction of the main vein and a branch vein. The comparatively short vertical extent of this stockwork is characteristic of those formed by distributive fracturing at vein junctions and contrasts with that of The Patch.

Alteration and replacement.—Sericitic alteration is the dominant type associated with the gold-silver ores of both the pyritic and galena-sphalerite types. In areas of slight alteration, chlorite, epidote, and some carbonate have formed at the expense of the more easily attacked minerals. Near most of the veins alteration has been more severe and in many places has resulted in the replacement of all the original rock minerals except

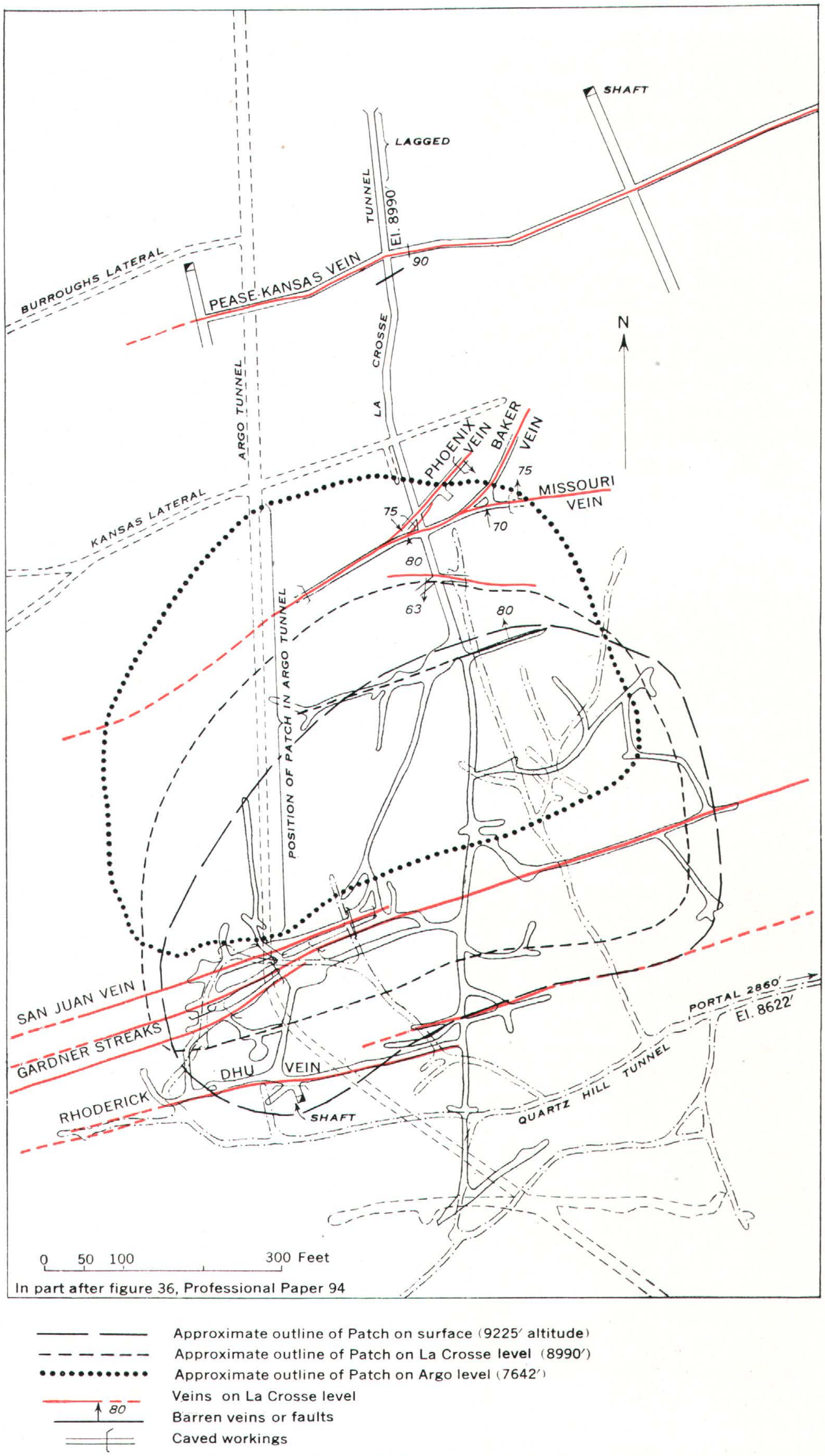


FIGURE 61.—Map of The Patch, Central City district.

quartz and apatite by sulfides, sericite, and in some places calcite or siderite. Sericite and pyrite are the dominant alteration products in the wall rocks. Galena, sphalerite, chalcopyrite, and tennantite are rarely found in the walls, occurring almost entirely as fissure fillings. Conversely, sericite occurs only as a replacement mineral and nowhere as a fissure filling. In places the walls may be largely changed to these minerals for a distance of 100 feet from the vein. In some places the original wall-rock texture is wholly effaced for several yards, and the only indication of its former presence is the abundance of sericite in the ore and the gradation of sericitic ore into undoubted wall rock. Near most ore bodies the alteration has been less severe, and the original foliated or porphyritic textures are still preserved.

In the incipient stages of alteration the feldspars, particularly plagioclase, are flecked with shreds of sericite, and the mafic minerals are mostly altered to chlorite and epidote. Hematite and magnetite occur in minute grains in the chlorite-epidote areas and in the groundmass. More extensive alteration results in the complete sericitization of all feldspars and of the temporary chlorite and epidote. Pyrite replaces magnetite and to a less extent quartz and silicates. In the most highly altered facies the original texture is entirely obliterated, and the rock has been wholly converted to an irregular fine-grained aggregate of quartz and sericite associated with irregular areas of relatively coarse quartz. Pyrite occurs in greater abundance and in larger crystals.

Replacement by pyrite was accompanied by the introduction of gold in some of the altered wall rock, and many of the pyritic gold ores and some of the gold-telluride ores are due to replacement. The chemical character of the walls apparently had little effect in localizing replacement. The strong rocks, such as granite gneiss, injection gneiss, pegmatite, and porphyry, broke with strong open fissures and became the loci of filled veins. An open fissure on passing into the schists of the Idaho Springs formation commonly spreads out along many small closely spaced, comparatively tight shear planes. This fractured schist seems to have offered the best opportunity for replacement. This selective replacement of suitably prepared ground is illustrated in many mines. In the Coeur d'Alene vein sharp-walled veins of galena and sphalerite formed in granite gneiss, but where the fracture entered schist, the ore changed to a pyritic gold replacement body. Similarly in the Druid mine the more micaceous folia of the Idaho Springs formation were more thoroughly replaced by ore minerals than the stronger feldspathic seams.

Gold-silver ores.—Most of the ore deposits of the district are worked primarily for gold and silver, but some copper and lead and a small amount of zinc and uranium are credited to the district's output. The pitchblende ores are only a local variant of the gold-silver veins. In nearly all the primary ores and in all but a few of the supergene ores gold predominates over silver in value. Bastin [81] classified the gold-silver lode ores under four types: Pyritic ores, galena-sphalerite ores, composite ores (pyritic-galena-sphalerite ores transitional in character between the first two types), and telluride ores.

As shown on plate 9, the most widely distributed ores of the region are those of the pyritic gold deposits. This type includes most of the ore bodies between Central City on the north and Pewabic Mountain on the south and most of those along Fall River below the mouth of York Gulch. Galena-sphalerite ores occur on Seaton Mountain near Idaho Springs, on Alps Hill, northwest of Russell Gulch, and on Nigger Hill, Maryland Mountain, and Silver Hill north of Central City and Blackhawk. Ores of the composite type are most common in the border zones between areas occupied largely by pyritic ores on the one side and by galena-sphalerite ores on the other. They occur just east and west of Central City and between South Willis Gulch and the summit of Seaton Mountain. The telluride ores are confined to a narrow belt extending southward from Bobtail Hill near Central City to the head of Gilson Gulch and southwestward from this locality to Chicago Creek.

Pyritic ores.—The pyritic ores are predominantly pyrite and gangue with subordinate amounts of chalcopyrite, tennantite, gold, and in places enargite and other metallic minerals. In these ores gold greatly predominates in value over the other metals. The gold and silver are chiefly associated with chalcopyrite and tennantite. Coarsely crystalline pyrite is proverbially of low grade. The chalcopyrite in most places makes up less than 5 percent of the ore by weight but locally amounts to as much as 50 percent. Silver and gold are rarely visible. Enargite is found in a few veins, in some of which it is as abundant as pyrite. Galena, sphalerite, molybdenite, and native bismuth are present here and there. The predominant gangue mineral is quartz, but locally siderite or fluorite may be abundant, and where the wall rock has been replaced sericite is abundant.

Most of the minerals characteristic of the pyritic ores were deposited during a single period of mineralization, but a prevailing order of crystallization is recognized. Where molybdenite is present, it appears to have been the first mineral to crystallize, but in most of the ore pyrite is the earliest mineral; and apparently it continued to crystallize throughout the period of ore deposition. Chalcopyrite began to form early in the period of mineralization, but its deposition reached a maximum in the later stages, as is shown by its char-

[81] Bastin, E. S., and Hill, J. M., op. cit., p. 105.

acteristic abundance in the medial portions of certain veins and in or near many vugs. The tennantite shows similar relations, but its period of maximum deposition was later than that of the chalcopyrite. A small amount of galena and sphalerite is apparently contemporaneous with the pyrite and chalcopyrite. Almost nowhere is banding developed. Vugs are only moderately abundant and are usually small in the pyritic ores, which are as a rule irregularly massive in texture.

The average gold content of the smelting ores is usually between 1 and 3 ounces, and the average silver content between 4 and 8 ounces to the ton. The copper content in most ores is below the commercial limit of 1.5 percent, but in some ores it may be 15 to 16 percent. The silica content is extremely variable, but in most lots is between 30 and 70 percent.

Galena-sphalerite ores.—In the galena-sphalerite ores the predominant primary sulfides are galena, sphalerite, and pyrite; subordinate chalcopyrite and a little tennantite and bornite also occur. Enargite, native bismuth, and molybdenite are found locally in small amounts. The common gangue minerals are quartz and either calcite or siderite, but rhodochrosite is present in a few veins. Gold and silver, probably alloyed, are finely distributed within the sulfides, and in a few veins visible gold is relatively abundant. In these ores also gold is associated with chalcopyrite and tennantite rather than with the pyrite, but in some ore shoots it is associated with sphalerite. Silver increases with tennantite and galena, and locally chalcopyrite and sphalerite are notably rich in silver. According to Bastin, galena, sphalerite, pyrite, chalcopyrite, bornite, enargite, quartz, siderite, barite, free gold, and rhodochrosite seem to have crystallized contemporaneously in most of the ores. Siderite and calcite are early in a few places, but most commonly are the latest minerals and occur alone or with quartz as linings in vugs. Tennantite is much less abundant in the galena-sphalerite ores than in the pyritic veins and was one of the last minerals to form. These ores are, in general, similar structurally and texturally to the pyritic type, and the wall-rock alteration is similar. The chief differences between alteration along these and the pyritic gold veins are in the more abundant development of calcite and in the presence of sparsely disseminated galena and sphalerite at a few places in the walls.

In the ores of the galena-sphalerite type the variations in metal content are even greater than in the pyritic ores. In general the galena-sphalerite ores are poorer in gold and copper and richer in silver than the pyritic ores. The gold content of the galena-sphalerite ores commonly ranges between 0.15 and 3 ounces to the ton and the average silver content between 5.50 and 40 ounces to the ton. The average percentages of copper, lead, and zinc range from less than 1 to as much as 17 percent of copper, 54 percent of lead, and 32 percent of zinc.

Composite ores.—The composite ores may be the result of dual mineralization, first with the minerals characteristic of the pyritic type and later with minerals characteristic of the galena-sphalerite type. Veinlets of the galena-sphalerite type cut sharply across pyritic ore in several mines in the district, but there are numerous transitions from the composite ores to one or the other of the pure types. Bastin believes the interval between the two stages of mineralization was short but sufficient to permit much local brecciation of the earlier ore before the later ore was deposited. In some ores composed of nearly solid pyrite with some chalcopyrite, the ores have been brecciated and the fragments cemented by quartz, galena, sphalerite, and chalcopyrite. At places in the Centennial-Two Kings vein, pyritic ore is sharply separated from ore of the galena-sphalerite type by a band of comb quartz. The metal content of the ores of the composite type varies greatly with the proportion of the two types present, but in general it is intermediate between the two.

Telluride ores.—The telluride ores show more diversity in mineral character than the ores already described and probably formed at a later stage in the Laramide revolution. So far as known, no tellurides of gold and silver occur in either the pyritic or galena-sphalerite ores. The most important shipments of telluride ore have come from the War Dance and East Notaway mines near Central City, the Gem vein near the Gem Shaft, the Jewelry Shop vein, and the Treasure Vault mine near Idaho Springs. These telluride shoots all lie in a narrow north-northeasterly zone extending from near the mouth of Chicago Creek to Bobtail Hill and are at the intersection of the Dory Hill fault with northeasterly veins in the northern half of the zone. (See pl. 9.) The telluride ores consist of gold and silver tellurides in a gangue of blue-gray fine-grained horn quartz and small amounts of fluorite, ferruginous calcite, and fine pyrite. The pyrite is less abundant in the veins than in the wall rocks. In general no very consistent sequence was observed, although fluorite and calcite line some vugs and were there the last minerals to form. Although the gold-telluride ore mined on the Gem vein came from the 12th level, most of the telluride ore thus far mined has been obtained within 125 feet of the surface and has contained free gold in even greater abundance than tellurides. This gold is partly and perhaps wholly the result of the oxidation of gold-telluride minerals. The tellurides occur chiefly as flakes or plates of pale brass-yellow color. Altaite, coloradoite, krennerite, petzite, and sylvanite have been identified by M. N. Short in ore from the Jewelry Shop mine, which is typical of the rich ores of this group. (See fig. 60, *D* and *E*.) The ratio of gold to silver in the telluride ore shipped from the War Dance mine commonly ranged between 1:1 and 3:1, and the average for 36.8 tons was 16.31 ounces of gold and 13.06 of silver to the ton. In the War Dance and Jewelry Shop mines the telluride ore formed in a network of small veinlets and as an irregular replacement of the wall rock near fractures. In the East Notaway mine the telluride veins are characteristically 1 to 3 inches wide and consist of dark fine-grained gray "horn" quartz, fine-grained pyrite, some antimonial tennantite, and varying amounts of the tellurides. All the vein minerals are essentially contemporaneous, but the sulfides are more abundant near the borders of the veinlets, and sylvanite is more abundant near the center.

Uranium ores.—Pitchblende associated with sulfides occurs in several veins on the south slope of Quartz Hill. As shown on plate 9, the pitchblende is largely restricted to a north-south zone about a quarter of a mile wide and a mile long and occurs in the east-northeast veins that cross it. Two north-northwesterly bostonite dikes cut diagonally across the productive belt, and, according to Alsdorf,[82] the parts of the dikes that lie within the zone outlined on plate 9, are strongly radioactive. It is possible that the uranium-bearing solutions are related to a deep bostonite magma apexing in a narrow northerly zone at depth and that these fluids first followed fissures or dikes transverse to the east-northeasterly veins in which the ore has been found. For many years a small and sporadic output has come from this group and has been used mainly for specimens and for experiments. Pitchblende has been reported from the Alps, Belcher, Calhoun, German, Kirk, Leavenworth, Mitchell, Pewabik, Wood, and Wyandotte mines. The pitchblende occurs as a minor component of the pyritic ores, and most of these mines have been worked for gold and silver rather than pitchblende. Alsdorf believed that the pitchblende veins were earlier than the pyritic veins, but according to Bastin it is evident in a number of specimens that pitchblende, chalcopyrite, and minor amounts of pyrite and gray quartz crystallized contemporaneously. Other specimens contain sulfides that are later than the pitchblende. A rich specimen from the Calhoun mine contains abundant pitchblende sharply cut by veinlets of sphalerite, pyrite, and galena. Bastin believes that the pitchblende ores were deposited during the early pyritic mineralization and that ores of the galena-sphalerite types were later deposited in the fractures. The pitchblende ores are believed to represent a local and unusual variation of the main sulfide mineralization of the district.

Placers.—Although placer mining within the district has persisted to the present day, it had ceased to be of major importance before the end of the sixties. Productive operations were started in 1933 at the junction of Clear Creek and North Clear Creek, 5½ miles east of Idaho Springs. A dry-land dredge operated here in gravel that yielded 50 cents a yard in 1935. The most extensive placer workings in the district were in the valleys of Chicago Creek and Clear Creek near Idaho Springs, and they developed not only the present stream gravels but also glacial outwash gravels and gravels of possible preglacial age. These deposits, which are described by Spurr and Garrey,[83] have not been productive for some time. Intermittent placering continues in the district southeast of Central City, however, chiefly in the valley of North Clear Creek and in Russell Gulch, in spite of the fact that nearly all this ground has been worked and reworked several times. As would be expected, present yields are low.

Relation of ore to depth.—The primary gold-silver ores of the district extend without noteworthy changes from an altitude of about 7,000 feet to one of about 9,700 feet, a range of 2,700 feet. Individual lodes have been followed in mining to a depth of more than 2,500 feet without marked change in character. In The Patch, however, there seems to be a marked decrease in metalization at an altitude of about 8,000 feet, approximately 1,200 feet below the surface.

Secondary enrichment.—In most parts of the Central City quadrangle the natural position of the water table appears to have been 50 to 150 feet below the surface. This is indicated by the depth of oxidation in some of the mines and by early records of the water level in certain shafts. In some mines enriched ore is practically limited to the oxidized zone, between the surface and the ground-water level; in others it extends downward for more than 700 feet, far below ground-water level, and represents a secondary sulfide zone. Gold enrichment has occurred in the oxidized zone in all types of gold-silver ores; enrichment in silver is largely limited to the secondary sulfide zone of the galena-sphalerite veins; enrichment of copper, invariably on a small scale, is limited mainly to the pyritic ores; enrichment in lead is insignificant; and enrichment in zinc has nowhere been observed.

Gold enrichment is most striking in certain galena-sphalerite veins, which usually contain less than 0.1 ounce of gold to the ton where not oxidized but may contain 1.5 to 3 ounces of gold to the ton in the oxidized zone. The surface parts of these veins were worked by the pioneers for gold alone, but there is no indication of gold enrichment below the ground-water level. In the oxidized zone the ores underwent partial disintegration, which was accompanied by the conspicuous development of brown hydrous oxides of iron, an increase in porosity, and an incomplete freeing of the gold through oxidation

[82] Alsdorf, P. R., Occurrence, geology, and economic value of pitchblende deposits in Gilpin County, Colo.: Econ. Geology, vol. 11, pp. 266–275, 1916.

[83] Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., pp. 311–314.

of its sulfide matrix. A part of the gold freed by oxidation was taken into solution and redeposited in the oxidized zone or at the top of the supergene sulfide zone immediately below it. The evidence for supergene enrichment in gold below the ground-water level is not convincing. (See fig. 62.) In some places wire gold was found in cavities below this level, but it is uncertain whether the gold was deposited by descending solutions or by late hypogene solutions.

In the Central City district the oxidized ore is generally lower in silver than the primary ore. Small amounts of silver are precipitated in the oxidized zone as silver chloride or native silver, probably through reaction with residual sulfides. Much of the silver is dissolved during oxidation and may be deposited at or below ground-water level as native metal or in sulfo compounds. In the absence of precipitating agents the silver enters the ground-water circulation and is lost so far as the ore deposits are concerned. Supergene silver minerals have never been recognized in ores of the pyritic type, in spite of the fact that silver is fairly abundant as a primary constituent. Perceptible silver enrichment is practically limited to the ores of the galena-sphalerite type. Pyrite, quartz, and chalcopyrite, the principal minerals of the pyritic ores, are comparatively ineffective in neutralizing the acid sulfate solutions that carry silver, but galena, sphalerite, and carbonates are effective in neutralizing such solutions and precipitating the silver. The form in which the silver is precipitated seems closely related to the composition of the associated supergene copper minerals, and two contrasted types of silver enrichment have been noted. In one silver was redeposited in sulfo compounds (proustite, pearcite, and polybasite) associated with supergene chalcopyrite; in the other it was redeposited as native silver in association with supergene chalcocite, bornite, and covellite. Secondary silver minerals are not equally abundant in all galena-sphalerite veins. This is apparently due in part to physical causes, but in most places it can be explained by differences in mineral composition. Silver enrichment seems to have been of slight importance in the Gladstone mine near Idaho Springs and in the Topeka vein near Russell Gulch. In these veins carbonates are rare, and pyrite and chalcopyrite are unusually abundant.

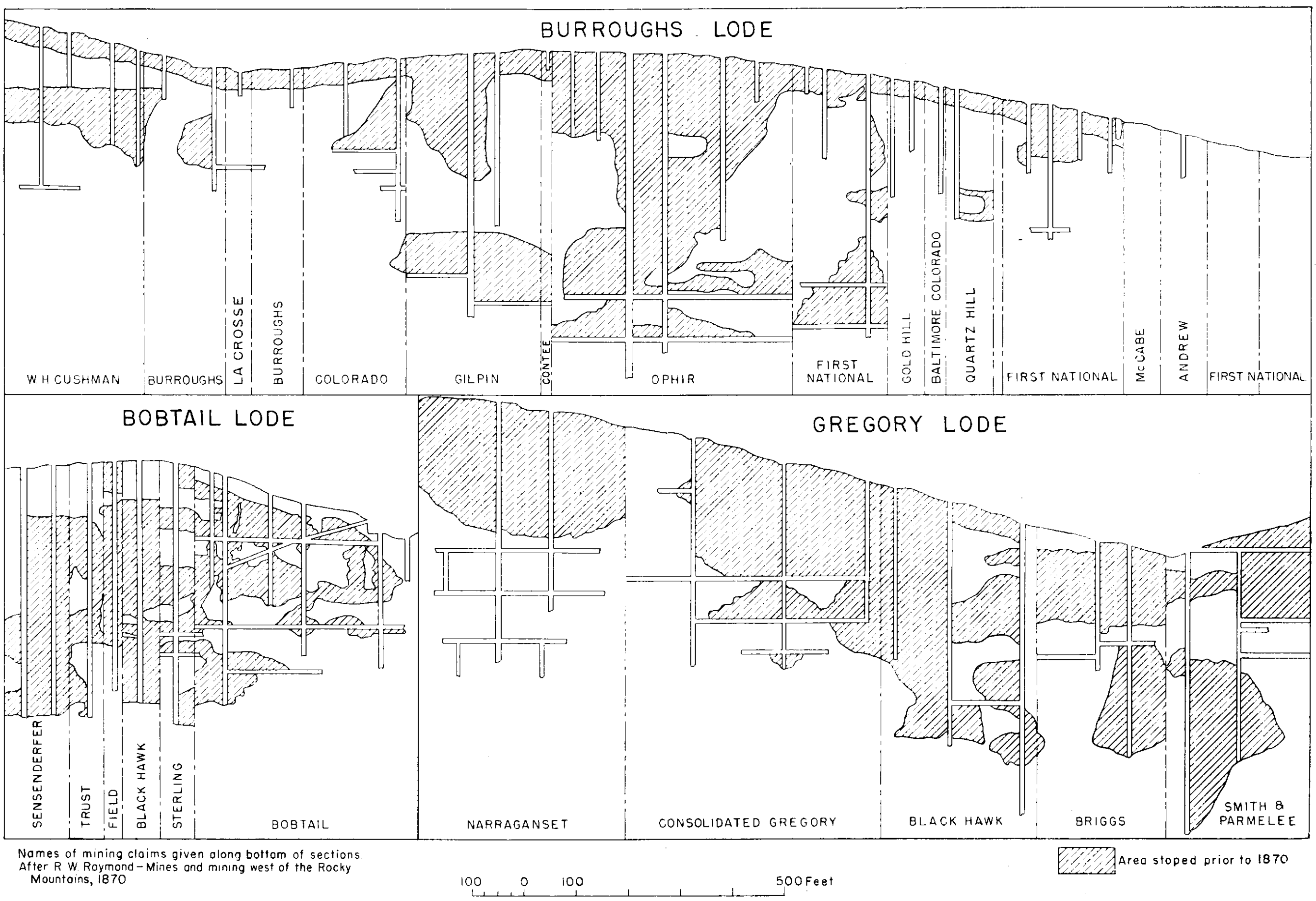


FIGURE 62.—Relation between commercial ore and the surface in veins of the pyritic gold group, as illustrated by longitudinal sections of the early workings on the Bourroughs, Bobtail, and Gregory lodes. The Bourroughs vein crops out on a side hill at an altitude of more than 9,000 feet near remnants of the Overland Mountain erosion surface and shows residual enrichment. The Bobtail lode crops out on a rolling plateau at 8,600 feet, a part of the Overland Mountain surface, and the presence of enriched ore beneath a leached zone is evident. The Gregory lode crops out in Gregory Gulch, where erosion has cut through the rich surface ore.

The supergene silver minerals pearcite, proustite, polybasite, and native silver occur in two ways—as fillings or linings of fractures or vugs in primary ore and as replacements of the primary sulfides and gangue.

The rich silver ores were reached at or near the ground-water level; they attained their richest development in the first 100 or 200 feet below this level and then decreased gradually downward until at a depth of 500 or 600 feet evidence of enrichment was rare or absent. The silver content of enriched ore of smelting grade ranged from a few tens of ounces to as much as a thousand ounces or more to the ton in picked lots. Bastin believed that the decrease in silver content of the enriched ores with increasing depth was the prime factor in the decline in importance of silver mines in the district. The gold, copper, lead, and zinc contents of the silver veins have been little affected by enrichment below the oxidized zone.

Downward enrichment in copper is of slight economic importance. Commonly it is restricted to the development of thin films of chalcocite or bornite on chalcopyrite in the upper parts of the ore bodies, but in some places small amounts of secondary chalcocite ore and very rarely of native copper have been noted. Enrichment in copper is most extensive below ground-water level in pyritic ores that are unusually rich in primary copper minerals.

Smithsonite, anglesite, and cerussite were each noted in a few ores, but secondary sphalerite or galena were nowhere observed. A sulfate of uranium has been noted in some of the pitchblende ore but in insignificant amounts.

Localization of ore.—The localization of ores in the Central City-Idaho Springs district depends primarily upon the position of the underlying sources of the mineralizing solutions and secondarily upon the fractures available for the solutions in their journey from the source towards the surface. Judging from the narrowness of the zone to which the telluride ores of the district are limited, their source must have been so restricted that it was tapped only by the south-southwesterly Dory Hill fault and its blind extension, which lie transverse to the general strike of the fractures in which the tellurides themselves were deposited (pl. 9). The localization of the pitchblende ores in a much shorter north-northeasterly zone also suggests a local and somewhat linear transverse source. With an upward journey of any great distance one would expect the solutions to spread laterally and give rise to a broader and broader zone of mineralization with increasing distance from the source. The great length of the telluride zone, together with its extreme narrowness, suggests that the linear source was not far below the present ore bodies. The much greater width of the pitchblende ore zone suggests that its source is at greater depth than that of the tellurides. The extensive area covered by the pyritic gold ores and the galena-sphalerite ores would indicate a linear source at much greater depth or a source that itself has a broad areal expanse.

Most of the ore shoots of the district are apparently due to the presence of open spaces in premineral faults. The most open places along these faults are in brittle wall rocks and at the junctions with branch fissures or cross fractures. The most favorable wall rocks in the order of favorability seem to be granite gneiss, pegmatite, injection gneiss, porphyry, and schist of the Idaho Springs formation. Many fractures are well mineralized in the granite gneiss, but become barren where they enter the schist. This is well illustrated in the Gold Collar, Coeur d'Alene, Frontenac, and Jefferson-Calhoun veins. (See fig. 63.) In those veins where the ore is due to replacement, however, some of the best ore may be found where the vein or the fracture zone splits up into many small slips in the schist. In some veins, as in the Chase, a junction with a northwesterly cross shear zone is marked by the development of valuable ore shoots in the northeasterly vein and in the northwesterly vein as well. In many places the thin wedge between the main vein and branch or spur vein was shattered and was the site of important ore deposition. This is well illustrated by one of the richest ore shoots in the Hubert mine. In a similar way the main fissure near the junction with cross veins has generally been better mineralized than at some distance from their intersection. This is illustrated in many mines, but is especially well shown near the junction of the Elizabeth and Gunnell veins. The conditions that obtain at intersections of cross veins and branch veins are duplicated in veins that are nearly parallel in strike but intersect, owing to marked differences in dip. Ore shoots localized by the low angle junctions of veins are illustrated by the ore shoot on the Concrete vein just above its junction with the Slaughterhouse vein and by the ore body in the Old Town vein just below its junction with the Wautauga vein. Most of the well-mineralized veins end along the strike and in depth by horsetailing, that is, by breaking up into smaller and smaller branch veins (fig. 30). The disappearance of the veins by spreading out into many unimportant fractures is especially common where they leave the stronger wall rocks and enter schist, the foliation of which is subparallel to the different parts of the vein in the more brittle wall rock. Good ore shoots have been found localized where a vein parallel to the foliation of the schist begins to cut across the foliation. The horsetailing of a vein in depth is illustrated by the Concrete vein about 200 feet below the Argo tunnel level (fig. 30). Although the appearance of this type of fracture generally marks the disappearance of the vein, it also quite commonly indicates the transition zone between two overlapping master fractures.

Although few of the veins of the Central City-Idaho Springs district are strong and well-mineralized in the

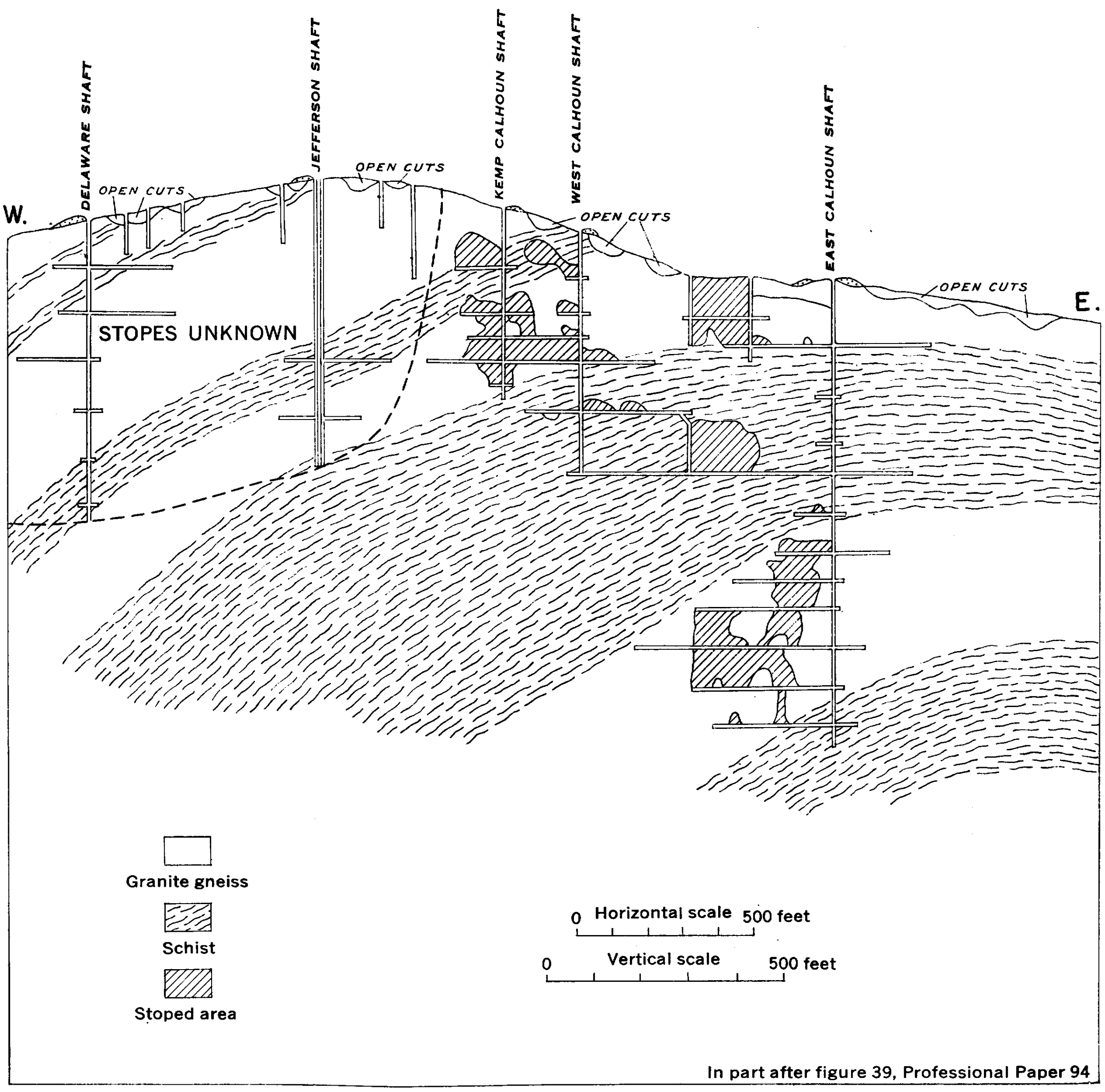


FIGURE 63.—Section of the Jefferson-Calhoun vein, showing influence of injection gneiss on the localization of ore shoots.

porphyry stocks and plugs, several important ore bodies have been found along the walls of dikes. The ore bodies of the deepest gold mine in the district, the California-Hidden Treasure, follow a bostonite dike (pl. 16). Although veins parallel to the foliation of the Idaho Springs formation are generally weakly mineralized, this is not true if one or both walls are pegmatites. The Frontenac-Aduddell vein, which follows a pegmatite dike in the Idaho Springs formation until it enters granite gneiss at depth, is strong and well-mineralized.

The relation of ore shoots to direction of movement of the walls was not ascertained by Bastin, but in the few veins studied by the writers it is in harmony with the expected positions of open spaces created by the movement (pl. 15).

GUNNELL-GRAND ARMY MINE

The Gunnell-Grand Army mine [84] and the Concrete mine are on the same strong east-west vein just west of Central City, but as the two mines are worked separately and contain somewhat different types of ore they are described under separate headings.

The Gunnell-Grand Army mine, on the south side of Prosser Gulch just west of Central City, has been one of the most productive in the district. Its drifts, crosscuts, and shaft approximate 25,000 feet. The vein was discovered in the early sixties, but extensive development was not begun until 1874. The Grand Army shaft is 1,200 feet deep, with levels at 100-foot intervals. A winze from the 1,100-foot level connects with a raise from the Argo tunnel workings (pl. 16). A pump shaft

[84] Bastin, E. S., and Hill, J. M., op. cit., pp. 216–218.

connects with the workings in the eastern part of the property. The workings are along the Gunnell North, Gunnell Middle, Gunnell South, Hattie, Wheeler, Elizabeth, and Slaughterhouse veins. The Gunnell veins range in strike from N. 70° E. to N. 88° E. and in dip from about 60° N. to 70° S., and the other veins are approximately parallel to them. It is reported that most of the ore above the 900-foot level has been removed.

The Gunnell-Grand Army system of veins is predominantly pyritic, but some of the smaller veins are of the galena-sphalerite type, and the larger veins have locally been reopened and further mineralized with this type of ore. Westward in the Concrete workings, the ore was almost exclusively of the galena-sphalerite type. On the Argo tunnel level the writers saw only pyritic ore. The Gunnell South vein between the 1,100-foot level and the Argo tunnel level is mainly pyritic but shows galena-sphalerite ore in places. It ranges from 6 inches to 3 feet in width and consists of veinlets of ore bordered by wall rock containing disseminations of ore. The Gunnell Middle vein is also predominantly pyritic. It ranges from 6 inches to 2 feet in width in the lower levels. The Elizabeth vein joins the Gunnell North vein in the Argo tunnel (pl. 16). The Elizabeth vein has yielded little ore, but near its intersection with more productive veins it has probably caused an enlargement of the ore bodies. Below the Argo tunnel the vein shows signs of breaking up and disappearing in depth; but it is possible that a blind vein is present a short distance to one side and will persist to greater depth. The walls in the lowest levels are schist, in much of which the foliation is nearly parallel to the vein.

Typical sampling works assays of the ore as given by Bastin[85] range in tenor from 0.55 to 2.40 ounces of gold and 2.00 to 19.17 ounces of silver to the ton and from a trace to 1.40 percent of copper. On the Argo tunnel level the Elizabeth vein assayed 0.05 to 0.29 ounce of gold to the ton for a width of 7 to 24 inches. The Gunnell North vein averaged 0.33 ounce of gold for widths of 11 to 20 inches. The Gunnell South vein averaged 0.61 ounce of gold to the ton for an average width of 22 inches in a block of ground 235 feet long; in another block it averaged 0.42 ounce for a width of 10 inches, and in a third block, 0.76 ounce for an average width of 25½ inches. Seventy-five feet above the Argo tunnel level the Gunnell South vein averaged 0.91 ounce of gold for a width of 22 inches, and in some blocks of ground averaged 1.70 to 1.80 ounces for a width of 26 to 35 inches. Shipments of ore from the mine from 1874 to 1889 show an average value per ton of $56.59 for smelting ore and of $14.02 for concentrating ore. The value of the total gross output of the mine from 1874 to the close of 1911 was about $2,760,000.

[85] Bastin, E. S., and Hill, J. M., Economic Geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colo.: U. S. Geol. Survey Prof. Paper 94, p. 318, 1917.

CONCRETE MINE

The Concrete mine[86] is on the south side of Prosser Gulch, about a mile west of Central City. It was at first developed by an inclined shaft 1,285 feet deep, near the east line of the property. In 1929 a raise from an Argo tunnel lateral holed through to the shaft (pl. 16). The Golden Treasure shaft, following the Golden Treasure-Slaughterhouse vein, enters the Concrete workings 540 feet west of the Concrete shaft at a depth on the incline of 674 feet. Below this, the Golden Treasure shaft follows the Concrete vein to a depth of more than 1,300 feet. Ten levels have been driven from the shaft, one of which connects with the Slaughterhouse workings and one with the Gunnell workings. The Concrete claim was located in 1879, and its gross output has been valued at about $800,000.

Country rock throughout the entire mine is granite gneiss. The vein, which is the westward extension of the Gunnell-Grand Army vein, strikes N. 74°–85° E., with an average of about N. 78° E. The vein dips from 50° to 82° S. down to the 750-foot level, and on the 1,000-foot level about 57° N.; below that it is nearly vertical. Above the 1,033-foot level the vein for the most part ranges from 1 to 3 feet in width, but locally it widens to 8 feet, and in some places it is represented by a single narrow slip. Below the 1,033-foot level the vein widens rapidly to a maximum of 25 feet at the 1,127-foot level.

The Concrete vein belongs to the galena-sphalerite type. It consists of crushed and silicified granite gneiss, which has been impregnated with small scattered crystals of sulfides and is cut by a network of sulfide veinlets as much as several inches in width. The sulfides are, in the order of abundance, dark sphalerite, galena, pyrite, and chalcopyrite, but some veinlets consist almost exclusively of galena and sphalerite and others mainly of sphalerite and chalcopyrite. Pyrite is the most abundant sulfide in the wall rock adjacent to the veinlets. Quartz is the chief gangue mineral. Postmineral movement is indicated by gouge slips that cut the ore and by slickensides that are either vertical or pitch eastward at 80°. Movement along northward-dipping splits from the Middle and South Gunnell veins has apparently faulted out the Concrete vein on the Argo tunnel level, but the vein is present below these faults on the 100- and 200-foot sublevels (pl. 16).

Two main ore bodies have been developed, both west of the shaft. The upper one has been stoped from a depth of about 450 feet down to the 760-foot level where it is about 300 feet long. The Slaughterhouse-

[86] Idem, pp. 214–216.

Golden Treasure vein is said to join the Concrete vein between the 608- and 760-foot levels. This junction may explain the formation of the ore shoots. The second ore shoot extends from the 937- to the 1,127-foot level west of the shaft and is developed by workings from the Golden Treasure shaft. The most productive parts of this shoot appear to be near or at the junction of the Concrete vein with the Elizabeth vein. The vein is entirely pyritic in character below the Argo level.

About 12 percent of the ore mined in the twenties was shipped direct to the smelter. The tenor of about 307 tons of smelting ore was 1.03 ounces of gold and 8 ounces of silver to the ton, 23.80 percent of lead, and 10.60 percent of zinc. Ore concentrated about 18 to 1 yielded a product having an average content of 0.64 ounce of gold and 5.80 ounces of silver to the ton, 12.30 percent of lead, 11.20 percent of zinc, and 12.10 percent of silica. Thirty-two lots of smelting ore shipped from 1893 to 1909, inclusive, ranged in tenor from 0.40 to 4.13 ounces of gold and from 3.08 to 15.80 ounces of silver to the ton, from less than 1.5 to 3.70 percent of copper, and from less than 5 to 64 percent of lead.

MAMMOTH, GREGORY, FISK, COOK, AND BOBTAIL VEINS

Mining near Blackhawk along the Mammoth, Sleepy Hollow-Fisk, Cook, Gregory, O'Neil, and Bobtail-Denmark veins and along their branches and several minor veins was controlled for many years by the Fifty Gold Mines Co., and most of the development on the three chief veins was carried on through the Cook shaft, 1,450 feet deep, the Bobtail tunnel, and the Gregory incline. The Gregory, located May 6, 1859, was the first gold lode to be discovered in Colorado. The Gregory incline slopes for 1,709 feet at about 25° to a point on the Gregory vein 700 feet below the surface. The relations between the veins of the group are complex. (See pl. 15.)

The Mammoth is probably the widest and most conspicuous lode in the vicinity of Central City. It can be traced along the surface for nearly 6,000 feet. The same general mineralized zone continues westward to Spring Gulch, where it is represented by the National and Hecla veins, and finally enters The Patch, from which it emerges as the great California-Hidden Treasure lode. On Mammoth Hill the lode is worked through an almost continuous series of shafts and pits, the principal one being the Mammoth shaft on the east side of the hill. The ore consists predominantly of pyrite but is workable only where chalcopyrite is also present. It is well exposed in the Bobtail tunnel where it was being stoped in 1938.

As exposed on the surface, the Cook, Fisk, Sleepy Hollow, and After Supper shafts seem to be on one great lode, which preserves a fairly constant trend of about N. 40° E. Near the Cook shaft this main lode seems to be joined from the west by the Mammoth lode and from the east by the Bobtail lode, but the relations are somewhat complicated and can best be understood by referring to plate 15.

In the Mammoth and Fisk veins the left-hand walls moved ahead almost horizontally, but in the Bobtail the right-hand wall moved forward. The wall rock on the Bobtail tunnel level is largely granite gneiss, which is nearly horizontal. Copper stain is locally prominent in the easternmost workings of the tunnel but was not observed in the central or western parts.

The northeast part of the Gregory vein under Bates Hill is worked by a drift tunnel extending entirely through the hill. The average strike of this part of the vein is about N. 45° E., and its dip is 80°–85° SE. The vein material is predominantly pyritic, but locally ore of the galena-sphalerite type is present. The vein ranges in width from 2 to 5 feet. The wall rock is chiefly granite gneiss.

The ores of all of the veins in this group belong almost exclusively to the pyritic type, though in a few places, notably in the eastern part, galena-sphalerite ore also occurs. Pearce recognized the presence of tellurium in certain ores from the Gregory mine. Raymond mentions the discovery in 1874 of a pocket of ore in the Gregory vein containing a large amount of free gold.

The tenor of 410 tons of ore shipped from these veins from 1888 to 1909 ranged from 0.52 to 26.4 ounces of gold and from 1.5 to 21 ounces of silver to the ton, from less than 1.5 to 13.75 percent of copper, and from 30 to 70 percent of silica. Sampling of the so-called Fisk-Mammoth vein on the 14th level of the Cook shaft shows 0.12 to 0.52 ounce of gold and 0.4 to 4.28 ounces of silver, with an average of about 0.3 ounce of gold and 2.0 ounces of silver to the ton, over a width of 3 to 6 feet. Assays of a solid sulfide veinlet showed a maximum of 5 ounces of gold and 11 ounces of silver to the ton.

AFTER SUPPER-SLEEPY HOLLOW VEIN [87]

The Sleepy Hollow vein crosses North Clear Creek at Blackhawk. It appears to be the northeastward extension of the Fisk lode. The After Supper or Banzai shaft, north of Blackhawk, is 714 feet deep. The Sleepy Hollow shaft, about 700 feet south of Blackhawk post office, is more than 1,000 feet deep. The American shaft is on the same vein 500 feet southwest of the Sleepy Hollow. In 1912, the total output of the Sleepy Hollow mine was reported to have a value of $800,000, and that of the After Supper mine $80,000.

The vein strikes about N. 45° E. and dips from 80° S. to 80° N. Below the ninth level of the Sleepy Hollow shaft the vein splits into a vertical branch and one dipping 70° N. The wall rock is schist, pegmatite, and granite gneiss.

[87] Bastin, E. S., and Hill, J. M., op. cit., pp. 226–227.

The vein filling shows two periods of mineralization. An early vein of crushed silicified wall rock and pyrite was reopened and the fractures were filled with quartz, galena, sphalerite, and chalcopyrite. Some ore from the Sleepy Hollow mine is reported to have carried gold tellurides.

On stope maps of the Sleepy Hollow mine the vein is shown to have been extensively stoped from the second to the eighth levels. Stopes above the first level are not shown, but are reported to be extensive. The ore ranged in tenor from 0.28 to 34.25 ounces of gold and from 2 to 492 ounces of silver to the ton, but averaged about 2 ounces of gold and 10 ounces of silver to the ton. A few lots of smelting ore carried as much as 20 percent of lead and a few others as much as 5.7 percent of copper.

HIDDEN TREASURE-CALIFORNIA-GARDNER LODE

The Hidden Treasure-California-Gardner lode,[88] on the north slope of Quartz Hill about 1¼ miles S. 60° W. of Central City, is one of the strongest and most persistent in the district. It is worked to a depth of 2,250 feet through the California shaft, which is the deepest in the district (fig. 64). The vein trends about N. 86° E., and as exposed on the surface and throughout most of the workings, even down to the Argo level, it parallels for most of its length a dike of bostonite porphyry (pl. 16).

The vein is of the composite type; in the Hidden Treasure workings it is chiefly of the galena-sphalerite type and in the California workings almost exclusively of the pyritic type. Both types of ore are clearly later than the bostonite porphyry dike.

The following table gives the gold and silver content of the lode.

Gold and silver content, in ounces per ton, of ore from Hidden Treasure-California-Gardner lode[1]

	Gold	Silver
Iron pyrites	0.65	4.85
Copper pyrites	.85	53.50
Gray copper	.90	38.65
Blende	.16	6.45
White quartz	3.32	7.35
Bluish quartz	3.56	5.84
Flinty quartz	.18	1.90
Feldspathic gangue	.90	2.35

[1] Bastin, E. S., and Hill, J. M., Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colo.: U. S. Geol. Survey Prof. Paper 94, p. 234, 1917.

The Gardner vein as exposed in the Argo lateral ranges in dip from 75° S. to 80° N. It follows the south side of the dike of bostonite porphyry; the other wall is schist. Vein material in these laterals is entirely pyritic, and sampling in most places shows a gold content between 0.05 and 0.50 ounce and a silver content between 0.50 and 3.50 ounces to the ton. In ore with noticeable amounts of chalcopyrite or "gray copper" the gold content reaches as much as 3.24 ounces and the silver content 9 ounces to the ton.

THE PATCH, SAN JUAN MINE, AND LA CROSSE TUNNEL[89]

The Patch, on the crest of Quartz Hill, about 1 mile S. 50° W. of Central City, has been exploited chiefly through the San Juan mine. The ore body is an irregular stockwork, with the ore minerals deposited in spaces between the fragments of breccia or in irregular networks of fractures. The coarse breccia that makes up The Patch is a pipelike body that pitches steeply north from the surface to below the Argo tunnel (fig. 61). The San Juan mine is developed by a shaft 916 feet deep, from which 11 levels have been turned. The workings also join the La Crosse tunnel (fig. 61). The chamber stopes connecting with this tunnel are of immense size.

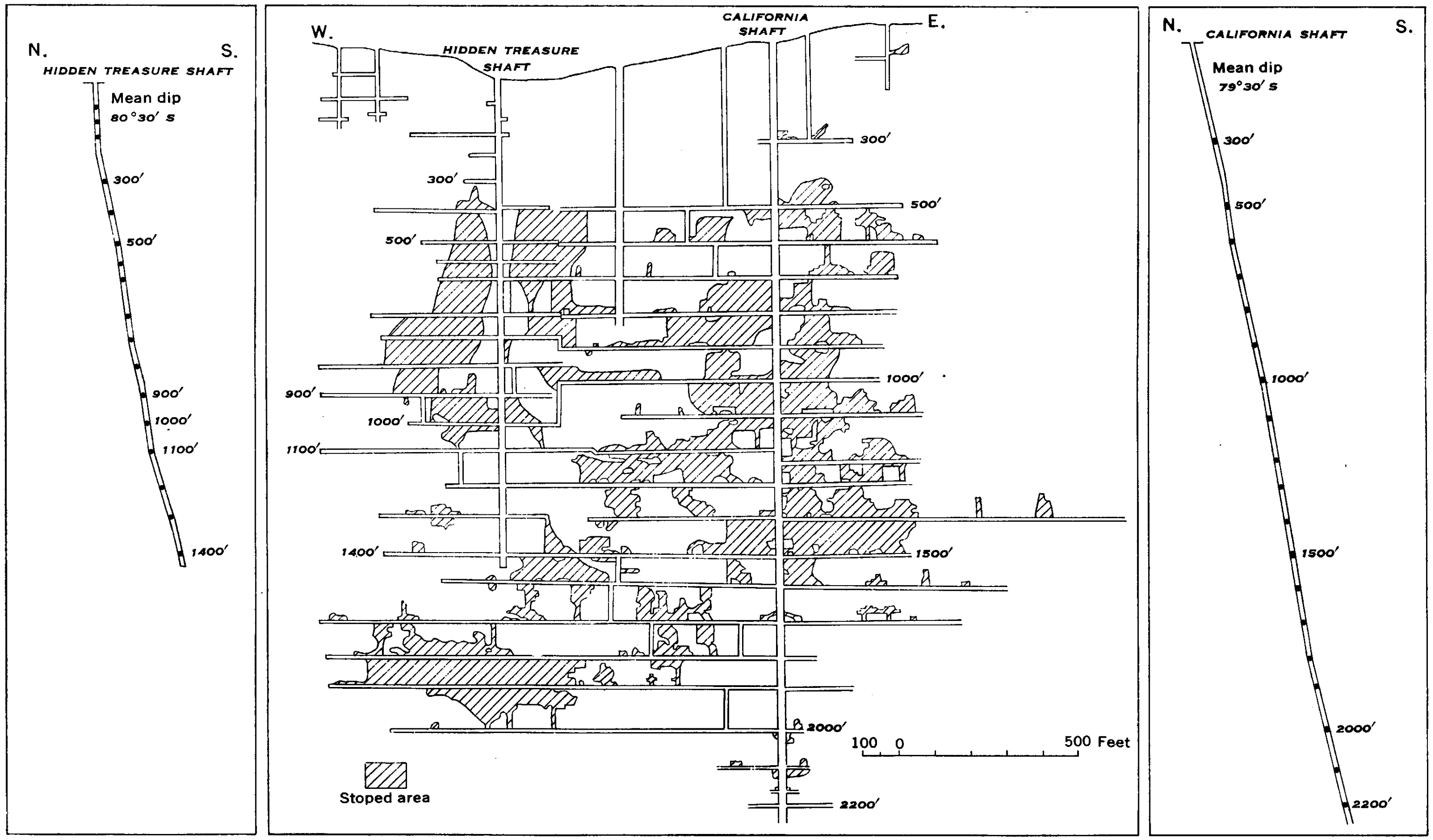
The prevailing wall rock of The Patch is granite gneiss, but bostonite porphyry occurs at several places. These rocks have been cut by a most irregular network of fractures that have formed blocks. These blocks in some places show little differential movement, but elsewhere they have been moved over each other and partly rounded, and blocks of gneiss have become mixed with blocks of pegmatite and porphyry. These relations show conclusively that mineralization was later than the intrusion of the bostonite porphyry. Not all parts of the breccia are mineralized. The sulfides and quartz gangue occur principally in the interstices among fragments of the breccia but in part as true fissure fillings and as replacement of the blocks or their crushed matrix. Disseminated sulfides may be present even in the centers of the blocks. Several northeasterly zones of maximum mineralization are distinguishable and have been followed by drifts in the San Juan mine.

In one type of ore sphalerite is predominant with a little associated pyrite, galena, and quartz; in the other type the minerals are pyrite, chalcopyrite, and quartz with a little antimonial tennantite. Vugs 2 to 3 inches across are common, and in them crystals of clear white quartz occur in abundance. In the northern part of The Patch, as exposed in the La Crosse workings, the ore is almost exclusively of the galena-sphalerite type. Some galena-sphalerite ore persists as far as the crosscut leading into the San Juan workings, but in the latter the pyritic type of ore is almost exclusively present.

The La Crosse tunnel cuts the Phoenix-Kansas vein 180 feet from the portal, the Phoenix-Burroughs vein 500 feet from the portal, the Missouri vein about 525 feet from the portal, and The Patch 600 feet from the portal. The Missouri vein joins the Phoenix-Burroughs about 70 feet west of the tunnel and the Baker vein about 50 feet east of the tunnel. The La Crosse

[88] Bastin, E. S., and Hill, J. M., op. cit., pp. 97, 132, 137, 233–234.

[89] Idem, pp. 234–237.



After figure 34, Professional Paper 94

FIGURE 64.—Sections of the California vein.

level of the San Juan mine also connects with the workings on the Gardner vein. This vein as exposed just west of The Patch is a sharp-walled fracture filled with pyrite and chalcopyrite. As The Patch is approached, the vein breaks up into a series of branches and then into a network of very small veins, and this network passes into The Patch.

Assays of 117 tons of ore shipped from the San Juan mine between 1888 and 1909 show a trace to 12.2 ounces of gold and 2.15 to 34 ounces of silver to the ton and from less than 1.5 to 9 percent of copper. The gold content of most of the ore in the largest of the San Juan stopes is said to have ranged from 0.44 to 0.78 ounce of gold. The average value may be placed at about $15 per ton. Most of the ore mined since 1900 was of comparatively low grade. Ore shipped in 1910 contained 1.27 ounces of gold and 4.54 ounces of silver to the ton and 0.85 percent of copper. Milling ore contained 0.226 ounce of gold and 0.3 ounce of silver to the ton. The gross output of the mine is said to have been valued at $600,000.

The Patch, where traversed by the Argo tunnel, has yielded almost no workable ore but is cut by a number of pyritic veins. The Argo tunnel lies about 1,600 feet below the collar of the San Juan shaft and goes through The Patch for a distance of 545 feet (pl. 16).

GERMAN AND BELCHER MINES

The German and Belcher mines [90] are on the summit of Quartz Hill, about 1⅓ miles S. 57° W. of Central City, and are noteworthy for the pitchblende content of their ore. The German shaft is 600 feet deep, and the workings of the two mines are connected. Stoping has been limited principally to ground above the 130-foot level. The vein in most parts of the mine strikes about N. 75° E. and dips 75°–80° S. The wall rocks are mainly schist and pegmatite, and exceptionally of granite gneiss. Two dikes of bostonite porphyry are exposed on the 500-foot level and are cut off by the vein.

In general the vein material in the German mine is of the composite type modified by the presence of pitchblende. In places the vein is a typical fissure filling, but in most parts replacement along small fractures has been important. The vein ranges in width from a few inches to about 3½ feet. The chief ore minerals are pyrite, sphalerite, chalcopyrite, and galena. In some places pyrite is the principal sulfide and in others galena and sphalerite. An assay of the galena-sphalerite ore from the 300-foot level west gave 2.12 ounces of gold and 10.9 ounces of silver to the ton and 0.015 percent of uranium oxide.

The low-grade uranium ore exposed in the workings consisted of altered schist or pegmatite highly impregnated with pyrite and with less amounts of sphalerite and still smaller amounts of pitchblende, containing about 0.25 to 0.5 percent of uranium oxide. It forms an intimate part of the sulfide vein. Generally the high-grade pitchbende ore forms irregular masses in the low-grade disseminated ore. The largest piece of pitchblende known to have been found in the mine came from the 130-foot level west; it weighed 240 pounds and contained 88 percent of uranium oxide. According to Rickard, the more solid pitchblende, either in lens form or in well-defined streaks, seldom exceeded 3 to 4 inches in width. One specimen of rich pitchblende ore showed uraninite cut by small seams of sphalerite, pyrite, and galena. Another specimen showed botryoidal pitchblende cut by minute veinlets of pyrite, chalcopyrite, and dark-gray quartz. In the more shattered parts fragments of pitchblende lay in a matrix of these sulfides. Rickard stated that by hand sorting, a selected grade of pitchblende containing 15 to 60 percent of uranium oxide could be recovered. The ratio of mill ore to selected pitchblende was about 40:1.

An assay of coarse concentrates from the German and Belcher mines gave the following result: Gold 1.50 ounces and silver 3.71 ounces to the ton, copper 1.42 percent, lead 0.65 percent, silica 10.60 percent, iron 36.69 percent, sulfur 41.05 percent, and uranium oxide 3.22 percent. Assays of pitchblende ore show 0.00 to 1.20 ounces of gold and 0.00 to 21.80 ounces of silver to the ton, 0.00 to 12.95 percent of zinc, and 1.10 to 1.47 percent of uranium oxide. Assays of 28 tons of smelting ore shipped in 1909 from the German and Belcher mines gave 0.31 to 5.99 ounces of gold and 2.00 to 21.60 ounces of silver to the ton and 0.00 to 1.90 percent of copper; one lot contained 9.70 percent of lead. According to a report of the United States Bureau of Mines in 1913, the total production of pitchblende ore from the two mines from the fall of 1911 to January 1, 1913, was 240 pounds of high-grade ore containing more than 70 percent of U_3O_8, and 1 ton containing 2 percent of U_3O_8.

GEM-FREIGHTER'S FRIEND LODE

The veins worked in the Gem and Freighter's Friend mines [91] form part of a well-defined system of mineralized fractures that crop out on the summit of Seaton Mountain 1⅓ miles north of Idaho Springs. The system includes a number of subparallel branching fractures. The Gem workings consist of a shaft with 18 levels; the lode is also cut by the Argo tunnel 1,420 feet below the collar of the shaft. A winze below the Argo level increases the total vertical extent of the workings to 1,504 feet. The Freighter's Friend workings comprise one shaft with five levels.

[90] Bastin, E. S., and Hill, J. M., op. cit., pp. 240–243.

[91] Idem, pp. 290–292, 297.

The average strike of the Gem lode is about N. 70°-75° W., and the dip is 35°–80° N., averaging about 60° N. The prevailing wall rock is granite gneiss, but monzonite porphyry is abundant on the 9th, 13th, 17th, 18th, and Argo levels, particularly west of the shaft. In most of the workings the lode consists of two nearly parallel veins 20 to 30 feet apart, but in places it is a single well-mineralized fissure. The shaft follows the footwall vein down to about the 9th level and below that follows the hanging-wall vein. The foot-wall vein in some places is 4 or 5 feet wide, but in others is ill-defined and poorly mineralized. Although the Freighter's Friend workings are on the same general lode as those of the Gem mine, the two mines have not been connected, and the exact correspondence between individual veins within the lode is not known.

Vein material in the Gem mine is dominantly pyritic, but in many places it contains other sulfides. Rhodochrosite veinlets containing sphalerite and chalcopyrite cut coarse-grained pyrite in places. At one place on the Argo level small veinlets of galena-sphalerite ore cut coarse-grained pyritic ore in the Gem vein. Thus there were two periods of mineralization in this vein. The first is represented by chalcopyrite, pyrite, quartz, and possibly tetrahedrite; the second by galena, sphalerite, tetrahedrite, enargite, rhodochrosite, and bornite. An ore shoot about 100 feet long by 100 feet high near the Gem shaft on the 12th level contained tellurides of gold. A specimen from this shoot showed sylvanite in a gray quartz matrix. This part of the vein is almost on the strike of the Dory Hill fault (pl. 9). The second period of mineralization is better represented in the Freighter's Friend than in the Gem workings.

Smelting records from 1897 to 1910 show that pyritic ores consisting largely of pyrite with subordinate chalcopyrite are most abundant. In most of this ore the gold content ranges from 0.3 to 3 ounces to the ton, generally less than 1 ounce, and the silver content between 5 and 30 ounces to the ton. Unusually high gold contents are commonly accompanied by unusually high silver contents. The copper content in general is below the commercial limit of 1.5 percent but is as much as 5 percent in a few places. Ore containing lead in quantities sufficient to be of economic value (more than 5 percent) is more abundant in the Freighter's Friend than in the Gem mine. The lead content of some shipments has been as high as 65 percent and that of zinc as high as 23 percent. A comparison of the silver content in the pyritic and lead ores showed that much of the galena was not highly argentiferous, although it contained more silver than the pyrite. Assays of ore from the 11th level east in the Gem mine support the conclusion that the previous metals are most closely associated with the copper minerals. One shipment of pyritic ore averaged 0.28 ounce of gold and 7.85 ounces of silver to the ton; of two shipments of cupriferous pyrite ore, one averaged 0.93 ounce of gold and 17.60 ounces of silver to the ton and 2.30 percent of copper, and the other averaged 1.3 ounces of gold and 19.30 ounces of silver and 4.1 percent of copper; lead ore averaged 0.25 ounce of gold and 15.80 ounces of silver, 23.45 percent of lead, and 9.35 percent of zinc.

LITTLE MATTIE-NEWTON VEIN SYSTEM

The Little Mattie-Newton group of veins,[92] developed principally in the Little Mattie and Newton mines is 2 to 2½ miles west-southwest of Idaho Springs. The main workings consist of the Little Mattie shaft, which is 650 feet deep and has 8 levels, and a tunnel 6,400 feet long, which follows the vein northeastward to a point 500 or 600 feet beyond the Newton shaft, with which it connects. The Little Mattie workings aggregate about 10,000 feet and the Newton workings about 4,000 feet. The Newton and General Thomas shafts are 275 and 250 feet deep, respectively (pl. 17).

The group comprises a single exceptionally strong northeasterly vein with branches at each end. The main vein is opened at short intervals through a distance of about 3½ miles, and almost throughout its course it is closely associated with one or more porphyry dikes. To the northeast the main vein breaks up into two branches, which are distinguishable in the Star and Red Lion tunnels. They follow the general course of two porphyry dikes. To the southwest the main vein breaks up into several well-marked but less highly mineralized fractures, one of which is found in the Archer mine and another in the King Solomon and Dorritt workings.

The country rocks along the Little Mattie-Newton vein are mainly pegmatite, gneiss, and porphyry. In places pegmatite alone forms the wall rock for long distances, but at other places it is intimately mixed with the gneiss, which commonly trends parallel to the vein and dips between 60° and 75° NW. In many places bostonite porphyry forms one or both walls of the vein.

The vein strikes approximately N. 40° E. and dips 65°–70° NW. Slickensides on the wall range from horizontal to a pitch of 15° SW. The vein or vein zone ranges in width from 1 foot to several feet; it contains footwall and hanging-wall streaks of ore connected by a network of minute stringers and seams of ore. In many places the zone through its entire width may contain ore of shipping grade; in one place 65 percent of a 10-foot zone was shipped direct to the sampler, and in another place 75 percent of a zone 3 to 11 feet wide was shipped.

The ores from the main vein are predominantly gold-bearing in places, but in other places silver is of greater value than gold. Ores of the West and so-called South

[92] Spurr, J. E., Garrey, G. H., and Ball, S. H., Economic geology of the Georgetown quadrangle: U. S. Geol. Survey Prof. Paper 63, p. 358. 1908.

veins are more valuable for silver than gold, but to the east gold is the more valuable constituent. Quartz is the chief gangue mineral, and the metallic constituents are galena, sphalerite, tetrahedrite, polybasite, and small amounts of argentite. Pyrargyrite, native silver, and native gold occur in a few places. Soft black sulfides or sulfurettes extended down as far as the sixth level. The highest grade of ore and the largest ore bodies in the Little Mattie mine were found between levels 4 and 7. The ore bodies in places extended continuously from these lower levels to the surface.

In 1908 a rather large tonnage of ore said to average about $200 to the ton was mined from the 6th level. Below level 7 the ore was decidedly leaner, and except for some milling ore obtained from just above level 8 at the southwest end of the mine little ore of commercial grade was found.

According to Mr. Sutherland, superintendent of the mine in 1905, ore on level 7 west of the Cross vein averaged between 100 and 300 ounces of silver and 2 to 3 ounces of gold to the ton, whereas the ore east of the Cross vein contained only 7 to 30 ounces of silver and about 2½ ounces of gold to the ton. Small isolated pockets of ore contained 30 to 42 ounces of gold and 400 to 600 ounces of silver to the ton, 5 to 10 percent of lead, and 5 to 10 percent of copper.

The main vein of the Little Mattie workings is offset 6 to 20 feet by a fault, which has been mineralized to form the Cross vein. The fault strikes about N. 28° W. and dips 65° NE. To the northeast of this fault the ore was much more pyritic than to the southwest and contained gold in commercial quantity but very little silver; to the southwest a substantial amount of argentiferous lead ore was mined. The Cross vein contains no pay ore, although values of $2 to $6 in gold have been obtained from it. It lies along a premineral fault. Several smaller faults also cut the vein (pl. 17).

STANLEY MINE [93]

The Stanley vein crosses Clear Creek about 1½ miles west of Idaho Springs and extends southwestward up the slope to the ridge between Clear Creek and Spring Gulch. The workings consist of four main tunnels—the Whale, York, Golden Link, and Road Level—and two shafts—the Gehrmann, with eight levels, and the Golden Link (pl. 18). The vein has been developed by underground workings for a distance of about 4,000 feet along the strike and for a vertical distance of about 1,500 feet. The ore mined in 1904 averaged about $40 to the ton after being sorted; it contained 1 to 2 ounces of gold and 20 to 40 ounces of silver to the ton, 25 to 30 percent of lead, and 2 to 3 percent of copper. Ore shipped in 1910 had a tenor of 0.85 ounce of gold and 15.3 ounces of silver to the ton, 0.70 percent of copper, and 1.4 percent of lead. The total gross output of the mine to 1910 is said to have been valued at about $3,650,000.

Southwest of the Golden Link shaft the main Stanley vein splits, and the branches diverge to the southwest. Near Clear Creek the Stanley splits into two branches that diverge slightly to the northeast. This split is about 200 feet west of the Stanley shaft house. The more northern split is the principal one and retains the name Stanley vein. The other is called the Crockett. The Stanley vein follows a zone of crushing, sheeting, and faulting that is of compound origin and was the site of repeated movement. The vein is mainly along a single zone, which trends about N. 50° E., but it shows local branching. The most important branch noted underground is called the Joker vein. It is subparallel to the main lode but gradually diverges in a northeasterly direction. The Joker vein dips 80° S. and the Stanley 60° N., and they probably join above the Road Level tunnel.

The principal ore bodies of the Stanley mine were unusually irregular (pl. 18). Most of them were made up of large segments of the original vein that had been left almost intact and, unlike much of the vein, had been little broken up by the strong postmineral fault that followed the vein. In places, however, the original vein was thoroughly brecciated for long stretches. The ore was dragged out and mixed with so many rock fragments that it became too low grade to be worked. Originally some of the best ore seems to have been formed at the intersection of branches, as is common in this region. In the Road Level tunnel, at the junction of the main Stanley vein with the Joker vein, a large quantity of high-grade ore was found. On the Stanley vein the big stope nearest to the portal of the Road Level tunnel is said to have been at the junction of this vein with the Crockett.

The principal wall rock of the mine is gneiss, which is quartzose in some places, biotitic in others, and locally hornblendic. Pegmatite is locally abundant, and dikes of both bostonite and biotite latite porphyry are exposed in the mine workings. The chief gangue mineral is quartz, and the chief ore mineral is pyrite, accompanied by appreciable chalcopyrite and galena and by minor tetrahedrite. A little siderite occurs free in vugs, and cherty silica forms coatings on walls and geodes.

The original fissure zone was occupied by a bostonite porphyry dike, which was torn apart and displaced by differential movements during subsequent stages of mineralization and intrusion. In the Hukill tunnel, and also in the intermediate levels, a breccia containing fragments of gneiss, pegmatite, and bostonite porphyry is cemented by quartz, pyrite, chalcopyrite, and galena. A dike of biotite latite also follows the vein and encloses angular fragments of pyritic lead ore and the

[93] Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., pp. 341–349.

earlier bostonite porphyry, as well as of pegmatite, gneiss, and alaskite. In addition to enclosing angular fragments of the vein, flowage in this dike along the contact caused streaks of galena and pyrite to be drawn out with the igneous rock into fine, wavy metallic threads. Unfortunately for present-day study, the latite dike has not been recognized at the surface. The latite shows very little mineralization and is relatively fresh; however, in a few places it is traversed by pyritiferous quartz veins, which indicates a weak later mineralization. It appears that practically the whole formation of the vein took place during the interval between the intrusion of the bostonite and the latite. The strongest, widest, and best parts of the vein commonly lie between gneiss walls. In the Road Level tunnel a large ore body extending for 500 feet between gneiss walls ended in a weak and discontinuous vein where the latite dike enters the vein zone.

After the injection of the latite dike the fissure was again reopened, and a breccia of subangular to rounded fragments was formed in places. This breccia zone extends along the vein or along the biotite latite porphyry and is locally several feet thick. Fragments of bostonite and biotite latite porphyry and the various older rocks are present. Striations along the walls of this breccia pitch from 34° to 60° SW. Many of the openings along this fracture were filled by a fine mud-like material, which was thought by Spurr to be an infilling of water-borne sediment but which is quite probably the matrix of an intrusion breccia similar to that found in the Logan and Yellow Pine mines of the Gold Hill district. Locally ore fragments are sufficiently abundant in the breccia to be mined. In places the breccia contains scattered or locally abundant sulfides, including galena and chalcopyrite, as an interstitial cement to the rock fragments. In a few places this postbreccia mineralization may have formed seams of sufficient size to be of economic value. On the whole, however, it has been of little consequence from an economic standpoint. Silica has so thoroughly cemented the fragmental material in places as to form a rock that is as hard and firm as the latite porphyry; in fact, much of the hard, fine-grained part of the breccia, according to Spurr, is not easily distinguishable from some of the dense varieties of latite.

The gneiss of the wall rock shows abundant calcite and chlorite as decomposition products, and in places the feldspars have been entirely altered to sericite. The bostonite porphyry is highly altered, the feldspars having been converted largely to kaolin and partly to sericite. The ferromagnesian minerals have been entirely altered to calcite and magnetite or hematite; abundant deep-purple fluorite occurs along cracks in the rock and is abundant in some parts of the groundmass. The mineral is closely associated with calcite and is relatively late. The latite porphyry is altered along small cleavage cracks, the calcic feldspars having changed to calcite and the orthoclase to kaolin.

The geologic history of the Stanley vein may be summarized as follows: (1) Fracturing and faulting of the pre-Cambrian gneiss; (2) intrusion of a dike of bostonite porphyry; (3) renewed movement, which formed porous zones of crushed material and open, rubble-filled fissures; (4) deposition of pyritic galena ore, which cemented the openings with quartz and metallic minerals; (5) reopening of the old break; (6) intrusion of biotite latite porphyry; (7) faulting, with the formation of open fissures and the emplacement of intrusion breccia; and (8) silicification and the deposition of small amounts of ore.

EAST NOTAWAY MINE

The East Notaway mine,[94] about a mile southeast of Central City and on top of the ridge between Lake Gulch and Russell Gulch, is developed by an inclined shaft 650 feet deep. It is characterized by numerous irregular dikes of monzonite porphyry and by two distinct types of mineralization. The wall rocks are monzonite porphyry and schist with associated pegmatite. The North, or Shaft vein, consists predominantly of coarse-grained, low-grade pyrite, in which little mining has been done.

Crosscuts south from the shaft on each level cut the Homestake and Notaway veins, which are closely associated. On the 651-foot level the Homestake vein dips 55° N. and consists of 6 inches of coarse pyrite and quartz, 3 inches of brecciated pyrite and gouge, and 15 inches of pegmatite containing disseminated pyrite and small pyrite stringers. A 10-foot dike of monzonite porphyry lies on the hanging wall.

The Notaway vein differs entirely from the Homestake, both in value and in mineral character. On the 555-foot level it consists of three or four subparallel stringers of horn quartz as much as 1½ inches wide in a 4-inch to 6-inch zone. In places, as along most of the 555-foot level east, the Notaway vein occurs alone, but elsewhere it lies in or along the Homestake vein and is mined with it. In such places the Notaway horn-quartz ore cuts sharply through the heavy pyritic Homestake ore and is plainly later. Both veins cut through monzonite porphyry in places.

The ores of the Shaft and Homestake veins are of the pyritic type and consist predominantly of pyrite in a gangue of quartz and altered rock. In the Homestake vein chalcopyrite and tennantite are present in a few places. The Notaway vein consists typically of 1 to 3 inches of dark-gray horn quartz, fine-grained pyrite, tennantite, varying amounts of a gold and silver telluride and native gold. A polished section of rich

[94] Bastin, E. S., and Hill, J. M., op. cit., pp. 264–265.

ore shows pyrite, tennantite, and microcrystalline quartz to be abundant along the borders of the vein and apparently contemporaneous. Toward the center the sulfides decrease in abundance, and sylvanite(?) appears associated with native gold. Most of the sylvanite occurs alone, but in places it is intergrown and apparently contemporaneous with tennantite. The large crystals of sylvanite are platelike or bladelike in form. The native gold appears to be primary and not an alteration product of sylvanite.

The pyritic ore of the Shaft vein is everywhere below workable grade; its tenor is about 0.15 ounce of gold to the ton. Most of the ore of the Homestake vein is likewise of too low grade to be worked, but where chalcopyrite and tennanite are present its value may reach $200 per ton. The gold content of the Notaway vein is notably irregular. One shipment from the 500-foot level had a gold content of 32 ounces to the ton, and the next shipment of similar appearance from the same stope averaged only 2 ounces. Another lot averaged 27 ounces and the next only 7 ounces. Such irregularity is not unusual in the telluride ores of the district.

About a third of the output is smelting ore, and the remainder is concentrating ore. Smelting ore shipped in 1909 had a tenor of 0.39 to 11.6 ounces of gold, average 3.3 ounces to the ton; 2 to 11.04 ounces of silver, average 5.44 ounces; and 6.71 percent or less of copper. Ore shipped in 1910 had a tenor of 0.27 to 13.3 ounces of gold, average 2.52 ounces; 1.8 to 15.25 ounces of silver, average 4 ounces; and 8.5 percent or less of copper. The average metal content of the concentrating ore for 1910 was 0.18 ounce of gold and 0.426 ounce of silver to the ton.

JEWELRY SHOP VEIN

The Jewelry Shop mine, on Chicago Creek half a mile west of Idaho Springs, is owned by the West Gold Mining Co. It is developed by a crosscut tunnel 150 feet long, cutting the vein about 75 feet below the surface, and by a drift about 300 feet long. The mine was opened in February 1926 and 6,000 tons of ore was shipped to the Golden Cycle mill from March 1926 to November 30, 1926.

The country rock of the vein comprises biotite schist, quartz schist, and granite gneiss of the Idaho Springs formation, cut by a few small bodies of pegmatite. The main vein, or "main break," as it is called, strikes N. 85° E. along the crest of a small sharp fold in the schist and dips almost vertically (fig. 65). Many small seams of pyrite and quartz cross the drift; they trend N. 20° E. and N. 20° W. and dip east at a low angle. Along the many vertical cross fractures that cut the main break at rather small angles gold and silver tellurides are abundant. These seams end within a short distance, but where they are closely spaced rich ore may be mined to a width of 40 feet from the main vein. The main vein apparently served as the main channel for the mineralizing solutions.

The ore shoots are vertical or pitch slightly to the east. The biotite schist is a very poor host rock, and only very low-grade ore has been found in it. The quartz schist and the "blue schist" (a chloritic talcose rock) are very favorable to the ore.

According to M. N. Short, who studied the telluride ore under the microscope, the following ore minerals, mostly tellurides, are present, listed in the order of their abundance: Altaite, coloradoite, petzite, krennerite, native gold, galena, sphalerite, and sylvanite (?). The gangue minerals are quartz, pyrite, sericite, siderite, barite, and opal. (See fig. 60, *D*, *E*.) The order of deposition of the gangue minerals is pyrite and sericite, siderite, kaolin, quartz, barite, and opal. The tellurides are found in the vuggy parts of the veinlets associated with barite and quartz. The tellurides are more or less intergrown and occur in small bunches or blades rarely more than a quarter of an inch in diameter, which are scattered in the gangue. The tenor of the ore shipped ranged from 5 to 50 ounces of gold to the ton.

OTHER MINES

Data on other representative mines are given briefly below. Detailed descriptions of these mines have been given by Spurr, Garrey, and Ball,[95] and by Bastin and Hill.[96]

BELMAN

Development.—Several shafts; Big Five tunnel; 800 feet of drifts.

Veins.—Belman: Strike, N. 67° W.; dip, 60°–70° E.; zone of crushed, silicified schist. Many parallel slips cut altered schist for 30 feet above vein. Fracture zone separates this schist from unaltered mass. Postmineral movement crushed ore.

Wall rock.—Schist.

Ore and sulfide minerals.—Pyrite and gold, some chalcopyrite and gray copper.

Gangue minerals.—Quartz and silicified schist.

Ore shoots.—Tunnel cuts ore shoot 600 feet in length and 110 feet in maximum height.

Tenor.—13 samples assayed 0.52 to 1.16 ounces of gold and 2.2 to 6.4 ounces of silver per ton.

BURROUGHS

Development.—Four main shafts, one of which, the Ophir, is 1,200 feet deep. Phoenix connects with 12 levels.

Veins.—Burroughs: Strike, N. 85° E.; 8 inches to 4 feet wide. Seams of pyrite in silicified wall rock.

Ore and sulfide minerals.—Chiefly pyrite and gold, some chalcopyrite, gray copper, galena, and sphalerite.

Gangue mineral.—Quartz.

Tenor.—1893–99: 251 tons of smelting ore averaged 4.3 ounces of gold and 9.97 ounces of silver per ton. 1910: 10 tons averaged 3.31 ounces of gold and 5.9 ounces of silver per ton.

[95] Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit. (Prof. Paper 63), pp. 314–382, 1908.

[96] Bastin, E. S., and Hill, J. M., op. cit. (Prof. Paper 94), pp. 208–303, 356–366, 1917.

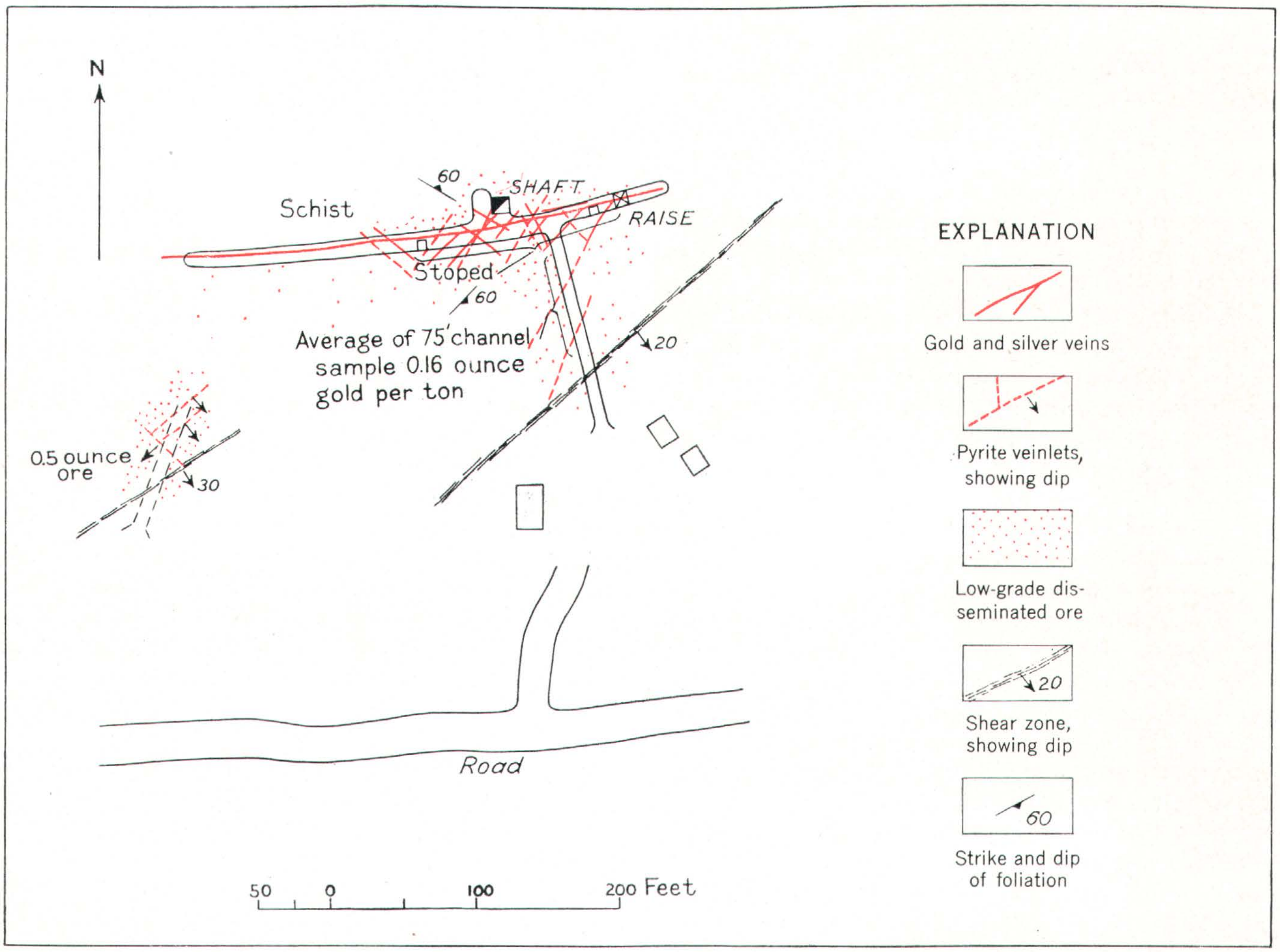


FIGURE 65.—Geologic map of the Jewelry Shop mine, Idaho Springs.

CASINO VEIN AND FOXHALL TUNNEL

Development.—Foxhall and Casino tunnels.

Veins.—Casino strikes east and is 4 feet wide. Irregular branching veins in schist. Foxhall tunnel intersects several minor veins, including Total Eclipse and Danube, which are mostly barren.

Ore and sulfide minerals.—Chiefly gold tellurides, some galena, sphalerite, and gray copper.

Gangue minerals.—Quartz and calcite.

Tenor.—Very irregular. Typical sampling works assay on 3,414-pound lot: 2.25 ounces of gold and 3.00 ounces of silver per ton.

CHEMUNG-BELMONT

Development.—Shaft 820 feet deep; 10 levels.

Production.—$500,000.

Veins.—Chemung-Belmont: Strike, N. 55°–73° E.; lode forks near shaft and reunites to west and in depth; north branch is Chemung and south is Belmont.

Wall rock.—Schist and pegmatite.

Ore and sulfide minerals.—Chiefly gold and pyrite, some tennantite, galena, sphalerite, and chalcopyrite.

Gangue mineral.—Quartz.

Tenor.—95 tons to sampling works, 1889–1902, averaged 1.74 ounces of gold and 16.03 ounces of silver per ton and 1.5 to 7.5 percent of copper.

CLAY COUNTY

Development.—Shaft; National tunnel connects with 6th level.

Production.—$600,000 to $700,000.

Veins.—Clay County: Strike, N. 21° E.; dip, steeply northwest; country rock contains stringers and disseminations of pyrite, gray copper, and quartz brecciated and cemented by sulfides.

Wall rock.—Idaho Springs formation, pegmatite, and monzonite porphyry.

Ore and sulfide minerals.—Pyrite, gold, gray copper, chalcopyrite, galena, and sphalerite.

Gangue mineral.—Quartz.

Ore shoots.—Production chiefly from 3d level.

Tenor.—57.5 tons of smelting ore, 1891–99 averaged 0.60 to 0.65 ounce of gold and 11.28 ounces of silver per ton and 1.5 to 6 percent of copper.

EDGAR

Development.—4 drift tunnels and 3 shafts. Vein also cut by Big Five tunnel.

Veins.—Edgar: Strike, N. 65° E., dip, 70°–85° NW. Few inches to 3 feet of crushed, slightly silicified wall rock containing stringers and disseminations of sulfides.

Wall rock.—Chiefly schist, some monzonite porphyry.

Ore and sulfide minerals.—Galena, sphalerite, and pyrite.

Tenor.—In the seventies, first-class ore averaged 0.5 ounce of gold and 80 ounces of silver per ton and 45 to 50 percent of lead.

176 tons, 1898–1909, averaged 0.6 ounce of gold and 16.07 ounces of silver per ton and contained from less than 1.5 to 6.5 percent of copper, 59 percent or less of lead, and 16 percent or less of zinc.

FRONTENAC AND ADUDDELL

Development.—Each mine has a shaft and 8 levels, which connect at 2 places.

Production.—Gross to 1911, about $2,250,000.

Veins.—Compound vein system of two or more parallel veins. Strike, N. 50° E.; dip, 50°–80° NW. Individual veins as much as 6 feet wide. Veins cut and offset by barren Flat vein.

Wall rock.—Chiefly granite gneiss; apex of lode in schist and granite.

Ore and sulfide minerals.—Pyrite, chalcopyrite, galena, sphalerite, and gray copper.

Gangue minerals.—Quartz and some rhodocrosite.

Tenor.—1894–1909: Ore contained 0.18 to 0.94 ounce of gold and 5.3 to 23.5 ounces of silver per ton, 0 to 22.5 percent of lead, and 0 to 14.8 percent of zinc.

GILPIN-EUREKA

Development.—Inclined shaft 700 feet deep with 6 levels.

Production.—$467,000 through 1910.

Veins.—Eureka: Strike, N. 70° E.; dip, 45°–70° N.; average width, 2½ feet. South vein: Strike, N. 85° E.; dip, 65°–70° N.; width, 12 to 24 inches; joins Eureka on 3d level, 200 feet west of shaft. North vein: Strike, N. 85° E.; dip, steeply north; width, 10 inches; poorly mineralized except for one lens of ore; joins Eureka near shaft. Spur vein: Strike, N. 68° W.; dip, 80° SW.; intersected by workings on 3d level 450 feet east of shaft; mostly narrow, but 2 feet wide at junction with Eureka.

Wall rock.—Granite gneiss, one small lens of schist.

Ore and sulfide minerals.—Pyrite, sphalerite, galena, and chalcopyrite.

Gangue minerals.—Silicified granite gneiss and quartz.

Changes with depth.—Highest grade ore near surface.

Ore shoots.—Principal ore body on Eureka vein west of shaft, extending to junction with South vein. Large ore body on South vein at junction with Eureka. Small ore body on Spur vein at junction with Eureka. On North vein, one small lens of ore 80 feet long.

Tenor.—1897–1908: 30 tons of smelting ore averaged 1.91 ounces of gold and 12.37 ounces of silver per ton, 16 percent of lead, and 12 percent of zinc.

CROWN POINT AND VIRGINIA

Development.—Inclined shaft and extensive workings.

Production.—$500,000.

Vein.—Crown Point: Strike, N. 50° W.; dip, 75° NE. Apparently continuation of Belman vein.

Wall rock.—Schist, granite gneiss, and pegmatite.

Ore and sulfide minerals.—Pyrite and gold.

Tenor.—1897–1901: 102 tons sent to sampling works contained 0.24 to 3.72 ounces of gold and 1 to 12 ounces of silver per ton.

DRUID

Development.—Druid shaft 500 feet deep with 8 levels; Searle shaft 140 feet deep with 5 levels.

Veins.—Druid vein system: Strike N. 40°–70° E.; dip, 55°–80° NW.; series of subparallel mineralized fractures; South vein, few inches to 11 feet wide, more regular and persistent than others. Postmineral movement in several directions. Silicious ore is replacement of schist. Searle: Strike, N. 40°–70° E.; dip, 55°–80° NW. Svoldi: Strike, N. 30° E.; dip, 55° N.; cut off on north by Searle.

Wall rock.—Schist down to 350-foot level; granite gneiss below. Dike of monzonite porphyry in upper workings.

Ore and sulfide minerals.—Gold and pyrite, some chalcopyrite, galena, sphalerite, and enargite.

Gangue minerals.—Chiefly quartz, some rhodochrosite and barite.

Changes with depth.—Rich silicious ore confined to upper workings above 300-foot level.

Ore shoots.—Several shoots; one on North vein pipelike and 300 feet long.

Tenor.—Silicious ore from Druid averaged 2.5 ounces of gold and 22.57 ounces of silver per ton. Silicious ore from Svoldi averaged 3.02 ounces of gold and 30.17 ounces of silver per ton.

EAST LAKE TUNNEL AND OWATONNA VEIN

Development.—East Lake tunnel 550 feet long; 30-foot crosscut connects with Owatonna shaft workings.

Veins.—East: Strike, N. 50° E.; dip, 50° NW. Owatonna: Strike, N. 50°–60° E.; dip, 45°–50° NW.; consists of two parallel fissures about 15 feet apart, probably merging to the northeast; upper fissure consists of 2 to 2½ feet of altered wall rock with veinlets of sulfide.

Wall rock.—Schist and pegmatite.

Ore and sulfide minerals.—Gold, galena, sphalerite, and pyrite.

Gangue minerals.—Schist, breccia, gouge, and quartz.

Tenor.—1897–1910: 117 tons of smelting ore from Owatonna vein averaged 0.23 ounce of gold and 27.57 ounces of silver per ton, 36 percent or less of lead, and 25 percent or less of zinc.

DONALDSON-CHAMPION DIRT GROUP

Development.—Donaldson mine, 4 tunnels aggregating 2,000 feet; Kelly mine, 1,700 feet of tunnel workings; Little Albert mine, 1,400 feet of crosscuts connecting with 2,200 feet of drifts; Champion Dirt mine, 1,100-foot Centurion tunnel, which connects with a shaft and 2,100 feet of drifts; 6 tunnels connecting with 1,500 feet of drifts.

Production.—Total for group to 1908, $500,000.

Veins.—Donaldson-Champion Dirt: Strike, N. 60°–65° E.; dip, 25°–30° NW. Vein splits in west Donaldson workings, south branch continuing as main vein, other trending S. 75°–85° W. Pegmatite or gneiss heavily impregnated with pyrite.

Wall rock.—Gneiss, striking northwest and dipping west, intruded by dikes of pegmatite. Locally granite, bostonite, and alaskite porphyry.

Ore and sulfide minerals.—Gold and pyrite, some galena, chalcopyrite, and gray copper.

Gangue minerals.—Quartz, some siderite.

Changes with depth.—Oxidized zone 40 to 79 feet deep.

Ore shoots.—Shoot at split in main vein. Extensive stopes in upper oxidized zone.

Tenor.—Best ore averaged 6 ounces of gold per ton in mill-run lots. About 1906, oxidized ore contained 2.25 to 2.36 ounces of gold per ton.

HUBERT

Development.—Two shafts totaling 2,000 feet with 14 levels develop veins to depth of 1,050 feet.

Production.—About $1,000,000.

Veins.—Two principal veins with several branches. North vein: Strike, N. 78° W.; dip, 65° N.–70° S.; sulfides deposited in open spaces in breccia; some replacement; few inches to 3 feet wide. South vein: Strike, N. 75° E. to east; dip, 65° N. near surface, steeply south in lower levels; splits up to the west.

Wall rock.—Granite gneiss, brecciated along veins.

Ore and sulfide minerals.—Galena and sphalerite, some pyrite and chalcopyrite.

Gangue minerals.—Quartz and siderite.

Ore shoots.—Shoots irregular, some large. Large shoot on 960-foot level 27 inches thick, pitches 65° S.

Tenor.—1888–1909: 131 tons of smelting ore, contained 0.74 to 5.8 ounces of gold and 2 to 17.6 ounces of silver per ton, 5 to 37 percent of lead, and less than 37 percent of zinc.

IRON

Development.—Iron shaft 700 feet deep on incline with seven levels; Richardson shaft 400 feet deep with four levels.

Production.—Prior to 1904: Estimated to be between $1,500,000 and $2,000,000; 1904–10, $526,000.

Veins.—Grasshopper: Strike, east-west; dip, vertical; mineralization feeble. Iron: Strike, east-west; dip, vertical to 75° S.; 3 inches to 12 feet wide; dissemination of pyrite through fractured zone of altered gneiss. Mars: Strike, east-west; dip, 50° to 80° N.; 3 inches wide. Richardson: Strike, N. 40° E.; dip, 65° to 80° SE.; fractured zone 6 feet wide, sulfide veinlets less than 5 inches; joins with Iron vein.

Wall rock.—Chiefly granite gneiss, locally bostonite porphyry.

Ore and sulfide minerals.—Chiefly pyrite but some chalcopyrite and gray copper.

Gangue minerals.—Wall rock.

Ore shoots.—No regularity in shape or attitude of ore shoots.

Tenor.—Average smelting ore in 1910 contained 2.62 ounces of gold and 5.75 ounces of silver per ton and 1.55 percent of copper. Average concentrating ore contained about 0.5 ounce of gold per ton.

JEFFERSON-CALHOUN

Development.—Five shafts, 425 to 980 feet deep, 10 levels.

Vein.—Calhoun: Strike, N. 65°–85° E.

Wall rock.—Granite gneiss, hornblende gneiss, and schist.

Ore and sulfide minerals.—Galena, sphalerite, pyrite, chalcopyrite, gold, and pitchblende. Pitchblende is brecciated and penetrated by numerous later veinlets of pyrite, sphalerite, quartz, and galena.

Gangue minerals.—Quartz.

Ore shoots.—Several ore shoots 100 to 400 feet in pitch length, 75 to 250 feet in breadth; ore pinches out where vein enters schist; marked association of high gold content with high uranium.

Tenor.—1910: 54 tons of smelting ore averaged 1.07 ounces of gold and 10.1 ounces of silver per ton. Ore carried 0 to 29 percent of U_3O_8.

KANSAS

Development.—Seven principal shafts, LaCrosse tunnel, and minor tunnels.

Veins.—Alger-Kansas: Strike, N. 60° E.; dip, 80° S.; width, 18 inches to 4 feet. Kansas: Strike, N. 75° E.; dip, nearly vertical; 2 feet wide.

Wall rock.—Granite gneiss.

Ore and sulfide minerals.—Chiefly pyrite, some galena, sphalerite, and chalcopyrite.

Gangue minerals.—Wall rock and quartz.

Tenor.—Pyritic ore averaged 2 ounces of gold per ton. 1910: Concentrating ore averaged 0.15 ounce of gold and 0.16 ounce of silver per ton. 1894–1905: 348 tons of smelting ore averaged 1.62 ounces of gold and 6.5 ounces of silver per ton.

KOKOMO

Development.—Shaft 500 feet deep with 4 levels.

Vein.—Kokomo: Strike, N. 55° E.; dip, 70° NW.; continuation of Frontenac-Aduddel-Druid lode; as much as 4 feet wide.

Ore and sulfide minerals.—Pyrite, tellurides, gray copper, some galena and sphalerite.

Gangue minerals.—Quartz and some fluorite.

Tenor.—1893–1902: Sampling works assays showed 0.32 to 1.25 ounces of gold and 12.8 to 29 ounces of silver per ton.

OLD TOWN

Development.—Inclined shaft 2,205 feet long, with 21 levels; bottom level connects with Argo tunnel by 14,306-foot lateral.

Production.—Gross to 1910, $2,700,000.

Veins.—Old Town: Strike, N. 70°E.–N. 80° W.; dip, 35°–50° NW.; as much as 8 feet wide; branching system in upper levels, single vein from 11th to 20th level; joins with Wautauga vein, which dips steeply south at 6th level; granite gneiss along vein heavily impregnated with pyrite and traversed by sulfide stringers.

Wall rock.—Schist on first and second levels, granite gneiss below.

Ore and sulfide minerals.—Gold, pyrite, and chalcopyrite.

Gangue minerals.—Quartz.

Changes with depth.—Strength of mineralization decreases with depth.

Ore shoots.—Irregular compound ore shoot from surface to 16th level, about 1,400 feet in pitch length and about 1,000 feet maximum stope length.

Tenor.—Ore above 3d level contained almost 3 ounces of gold per ton. Ore from below 15th level averages 0.29 ounce of gold and 0.78 ounce of silver per ton.

PRIZE

Development.—Shaft 870 feet deep.

Production.—$400,000 to $500,000.

Vein.—Prize: Strike, east-west; 1 to 4 feet wide; eastward continuation of north Hubert vein; crushed granite gneiss and schist cut by pyrite stringers.

Wall rock.—Granite gneiss and schist.

Ore and sulfide minerals.—Pyrite.

Tenor.—Ore carried 0.5 to 2 ounces of gold and 3 to 16 ounces of silver per ton.

SARATOGA

Development.—Three shafts 400, 700, and 1,000 feet deep and 10 levels. Saratoga lateral from Argo tunnel 3,000 feet long, 1,300 feet below No. 2 shaft.

Production.—Gross, $2,500,000.

Vein.—Saratoga: Strike, east-west; dip, vertical; 5-foot altered zone. Vein formed by replacement of gneiss, with some fissure filling. Minor veins parallel to main vein.

Wall rock.—Chiefly granite gneiss, altered porphyry dike.

Ore and sulfide minerals.—Pyrite and gold.

Gangue minerals.—Quartz.

Ore shoots.—Many large stopes.

Tenor.—1893–1909: 1,019 tons of smelting ore averaged 0.90 ounce of gold and 2.32 ounces of silver per ton.

SEATON

Development.—Seaton shaft 450 feet deep, with 6 levels; Foxhall tunnel and Tropic tunnel; vein cut by Argo tunnel at vertical depth of 1,200 feet.

Vein.—Seaton: Strike, N. 85° W.; dip, 5°–80° N.; width, 1 to 2 feet, maximum 5 feet. Tropic vein branches from Seaton vein parallel to wall-rock structure. Ore minerals chiefly in network of small veins in main vein zone.

Wall rock.—Schist of the Idaho Springs formation with lenses of pegmatite.

Ore and sulfide minerals.—Chiefly galena and sphalerite. Some chalcopyrite, native silver, argentite, ruby silver, and gray copper.

Gangue minerals.—Quartz and some calcite.

Changes with depth.—Galena and sphalerite persist in depth to Argo tunnel level; native silver down to 6th level.

Tenor.—Very irregular. Typical sampling works assay on 3,414-pound lot, 2.25 ounces of gold and 3.00 ounces of silver per ton.

SPECIE PAYMENT

Development.—Discovered in 1875. Two inclined shafts, 585 and 380 feet deep. Two Brothers tunnel connects with 1,400 feet of drift on vein. Wolverine tunnel probably on this vein. Little Annie tunnel.

Production.—Gross estimated $1,500,000.

Veins.—Cross: Strike, N. 70°–80° E.; dip, 30°–75° N.; width, 15 inches. Specie Payment: Strike, N. 60° W.; dip, 15°–75° N., average 40° N.; width, 6 inches to 2½ feet. The two veins intersect without displacement. Veins consist of several subparallel fractures and veinlets, uncommonly vuggy.

Wall rock.—Schist with pegmatite and bostonite porphyry dikes.

Ore and sulfide minerals.—Pyrite, chalcopyrite and gold, some galena, sphalerite, and bornite.

Changes with depth.—Oxidized ore from early workings carried much free gold.

Ore shoots.—Several large stopes. In unoxidized ore highest gold and silver content is in chalcopyrite ore.

Tenor.—506 tons smelting ore averaged 1.88 ounces of gold and 5.8 ounces of silver per ton. Average concentrating ore in 1910 contained 0.35 ounce of gold and 3.7 ounces of silver per ton.

TOPEKA

Development.—Inclined shaft connecting with 15 levels.

Production.—Gross, $1,850,000, of which $480,000 is from stope on Klondike vein.

Veins.—Klondike: Strike, N. 35° E.; dip, 25°–40° NW; width, 4 inches to 15 feet; branch of Topeka vein on 7th level; carried free gold in bonanza quantities. Topeka: Strike, N. 50° E.; dip, 35°–60° NW.; width, 3 inches to 7 feet; single strong vein; slips along hanging wall and footwall.

Wall rock.—Chiefly granite gneiss, locally hornblende gneiss, some pegmatite.

Ore and sulfide minerals.—Pyrite, sphalerite and gold, some chalcopyrite and galena.

Gangue minerals.—Quartz and calcite.

Changes with depth.—Rich ore on Klondike confined between 7th and 8th levels.

Ore shoots.—Stope on Klondike between levels 7 and 8 is 280 feet long, 44 feet high, and 15 feet wide.

Tenor.—Ore from large stope on Klondike very rich. In 1908 zinc concentrate carried 0.3 to 0.4 ounce of gold and 2 to 4 ounces of silver per ton and 20 to 30 percent of zinc.

SUN AND MOON

Development.—3 shafts. Minot has 12 levels; Garden has 9 levels; Sun and Moon connects with small workings; winze from 12th level of Minot to Argo tunnel.

Production.—Gross, $2,000,000.

Vein.—Sun and Moon: Strike, N. 60° E.; dip, 50° NW.; width 6 to 12 inches; sheared and altered schist locally silicified, containing veinlets and disseminated pyrite; vein parallel to structure of wall rock.

Wall rock.—Granite gneiss in main workings; on Argo level schist with a little monzonite porphyry.

Ore and sulfide minerals.—Pyrite and gold, some galena and sphalerite.

Changes with depth.—Galena and sphalerite do not persist in depth.

Tenor.—1908–9: 836 tons smelting ore averaged 1.31 ounces of gold and 14.49 ounces of silver per ton.

TREASURE VAULT

Development.—Three shafts, deepest 130 feet; 450-foot drift tunnel connects with shafts by 50-foot inclined raise.

Production.—$30,000.

Veins.—Treasure Vault: Strike, N. 50° E.; dip, 29°–58° N. First Parallel: Strike, N. 50° E.; dip, vertical. Second Parallel: Strike, N. 50° E.; dip, 55°–70° S. Three main veins connected by cross fractures; small flat stringers take off from main vein and cut other two.

Wall rock.—Granite gneiss.

Ore and sulfide minerals.—Pyrite, gold tellurides, and gold.

Gangue minerals.—Chiefly quartz, some fluorite and calcite.

Changes with depth.—Tellurides found only to depth of 126 feet.

Ore shoots.—Gold localized near flat parts of veins. Tellurides related to flat branch slips from main vein.

Tenor.—Ore pockets average 0.5 to 1.5 ounces of gold and 0.5 to 50 ounces of silver per ton.

WAR DANCE

Development.—Shaft 375 feet deep, with 5 levels.

Production.—1908–11: Gold, 599.84 ounces; silver, 479.7 ounces; incomplete.

Veins.—"Sulfide" vein: Strike, N. 30°–55° E.; dip, 70° SE. to vertical; width, 3 feet. "Telluride" vein: Telluride ore in complex network of fractures; some parallel and some at an angle to main sulfide vein.

Ore and sulfide minerals.—Pyrite, gold tellurides, gray copper, and enargite.

Gangue minerals.—Quartz and fluorite.

Ore shoots.—Richest telluride ore in small branching veinlets.

Tenor.—1908–11: 36.75 tons sent to sampling works yielded 599.84 ounces of gold and 479.71 ounces of silver.

FREELAND-LAMARTINE AREA

As the area between Trail Creek and Chicago Creek, including the towns of Freeland and Lamartine, contains numerous important veins that are very similar to those of the Idaho Springs area, and as mineralization was practically continuous from Idaho Springs into this area, it seems logical to present its description as a supplement to that of the Central City-Idaho Springs district. The Lamartine and Freeland veins are part of a belt of strong fractures trending east-northeast from the head of Silver Creek through Lamartine and Freeland to the valley of Clear Creek near the mouth of Fall River. This belt probably continues west-southwest of Lamartine to Georgetown, but the intervening area has not yet been adequately studied. The Lamartine and Freeland veins have had a substantial output, and the possibility of undiscovered ore shoots in an extension of this belt should be considered, especially as the Lamartine ore body did not crop out and, according to report, was discovered accidentally. The rock throughout most of this area is gneiss and schist of the Idaho Springs formation, which has a general northeast trend and southeast dip. In the southern and southwestern parts of the area there are large irregular tongues of Boulder Creek granite, which connect with the large mass to the south. Scattered throughout the area are irregular masses and lenses of gneissoid granite, Silver Plume granite, and pegmatite. Intruded into all these rocks, but chiefly into the Idaho Springs formation, are numerous porphyry dikes of general northeast trend, but in the southeastern part of the area there are several that have a northwest trend. These dikes include bostonites of group 9 and alaskitic quartz monzonites of group 7. (See pl. 7 and fig. 12.) The veins of this region trend from east to northeast.

LAMARTINE MINE

The Lamartine mine,[97] between Lamartine and Trail Creek, 4¾ miles west of Idaho Springs, was located in 1867. In May 1888, the Lamartine ore body was discovered at a depth of 100 feet, and ore valued at $616,000 was taken out in 16 months. The total output in 1905 was 34,000 tons of ore, which yielded 39,292 ounces of gold, 2,677,471 ounces of silver, and 3,232,000 pounds of lead. The collar of the Lamartine shaft is at an altitude of 10,500 feet, and the shaft is 900 feet deep. Level 10, the bottom level, joins a drainage tunnel that extends along the Oneida vein 4,096 feet northeastward from the shaft to Trail Creek. The mine has more than 12 miles of workings.

The Lamartine vein strikes east and dips 70°–90° N.; it joins the northeastward-trending Oneida vein just east of the Lamartine shaft and probably joins the northwestward-trending R. E. Lee vein about 4,000 feet to the west. Silver Plume granite is prominent in the western part of the mine, but most of the country rock of the vein is granite gneiss and injection gneiss. The foliation of the gneisses strikes northwest and dips northeast. A bostonite porphyry dike is present in the south wall of the vein for about 1,000 feet west of the place where it swings northeastward into the Oneida vein. This part of the Lamartine vein is marked by many minor intersecting easterly and northeasterly veins, which are especially abundant near the junction of the Oneida and Lamartine veins; this zone coincided with the best part of the ore shoot. The vein had commercial ore for 3,000 feet along the strike. The crescent-shaped ore shoot was about 450 feet high in most places and terminated 100 feet below the surface at the eastern end near the Lamartine shaft, extended down to level 10 about 1,600 feet west of the shaft, and terminated about 400 feet below the surface at the western end of the shoot. On entering the Silver Plume granite in the western part of the mine the vein branched repeatedly and weakened as it approached the R. E. Lee vein. The ore is almost limited to the vertical parts of the vein and is notably poor where the dip is 75° or less. This distribution of ore suggests that the vein follows a premineral normal fault. Striations on the walls pitch 75° W. and indicate a nearly dip-slip movement.

The R. E. Lee vein was followed for a distance of 2,500 feet on level 6, but neither quartz nor ore was found. The Oneida vein is credited with an output from shallow workings valued at $600,000 but was almost barren throughout the Lamartine drainage tunnel; some low-grade ore was found 2,500 feet from the portal, but so far as known little work was done on it.

The ore of the Lamartine vein was chiefly galena and sphalerite with some pyrite and contained a substantial amount of gold and silver. The better grade of ore contained several ounces of gold and as much as 150 ounces of silver to the ton.

FREELAND VEIN SYSTEM[98]

The Freeland vein, about 4 miles west of Idaho Springs, was discovered in 1861. It is a strong trunk vein having a northeast strike and rather gentle dip, which averages 36° NW. It is about 2,200 feet long and is opened by several tunnels, the lowest of which has its portal near the bottom of Trail Creek. There are six levels beneath this lowest or Freeland tunnel. The McClelland tunnel has its portal on the Clear Creek side of the divide, below Dumont, and cuts the veins about 400 feet below the bottom of the Freeland shaft. This tunnel is more than 5,100 feet long. A map of the Freeland mine shows about 4 miles of underground workings. The Gum Tree vein, a branch of the Freeland vein, is opened by an inclined shaft and has several thousand feet of workings. The Toledo is also opened by an inclined shaft.

The wall rock of the Freeland vein system is chiefly dark-colored gneiss, but there is some pegmatite. The gneiss has a general trend of N. 20° E. Porphyry dikes are present here and there in the walls of the veins or close by, but no porphyry was found in the Gum Tree or Toledo workings. On the north side of the Freeland vein, not far from the shaft, is a dike of alaskitic quartz monzonite porphyry, and in the Harrisburg and Brighton mines there are dikes of bostonite exposed.

At the southwest end of the Freeland vein there are two strong branches, the Freeland Extension and the Split vein, both of which are ore bearing. The Freeland Extension, which is the southern of the two, has a southwest strike and a northwest dip of about 30°–60°, being flat near the surface and steepening downward.

[97] Spurr, J. E., Garrey, G. H., and Ball, S. H., op. cit., pp. 314–319.

[98] Idem, pp. 323–332.

The Split vein strikes northwest, nearly due west in places, and dips north at about 42°. These branches have been followed on the Freeland tunnel level for about 600 feet from the junction. At its northeast end the Freeland trunk vein has been explored nearly to Trail Creek. On the north side of Trail Creek are two ore-bearing veins that converge toward the southwest and probably join just north of the portal of the Freeland tunnel. The northeasterly trend of the Freeland vein is continued by the Toledo vein, which has an average strike of N. 65° E. and a dip of 22°–45° N., flattening to the east. The Gum Tree vein diverges from the Freeland trunk vein with a general east-west strike. Six hundred feet east of the supposed point of divergence the Gum Tree splits, a weak branch continuing east and a stronger one trending N. 65° E. They both dip 45° N. Farther east the stronger branch again divides and becomes weak. The Toledo vein has been explored underground for about 1,000 feet from the junction and the Gum Tree for about 1,300 feet. West of the junction is the Anchor vein, which has an east-west strike and a dip of 25°–45° N. It probably intersects the Freeland beneath Trail Creek and may be a continuation of the Gum Tree vein to the west. The junction of all these veins is beneath Trail Creek and cannot be observed. The Brighton and Harrisburg veins appear to be related to the Freeland group. The Brighton shaft, about 1,000 feet S. 60° W. of the Freeland Extension shaft, is on a vein that strikes northeast, parallel to the Freeland, and has a gentle northwesterly dip of about 30°. This vein probably joins the Freeland Extension vein on the northeast. The Harrisburg shaft is about 350 feet N. 20° W. of the Brighton shaft. The vein has a northwest to west strike, about the same as that of the Split vein, and a dip of about 40° N. It is reported that the Harrisburg and Brighton veins join and that the Brighton is the stronger vein.

The nature of the vein material and ore is much the same throughout the Freeland system. The deeper workings of the Freeland mine show ore composed mainly of pyrite and chalcopyrite with a little tetrahedrite (fig. 60, *F*). Only a small amount of sphalerite is present. Galena occurs chiefly in bunches near the surface and is rare in the deeper workings. The average ore contained about 1 ounce of gold and between 4 and 20 ounces of silver to the ton and 3 or 4 percent of copper. Smelter returns on ore taken from the Minnie level prior to 1905 showed values ranging from $15 to $40 per ton. A typical return sheet showed total value $30.87—gold 1.35 ounces, silver 9 ounces, copper 2.8 percent, lead and zinc none. It is reported that the gold and silver are closely associated and that there is no relation between the gold and copper. Some pyrite has a very high content of gold. The ore of the Toledo mine consists of pyrite and some chalcopyrite and tetrahedrite but little galena except near the surface. The Gum Tree ore consists largely of pyrite and chalcopyrite with tetrahedrite in small quantities; however, it contained considerable galena down to the 400 level. The massive pyritic ore is said to contain 2 to 3 percent of lead and 3 to 4 percent of copper. A representative shipment of sorted galena ore contained 0.42 ounce of gold and 13 ounces of silver to the ton, 56.5 percent of lead, and 2.2 percent of copper. The Anchor vein consists mostly of quartz and pyrite, with a little chalcopyrite and sphalerite. The Brighton vein contains considerable galena and sphalerite associated with the pyrite and chalcopyrite; its gangue is quartz, rhodochrosite, siderite, and barite. Ore from the Harrisburg vein contains galena and pyrite, with barite, quartz, and siderite.

The largest and most persistent ore body on the Freeland vein extends from the junction of the Split and Freeland Extension back to the east for a distance of about 1,800 feet. It appears to be thickest and strongest at the junction and to decrease gradually toward the northeast. It has been followed from the surface down to the lowest levels of the mine, which are about 1,040 feet below the collar of the Freeland shaft. Thus the the actual length of the shoot down the dip is 2,000 feet. The ore continues out along the Freeland Extension vein but not along the Split, although there are stopes farther west on the Split vein. On the Toledo vein an ore body about 600 feet long occurs on the east side of its junction with a small branching vein. The ore extends about 28 feet below the tunnel level. Postmineral movement along the Freeland vein is indicated by a postore breccia that occurs on the Freeland tunnel level.

The following estimated values of output of the Freeland mine, totaling $4,655,000, were furnished by the management in 1904: 1861 to 1879, $1,000,000; 1878 to 1888, $3,299,000, together with $200,000 during 4 months of this period when records were improperly kept; and value of output by lessees since 1888, $156,000. The value of the output of the Gum Tree is reported to be about $300,000 and that of the Toledo about $130,000. No figures for the output of the Harrisburg mine were available. The Brighton mine had no output up to 1905.

NORTH GILPIN COUNTY DISTRICT [99]

Scattered through the north-central part of Gilpin County are numerous veins of the pyritic gold type, but in general they are of minor importance. The area in which they occur is here designated the North Gilpin County district. This district comprises about 35 square miles; it extends northward from North Clear Creek to the Gilpin County-Boulder County line and

[99] Bastin, E. S., and Hill, J. M., Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colo.: U. S. Geol. Survey Prof. Paper 94, pp. 190–205, 1917.

eastward from Mammoth Gulch and Kingston Peak to the eastern border of the Central City quadrangle. It contains only small settlements. Apex is in the central part, Perigo and Gilpin are in the eastern part, and Tolland is in the northwestern part, on South Boulder Creek. The most important mines of the district are just south of Apex and in the vicinity of Gilpin.

Schist, of the Idaho Springs formation, is the most abundant rock in the district; it is cut by lenses and irregular masses of igneous rocks. In the south-central part of the district a long tongue of granite gneiss related to the Boulder Creek granite trends about N. 30° E. Other smaller tongues and lenses of this rock are scattered throughout the district and have about the same trend. Quartz diorite, also related to the Boulder Creek granite, occurs in a small area in the southwestern part of the district. A small irregular lens of medium-grained Boulder Creek granite about half a mile wide and trending N. 30° E., cuts the schist in the eastern part of the district. Small irregular lenses of pegmatite are common in the schist and in a few places occur in the granite gneiss. A large irregular stock of quartz monzonite porphyry of group 5 (pl. 7 and fig. 12) cuts the pre-Cambrian complex in the central part of the district. It is about 4 miles long in a north-south direction and about a mile wide in its widest part; it extends northward from about a mile south of Apex to Jumbo mountain and thence northwest to the vicinity of Tolland. On the north and northeast sides of this stock there is a system of radial dikes of the same rock, some trending about N. 70° W., some about N. 20° W., and some about N. 60° E. In the southeastern part of the district there are several dikes of bostonite porphyry, which have a general trend of N. 30° W. On the north side of South Boulder Creek, about two miles northeast of Tolland, there is a small stock of monzonite porphyry trending about N. 20° W. It is about a mile long and a third of a mile wide and is connected with the large stock by a dike striking N. 20° W.

ORE DEPOSITS

The veins of the district are scattered through a large area, and few of them are credited with even a moderate output. Some of them are apparently related to the transverse fractures that mark the disappearance of the strong early northwesterly faults so prominent to the southeast. (See pl. 2.) The veins south of Perigo are at the northwest end of the persistent Blackhawk fault, which also forms the northeast limit of the Central City district a few miles southeast. Similarly the veins near Phoenix occur where another persistent northwesterly fault begins to feather out. This area has been little studied, and the structural features are imperfectly known as yet, but the work that has been done suggests that a detailed study of the relation of the veins to the northwesterly fracture system may lead to the discovery of new ore bodies.

Some of the mines are opened along moderately persistent northeasterly fracture zones, which can be traced for 2 miles or more (pl. 3). Two of the most productive mines, the Perigo and Gold Dirt, are in a lode of this type on the northwest slope of Gamble Gulch, and the Geiger, Pettibone, and Snowden are in a similar lode, which crosses Silver Creek about a mile southeast of Dakota Hill. Neither of these lodes has been explored near its junction with the Blackhawk fault.

The veins all belong to the pyritic gold type; the majority of them have a northeast trend and southeast dip, but some have an east-west or northwest strike. The chief primary constituents of the veins are quartz and pyrite, with varying amounts of chalcopyrite, but most of the commercial ore is close to the surface and has been improved by supergene enrichment. A few of the veins contain galena and sphalerite, but these minerals are nowhere abundant. Pyrite occurs as disseminated grains in the veins and also as irregular veinlets in the wall rock and ranges from coarse to fine-grained. In places chalcopyrite is abundant enough to be of commercial interest. The primary ores are in general low grade, containing less than half an ounce of gold and an ounce or less of silver to the ton. Some of the mines have supplied fairly high-grade ore from the enriched upper parts of the veins, the best ore containing several ounces of gold to the ton. Many of the deposits are nonpersistent lodes made up of shear zones containing pyrite disseminated through several feet of sheared rock, but fissure fillings are somewhat more abundant.

The most remarkable ore deposit in the district is at the Evergreen mine, near Apex. It has been worked chiefly for copper. It has not had a large output but has aroused considerable interest because of the unusual occurrence of its ore, which has been attributed to magmatic differentiation modified by other processes.

Many of the gulches have placer ground, but the placer output was small until a dredge began operating on the Pactolus placer near Pine Cliff on South Boulder Creek. During 1937 and 1938, 5,846 ounces of gold and 491 ounces of silver were recovered from gravel that yielded approximately 0.0073 ounce of gold ($0.256) to the yard.

EVERGREEN MINE

The Evergreen mine[1] is of unusual interest in that it was worked primarily for copper, and because the ore minerals are irregularly disseminated in a Laramide igneous rock and not in fissure veins. The mine is in the valley of Pine Creek about half a mile south of the Apex post office. It is developed by a vertical shaft with levels at 60, 150, and 200 feet and by a tunnel, which has its portal about 50 feet north of the shaft and ex-

[1] Bastin, E. S., and Hill, J. M., op. cit., pp. 126–129.

tends about 555 feet north. The mining has been largely exploratory; no stoping has been done on the 200-foot level, and only 50 feet of stoping to a height of 15 feet has been done on the 150-foot level. In the tunnel, about 120 feet from the portal, there is a chamber stope about 40 feet long, 30 feet wide, and 2 to 12 feet high.

The prevailing rocks of the Evergreen mine are biotite and quartz-biotite schists of the Idaho Springs formation, which are injected by small amounts of granite pegmatite. These rocks have been cut by dikes of light-gray porphyry, which are probably offshoots from the large stock of monzonite that crops out less than half a mile north and east of the mine. The dikes are very similar to the quartz monzonite of the stock but differ chiefly in their content of quartz, garnet, wollastonite, and copper sulfides, which are absent from the stock. The porphyry dikes are made up chiefly of orthoclase perthitically intergrown with albite, quartz, augite, and oligoclase or andesine. Wollastonite occurs abundantly in bundles of prisms, commonly less than a millimeter in length. In places it is nearly equal to feldspar in abundance. Titanite, garnet, and small zircons are accessory minerals. Calcite is present locally as an alteration product of wollastonite.

Chalcopyrite and bornite are the chief ore minerals. Chalcocite occurs locally but is apparently an alteration product of the other minerals, for it occurs as seams in chalcopyrite and bornite. The ore minerals occur in scattered irregular masses in the dikes but are most abundant in breccias that border the dikes. These breccias are made up of more or less chloritized angular fragments of schist and pegmatite cemented by the porphyry. The sulfides are almost limited to the igneous matrix and occur as irregular masses and lenses of solid intergrown chalcopyrite and bornite, some as much as a foot in diameter. Bastin [2] states that the sulfides are wholly absent from the fragments of wall rock, but in a few specimens the writers noted minute seams of chalcopyrite lying along the foliation in the fragments and cut off abruptly by the porphyry.

Development work in the mine has largely followed the dikes, though some exploratory workings are in the schist. The north drift on the 200-foot level follows a dike for about 250 feet. This dike is 1 to 1½ feet wide, strikes about N. 25° W., and dips about 50° E. The drift on the 150-foot level follows what may be the same dike for 130 feet. On this level the dike has a border zone of schist breccia, which is in places 4 feet wide. Dikes are found at several places in the tunnel, but they are interrupted by numerous faults, and their exact relations are not certain. The narrow dikes in the tunnel are 2 to 3 feet wide, and the larger masses are much wider than the tunnel.

[2] Bastin, E. S., and Hill, J. M., op. cit., p. 126.

The richest ore in the mine was taken from a chamber stope about 120 feet from the portal of the tunnel. The stope is near the surface, and the ore is considerably oxidized. Much of the ore is a breccia of gray quartz in a matrix of porphyry. In hand specimens matrix and quartz fragments appear to be distinct, but in thin section the quartz of the fragments is seen to interlock with the minerals of the matrix, indicating some recrystallization. According to Bastin [3] the matrix sends off small branches or stringers of bornite and feldspar along minute cracks, which traverse a single quartz crystal or penetrate between two crystals. This quartz probably represents a phase of the pegmatite intruded into the schist of the Idaho Springs formation. In some specimens covellite occurs as an alteration product of bornite.

A number of specimens from the dump consisted of schist cut by narrow veins as much as a quarter of an inch wide composed almost wholly of chalcopyrite. In one specimen a veinlet of chalcopyrite cut sharply through the dike rock, which contained schist fragments and disseminated chalcopyrite and bornite. Other fragments from the dump showed fine-grained aggregates of quartz, calcite, chalcopyrite, specularite, pyrite, and sphalerite, with a little galena and bornite. Some of the specularite blades penetrated calcite crystals. These occurrences probably all represent mineralization of the vein type, which was later than the intrusion of ore-bearing porphyry. Economically they are unimportant.

Bastin [4] lists several possible hypotheses as to the origin of the ore but favors the one that postulates that the sulfides and materials necessary to form the wollastonite and garnet were absorbed from wall rocks by relatively deep-lying parts of the monzonite magma and then moved into fissures in the wall rocks and there crystallized as dikes, cementing the breccia. The occurrence in schist fragments of chalcopyrite plainly earlier than the porphyry might be interpreted as further evidence in favor of this hypothesis. It seems quite probable that the schist, before intrusion of the porphyry, contained stringers or disseminated grains of chalcopyrite.

In his hypothesis No. 4 Bastin suggests that the ore-bearing dikes may represent the combined effects of magmatic differentiation and digestion of wall rock and that the sulfides may have been derived either from the wall rock through absorption or from the magma by magmatic differentiation, and it is possible that the sulfides were derived from a combination of both these processes. The high concentration of sulfides in the material is presumably due to the fact that the sulfides introduced into the Idaho Springs formation ahead of the porphyry greatly supplemented the amount of sulfides derived from the porphyry magma itself. It

[3] Idem, p. 128.

[4] Idem, pp. 128–129.

seems evident that sulfide mineralization preceded, accompanied, and followed the intrusion of the dikes.

Subsequent to the intrusion of the porphyry dikes and their associated sulfides, the rocks in the vicinity were broken by numerous fractures and faults, which displace the ore-bearing dikes in many places. In general the faults are not mineralized, though some are quartz-filled and bordered by narrow leached zones. In one place narrow seams of calcite and quartz cut both dike and fault. One fracture plane in the schist on the tunnel level showed about an inch of quartz and calcite with a little chalcopyrite.

Ore shipped from this mine is said to average about 3 percent of copper and 0.20 ounce of gold and a few ounces of silver per ton. Its distribution, however, is sporadic, and, except for the chamber stope on the tunnel level, no large bodies have been found. Only a few carloads of ore have been shipped.

OTHER MINES

Data on other mines are given briefly below. Detailed descriptions have been given by Bastin and Hill.[5]

ANNIE H

Development.—Two shafts, 300 and 225 feet deep, 310 feet apart; tunnel 572 feet long joins shafts 155 feet below surface.

Vein.—Annie H.: Strike, N. 60° E.; dip, 30°–50° N.

Ore and sulfide minerals.—Pyrite and gold.

Tenor.—0.2 to 2.5 ounces of gold per ton; most assays show 0.80 to 1.0 ounce. Some picked lots of ore assayed 6 percent of copper.

GOLD DIRT

Development.—Discovered 1860. Drift tunnel and several shafts; main shaft several hundred feet deep.

Production.—October 1, 1860, to January 5, 1861, $11,526.94; equals one-sixth of the total production.

Vein.—Gold Dirt: Strike, N. 80°–85° E.; dip, 80°–85° S.; width, 8 inches. Postmineral movement has crushed and sheared ore in places.

Ore and sulfide minerals.—Pyrite and gold.

Changes with depth.—Ore oxidized near surface and richer than in depth. Ore below oxidized zone averaged 0.65 ounce of gold per ton for concentrating ore and 1.0 to 3.0 ounces of gold for smelting.

INGRAM

Development.—Shaft 270 feet deep and tunnel 120 feet long.

Production.—To 1912, $10,000.

Vein.—Ingram: Strike, N. 65° E.; dip, 70° NW. Vein cuts foliation of granite gneiss at acute angle.

Wall rock.—Granite gneiss.

Ore and sulfide minerals.—Chiefly chalcopyrite and pyrite, some galena and gold.

Gangue minerals.—Quartz.

Tenor.—14 to 20 percent of copper.

PERIGO

Development.—Two tunnels and several old shafts.

Veins.—Baker, Daisy, Ladysmith, and Perigo: Mostly trend east to northeast; complicated set of veins; 2½ to 6 feet wide. Toward southwest, branches unite to form single fracture zone, not very strong nor heavily mineralized. Veins consist of disseminations of pyrite in wall rock along fracture zones. Locally ore occurs in sharp-walled veinlets.

Wall rock.—Schist, granite gneiss, and pegmatite.

Ore and sulfide minerals.—Pyrite and gold, some galena.

Gangue minerals.—Wall rock.

Tenor.—42 tons of ore shipped from 1901 to 1909 contained 0.44 to 3.16 ounces of gold (average 1.23) and 1.20 to 4.70 ounces of silver per ton.

SMUGGLER

Development.—Drift tunnel 797 feet long; shaft 150 feet deep.

Production.—Total to 1912, between $50,000 and $75,000.

Vein.—Smuggler: Strike, N. 75° E.; dip 65° N.; ranges from small barren fracture to 8 feet in width and averages 2 or 3 feet. Wider parts of vein consist of crushed wall rock containing lenses and disseminated pyrite.

Wall rock.—Schist of the Idaho Springs formation, containing small tongues of granite gneiss.

Ore and sulfide minerals.—Pyrite and some hematite.

Gangue minerals.—Cherty silica and siderite.

Ore shoots.—Mineralization strong throughout most of the tunnel; largest ore body 290 feet in stope length, 80 feet high, averages 4 feet in thickness.

Tenor.—General run of mine ore averaged 0.5 ounce of gold per ton. 1910: Average concentrates sold to smelter contained 0.75 ounce of gold per ton. 1911: Average concentrates contained 1 ounce of gold and 1 ounce of silver per ton. Coarse pyrite contains 0.1 ounce of gold per ton.

WAR EAGLE

Development.—Shaft 200 feet deep with short drifts on three levels.

Veins.—War Eagle: Strike, N. 60° E. Vein material on dump is pyrite-impregnated country rock traversed by veins of coarse-grained pyrite with little quartz, as much as 1¾ inches wide.

Wall rock.—Granite gneiss.

Ore and sulfide minerals.—Pyrite and gold, some specularite and chalcopyrite.

Gangue minerals.—Quartz.

Tenor.—Average 0.75 ounce of gold per ton.

ELDORA DISTRICT

The Eldora district covers a few square miles in the vicinity of Eldora, about 3 miles west of Nederland. As defined here, the district includes the mines near Lost Lake and southwest of Grand Island as well as those south of the town (pl. 3). It has had only a small output and is of interest chiefly because of its gold-telluride ores, which were discovered about 1896. The deposits were actively developed during the following decade, but since 1906 the camp has been comparatively inactive. The only mine credited with a noteworthy output is the Enterprise, about half a mile south of Eldora.

The chief rocks of the district are biotite schist and quartz-biotite schist of the Idaho Springs formation and hornblende monzonite porphyry. Granite gneiss related to the Boulder Creek granite occurs in irregular masses, mostly to the north and to the south of the district, and there is a lens of granite gneiss just southwest of Eldora. In the western part of the district, about

[5] Bastin, E. S., and Hill, J. M., op. cit., pp. 194–205.

1½ miles southwest of Eldora, is a large stock of monzonite porphyry of group 3 and a small stock of coarsely porphyritic quartz monzonite of group 6 (pl. 7 and fig. 12). To the east and north of Eldora there are several eastward-trending dikes of hornblende monzonite porphyry and hornblende and biotite andesite, which form part of an extensive dike system that can be traced east for many miles.

The best known veins of the district are about half a mile south of Eldora. They contain tellurides and have been described by Lindgren [6] and Rickard.[7] They have a general east-west trend, are commonly 1 to 3 feet wide, and consist of sheeted zones containing several narrow seams of ore. The outcrops of the veins are very inconspicuous and are more likely to be indicated by depressions than by prominent outcrops.

The valuable metals in the ore are chiefly gold and a little silver; the valuable minerals are tellurides of gold, of which sylvanite and petzite are believed to be the most important. The tellurides occur as small specks in a fine-grained "horn" quartz or in greenish roscoelite, rarely as well-crystallized minerals. Sparse small grains of pyrite are present in the altered country rock. Molybdenite is moderately abundant but is in most places extremely fine-grained and intergrown with barite. Its presence in dumps is indicated by deep-blue stains, which were thought by Lindgren to be ilsemannite. The chief gangue minerals are barite, quartz, roscoelite, and horn quartz. The horn quartz is the most abundant, but barite is also abundant. Roscoelite is very prominent in the ores of the Mogul tunnel and the Enterprise mine. It forms dark yellow-green masses intergrown with quartz or irregularly distributed in the ore and in many places contains visible specks of the tellurides. Some of the roscoelite is intergrown with pyrite and may be surrounded and invaded by fine granular quartz with some adularia. The wall rock close to the veins is largely altered to sericite and contains disseminated pyrite. Vugs are fairly common in the vein and are frequently occupied by crystals of gangue minerals. Lindgren believed that these deposits were not formed at great depth and that the original surface could not have been much different from the general level of the peneplain marked by the high ridge lines of the region.

A few mines near Lost Lake, 2½ miles west of Eldora, have had a small output. Most of the ore has come from the Norway, Ma W, and Revenge veins near the intersections of the northeastward-trending Norway and Ma W with the northwestward-trending Revenge. (See pl. 3.) Small bodies of high-grade telluride ore have been mined on these three veins, and it is reported that most of the output has come from the Norway and Ma W veins. The Revenge shaft was full of water in 1938 and had not been worked since 1914, but development was being carried on in the Norway tunnel.

[6] Lindgren, Waldemar, Some gold and tungsten deposits of Boulder County, Colo.: Econ. Geology, vol. 2, pp. 457–460, 1907.

[7] Rickard, T. A., The veins of Boulder County and Kalgoorlie: Am. Inst. Min. Eng. Trans., vol. 33, pp. 567–568, 1903.

REPRESENTATIVE MINES

The Enterprise vein [8] crops out at an altitude of about 9,400 feet on the north side of Spencer Mountain about half a mile south of Eldora. It is developed by a shaft about 400 feet deep with 5 levels and about 1,200 feet of drifts. The Mogul and Swathmore tunnels cut what is supposed to be the Enterprise vein at greater depth. The vein fissure according to Rickard is about 5 feet wide and is traversed by numerous small seams of dark-gray horn quartz. This quartz contained enough telluride, chiefly petzite, throughout a 2- to 2½-foot width of vein to yield an average of 2 ounces of gold to the ton locally. About 1,800 tons of ore from the Enterprise shaft, treated in the Bailey mill at Eldora in 1896 and 1897, is said to have averaged about $10.80 per ton, mainly in gold.

The Mogul tunnel,[9] the portal of which is near Eldora station, extends southwest and south for more than 1,400 feet and cuts a number of easterly to northeasterly telluride veins, most of which are only slightly mineralized. It cuts the Enterprise vein 900 feet below the outcrop. Ore taken from the Mogul tunnel in 1905 is said to have averaged about an ounce of gold to the ton. Ore from this tunnel on the Enterprise vein is said to have averaged between 1 and 2 ounces to the ton. Much stoping has been done along one of the telluride veins for a distance of about 400 feet.

The Swathmore tunnel, a short distance above Eldora, trends southward and cuts the Enterprise and three other veins. Ore in the bins showed horn quartz, fine-grained pyrite, and some roscoelite. Tellurides are said to be present in narrow seams of horn quartz one-sixteenth to one-eighth of an inch wide cutting the roscoelite.

CARIBOU-GRAND ISLAND DISTRICT

The Caribou-Grand Island district lies in the west-central part of Boulder County, at an altitude of about 10,000 feet, at the head of Coon Trail Creek. It is about 20 miles west of Boulder and about 4 miles north-northwest of Nederland, from which it is easily accessible by road. The rich silver ores of the district were discovered in 1869 by William Martin, George Little, and Samuel Conger. Conger was better known for his discovery of the tungsten district to the east many years later. In 1870 a wagon road was constructed to the district and shipments commenced to Blackhawk, 20 miles away. Mining developed rapidly during the next

[8] Bastin, E. S., and Hill, J. M., op. cit., p. 188.

[8] Idem.

few years and, although several of the mines contributed substantially to the output, the Caribou vein and No-Name vein were by far the most productive. According to Bastin and Hill,[10] the value of the total yield from the Caribou and No-Name veins up to July 1880 was $1,168,000.

GEOLOGY

The small settlement of Caribou is near the eastern edge of a composite porphyry stock, which extends approximately a mile to the north, a mile to the south, and a mile to the west (fig. 66). This stock is composed of Paleocene (?) gabbro, monzonite, and quartz monzonite porphyries, with minor magmatic titaniferous iron ores and related mafic rocks.

A northwestward-trending belt of schist of the Idaho Springs formation wedges out just north of Caribou between the Eldora stock of monzonite porphyry on the west and an extensive mass of Boulder Creek granite to the east. According to Smith,[11] apophyses of the Eldorado stock cut the Caribou stock of monzonite porphyry. Boulder County Hill, half a mile east of Caribou, is close to the southern edge of the Boulder Creek granite stock, and Idaho Mountain, half a mile northeast of Caribou, is well within this granite mass.

Most of the Caribou stock is unusually calcic monzonite and quartz monzonite. Although the magnesia content, about 2.5 percent, is not abnormal, the proportion of lime, about 7 percent, and of iron oxides, about 8 percent, is unusual for monzonites of the porphyry belt. The mafic rocks for which the area is noted constitute not more than 5 percent of the stock, and of this group calcic gabbro is much the most abundant. The other mafic variants include pyroxenite, hornblendite, biotite amphibolite, biotite pyroxenite, magnetite pyroxenite, magnetite peridotite, and titaniferous magnetite. As shown in figure 66, most of the mafic rocks are in the southern part of the stock. Some are dikelike, some are angular, and some are irregular in shape. The contact between the monzonite and the mafic rocks is sharp in some places and gradational in others. Except for some stringers of magnetite that cut the magnetite pyroxenite, the relations of the different mafic rocks to one another are obscure.

The largest body of titaniferous iron ore is a dikelike mass of magnetite pyroxenite associated with biotite amphibolite and gabbro. It extends west of Caribou about 1,000 feet and there bends northwest and continues nearly 500 feet farther. The ore is essentially an intergrowth of diopside, magnetite, and ilmenite, locally cut by many stringers of magnetite a half to 2 inches, or rarely as much as 5 inches thick. This mass has been traced by geophysical methods and is believed to extend to a substantial depth.[12] Smith[13] mapped 24 other bodies of magnetite-bearing rock, but the majority of them are quite small.

Analyses given by Bastin[14] indicate that the high-grade ore contains about 65 percent of magnetite and 4.5 percent of titanium oxide and that the low-grade ore contains about 30 percent of magnetite and about 2.6 percent of titanium oxide.

The similarity in appearance and composition of the biotite amphibolite and the biotite pyroxenite to limy members of the Idaho Springs formation led the writers[15] to suggest that the mafic rocks were due to reaction between the monzonite magma and calcareous beds in the Idaho Springs formation. Smith rejects this explanation because of the lack of such beds at the surface in the immediate vicinity of the stock and believes the mafic rocks are an iron-rich magmatic residue formed through normal differentiation and that the iron ores were concentrated by filter-pressing to form separate masses of titaniferous magnetite rock.

ORE DEPOSITS

By far the majority of the veins of the Caribou district strike nearly east, but a few trend northeastward. The No-Name, a northeasterly cross vein, has been one of the most productive veins in the district; the fissure containing it apparently exerted a marked influence on ore deposition in the eastward-trending veins that it cuts. The largest and richest ore shoot in the district was localized at the junction of the No-Name vein and the eastward-trending Caribou vein.

The mines of Caribou lie on the slightly dissected Green Ridge erosion surface, which is unusually well-preserved in this region. As in many other veins that crop out on this old surface, the upper parts of the veins in these mines have been notably enriched. The gold-silver veins lie chiefly to the east of Caribou and show a striking change in tenor below the zone of oxidation. In most of them a marked change occurs at a depth of about 100 feet, but in a few of them good ore persists to a depth of 300 feet. West of Caribou nearly all the veins have been mined for their silver content. The richest ore was found close to the surface, but the change of value with depth was much more gradual. Silver ore was mined from a depth of as much as 1,000 feet along the No-Name vein.

[10] Bastin, E. S., and Hill, J. M., op. cit., p. 177.

[11] Smith, Ward, Geology of the Caribou stock in the Front Range, Colorado: Am. Jour. Sci., 5th ser., vol. 36, pp. 8–26, 1938.

[12] Heiland, C. A., Henderson, C. W., and Malkovsky, J. A., Geophysical investigations at Caribou, Colorado: U. S. Bur. Mines Tech. Paper 439, pp. 4–7, 1929.

[13] Smith, Ward, op. cit., pp. 8–26.

[14] Bastin, E. S., and Hill, J. M., op. cit., p. 129.

[15] Lovering, T. S., and Goddard, E. N., Laramide igneous sequence and differentiation in the Front Range of Colorado: Geol. Soc. America Bull., vol. 49, pp. 35–68, 1938. See also Jennings, E. P., A titaniferous iron ore deposit in Boulder County, Colo.: Am. Inst. Min. Eng. Trans., vol. 44, pp. 14–25, 1913, and Singewald, J. T., Jr., The titaniferous iron ores of the United States: U. S. Bur. Mines Bull. 64, pp. 126–128, 1913.

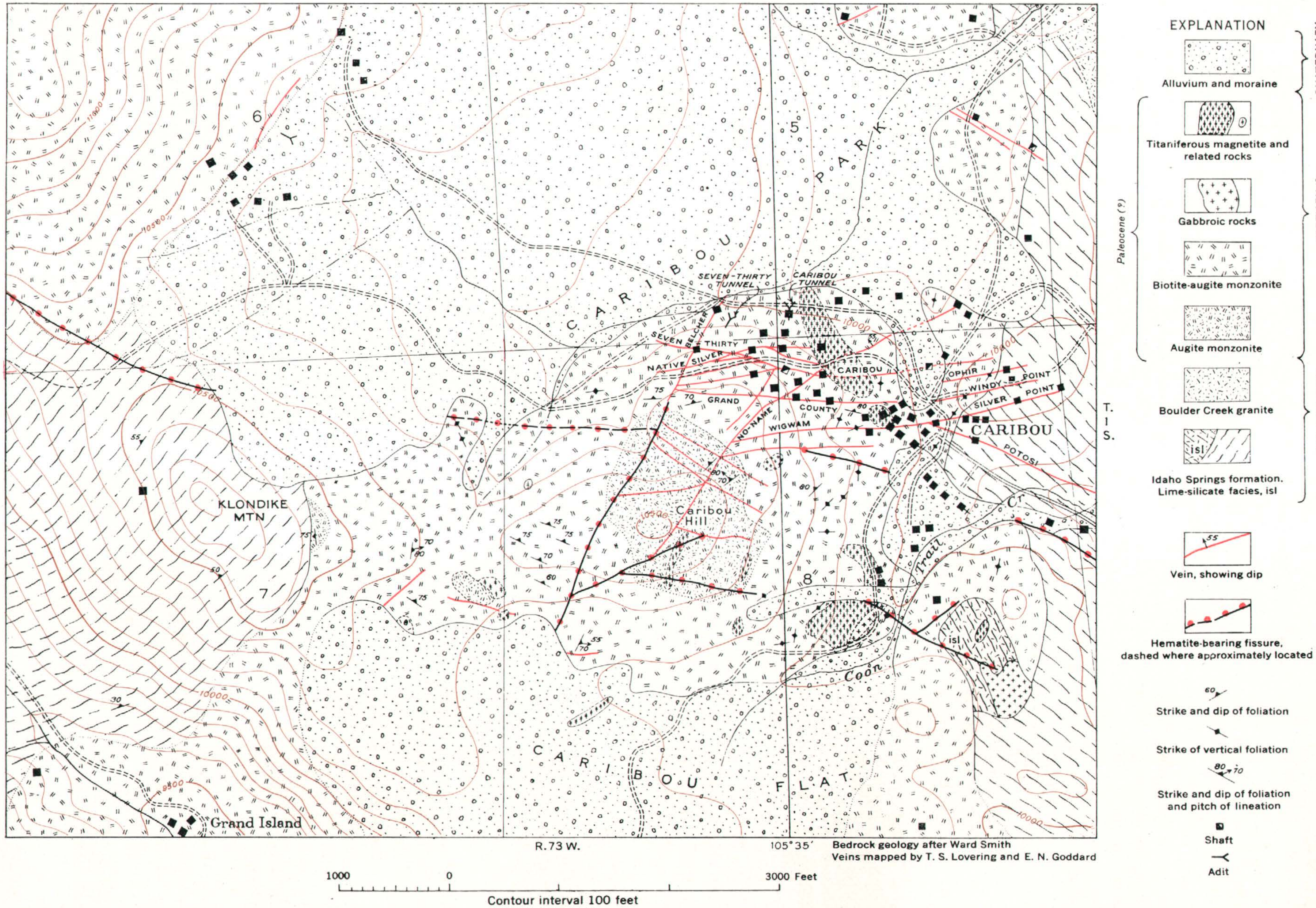


FIGURE 66.—Sketch map of the Caribou district.

The No-Name vein, the strongest and most persistent in the district, trends N. 65° E. and dips 55° to 60° NW. It cuts and displaces the eastward-trending Caribou vein, the eastern segment of which is 10 to 20 feet southwest of the western one. None of the easterly veins cut across the No-Name vein, and most of them stop abruptly when they reach it. This type of fracture pattern suggests that the easterly veins formed as tension fractures in the walls of the No-Name vein at the time it was opened. The pattern, as well as the direction of displacement, also suggests that the fractures were caused by northeastward-trending shearing forces (fig. 66).

CARIBOU AND ADJACENT MINES

The Caribou mine is about 1,500 feet northwest of Caribou. The vein strikes nearly due east. From the surface to a depth of 110 feet the dip of the vein ranges from 70° N. to vertical; below this depth the vein has a nearly constant dip of 75° N. Its intersection with the No-Name vein is only about 100 feet southwest of the titaniferous iron ore mentioned above. About 700 feet farther west the Caribou vein is crossed by the northeastward-trending Belcher vein. To the west of the Belcher the Caribou vein has been followed west through the Native Silver claim for a few hundred feet. A short distance east of its junction with the Belcher the Caribou vein gives off a branch, known as the Seven-Thirty vein, which trends about N. 80° W. and dips 60° N.

The main ore shoot on the Caribou vein occurred just west of its junction with the No-Name. This ore shoot dipped steeply to the east and left the Caribou vein at its junction with the No-Name, following the No-Name vein at depth. According to Mr. William Todd, whose father was superintendent of the Caribou mine for many years and who has himself worked in the Caribou and other mines in the district, the offset segment of the Caribou vein on the eastern side of the No-Name was sparsely mineralized and was explored for only a short distance. The ore shoot left the Caribou vein entirely at a depth of 300 feet and continued to pitch northeast along the No-Name vein to the bottom level. In the Caribou vein the width of the ore shoot was 2 to 5 feet, but in the No-Name vein widths of 5 to 7 feet were common.

The Caribou vein, as exposed on the 200-foot level of the No-Name, enters the No-Name drift on the hanging wall and appears to leave a few feet to the southwest on the footwall.[16]

Ore was found close to the surface on the Caribou vein as far west as its junction with the Seven-thirty vein, but little of the ore west of the main ore shoot extended to a depth of more than 100 feet (fig. 67). According to Endlich,[17] the walls of the vein are well-defined, but in the western part of the vein a dike of "granulite" 12 feet wide apparently crossed the vein at right angles without offset, a relation probably explained by the tensional origin of the vein. The ore minerals reported are galena, argentite, cerargyrite, native silver, gray copper, and chalcopyrite in a quartz gangue. The ore on the dump in 1933 contained galena, sphalerite, and chalcopyrite in a quartz gangue, together with some siderite and manganosiderite distinctly later than the sulfides and the quartz. Native silver is reported in all the ore mined from the Caribou and No-Name veins, even that from the deepest workings, which on the No-Name vein attained a slope distance of 1,000 feet. Rich oxidized silver ore from the Caribou is shown in figure 68, *A*.

Some pitchblende occurs in the No-Name vein at depth. In 1948 Consolidated Caribou Silver Mines, Inc., completed a 1,500-foot adit to the 1,040-foot level of the No-Name vein; pitchblende was found along the No-Name vein, northeast of the old silver stopes, irregularly distributed through a distance of about 100 feet.

In 1883, according to the Colorado Mining Directory,[18] the Caribou main shaft had a depth of 1,010 feet, and the shaft of the No-Name had a depth of 600 feet. The ore of smelting grade assayed 50 to 1,000 ounces of silver, and the material milled 20 to 50 ounces of silver to the ton. The output of the No-Name and Caribou veins at that time was valued at approximately $2,500,000. Only a few scattered precise figures are available regarding the output, but it is known that the mine was worked steadily from 1869 until well into the eighties. In 1869, 26 tons of ore brought $3,217 to the owner. In 1870, 425 tons of ore was shipped, averaging $173 per ton in value, or a total of $73,525. In 1876 the output from the Caribou mines was valued at $204,000. In 1881 and 1882 the value of silver bullion from the Caribou amounted to $227,982.88.

Several other veins parallel to the Caribou have supplied rich silver ore near their intersection with the No-Name vein. Lying on the west side of the No-Name and north of the Caribou are the Poor Man, Kalamazoo, I. X. L., Eureka, and Comstock, all dipping steeply to the north. On the east side of the No-Name and south of the Caribou are the Grand County and Wigwam veins. The character of the ore in all these veins is very similar, but in none of them, so far as known, has the ore been followed to a depth of more than 300 feet. The Poor Man, just north of the Caribou, is perhaps the second most important source of silver in the district. According to Burchard,[19] more than $100,000 worth of ore was removed in opening the mine,

[16] Van Diest, P. H., The crossing of the No-Name and Caribou: Mining Rev., vol. 6, p. 5, 1875.

[17] Endlich, F. M., Report on the mining districts of Colorado: Hayden Survey, 7th Ann. Rept., pp. 300–301, 1874.

[18] Corregan, R. D., and Lingane, D. F., Colorado Mining Directory for 1883, Denver, Colorado Mining Directory Co.

[19] Burchard, H. G., Report of the Director of the Mint, 1882, pp. 397–398.

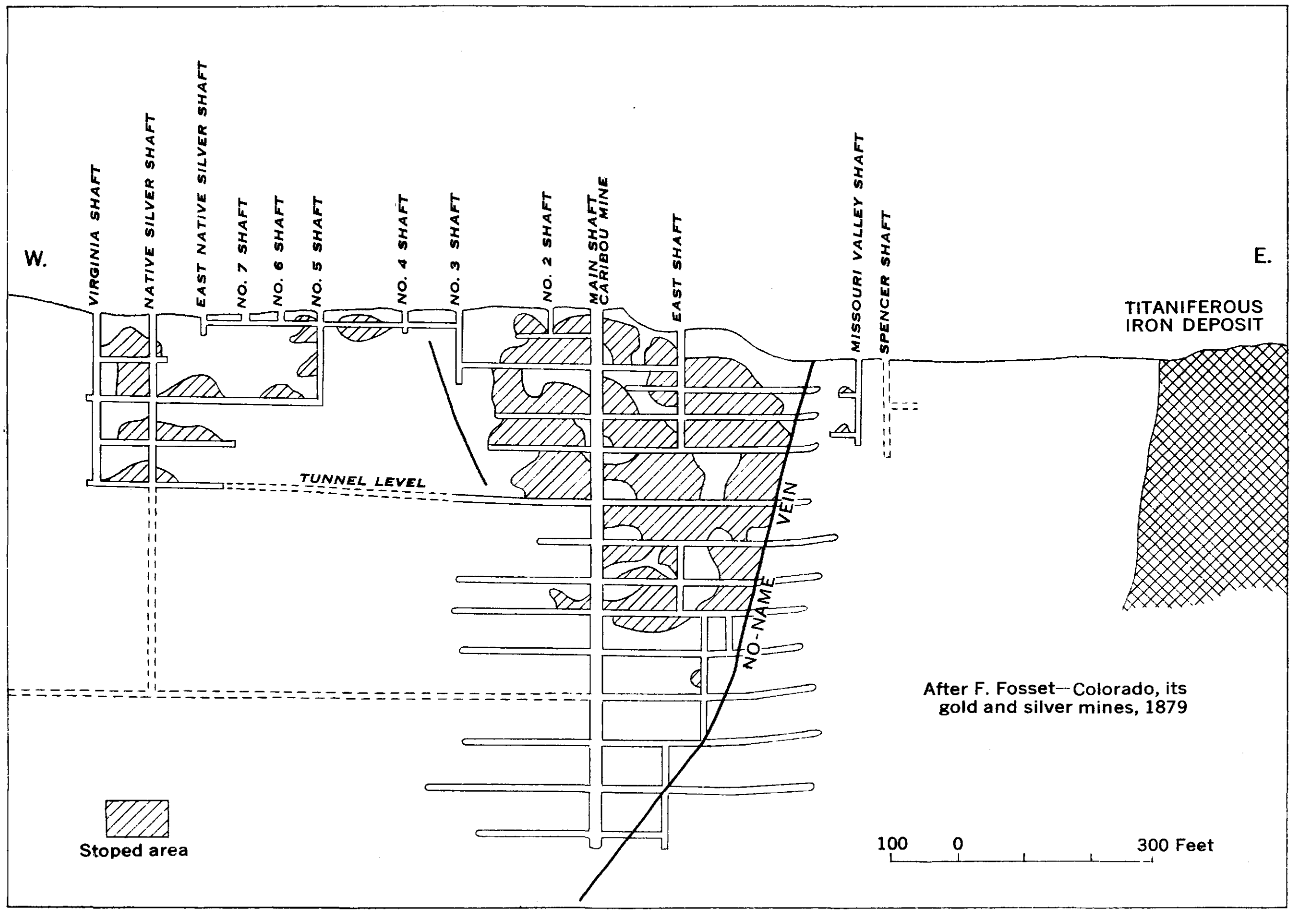


FIGURE 67.—Stope map of the Caribou vein.

and $17,000 worth of ore was taken out in sinking the shaft from 330 to 370 feet. The average mill run of the ore was said to be 300 ounces of silver to the ton. The vein was about 3 feet wide, but the part containing high-grade ore was rarely more than 6 to 8 inches wide.

A short distance east of Caribou are several well-known gold mines. About 800 feet east-northeast of Caribou the Silver Point vein strikes N. 80° W. and dips 75° N. It is about 3½ feet wide, and has been worked to a depth of 250 feet. In the oxidized zone its smelting ore averaged about 2 ounces of gold and 100 to 200 ounces of silver to the ton. The Elephant vein is just south of the Silver Point and nearly parallel to it. It contained lead-silver ore in a brecciated zone 2 feet wide. The Idaho vein is about 500 feet south of the northeast corner of sec. 8, T. 1 S., R. 73 W., and its shaft is about 300 feet southeast of the Silver Point shaft. It strikes N. 80° E. and is vertical. The vein has been traced west through the Nonpareil and Lulu claims and east through the East Idaho. About 3,000 tons of ore averaging 2 ounces of gold and 100 to 200 ounces of silver to the ton were shipped, but no ore was found below a depth of 90 feet. It is probable that the ore was concentrated by secondary or residual enrichment. The St. Louis mine is a short distance south of the East Idaho and is about 1,500 feet east of the Silver Point. The vein strikes N. 80° E. and dips 65° N. The ore was commonly 3 to 4 feet wide and contained free gold. Although a streak of high-grade ore 4 to 10 inches wide commonly averaged about 5 ounces of gold to the ton and contained very little silver, the average value of about 3,000 tons of ore shipped from the mine was between $15 and $18 per ton. A short distance southwest of the St. Louis mine is the Shoshone vein, which strikes due west and may be a continuation of the East Idaho and Bimetallic veins farther east.

Farther east on Boulder County Hill the best known veins are the Trojan and the Boulder County. According to Van Diest,[20] the Trojan contained gold exclusively at the 40-foot level, but at a depth of 60 feet silver ore appeared, and at a greater depth only argentiferous galena was found.

The Boulder County vein was first opened by a shaft on Boulder County Hill, about three-quarters of a mile northwest of Cardinal, in 1870, the year it was discovered by S. P. Conger.[21] The shaft is at an altitude of 9,500 feet and is 400 feet deep; more than 5,000 feet of

[20] Van Diest, P. H., op. cit., pp. 25–41, 1886.

[21] Bastin, E. S., and Hill, J. M., Economic geology of Gilpin County and adjacent parts of Clear Creek and Boulder Counties, Colo.: U. S. Geol. Survey Prof. Paper 94, pp. 111, 182, 183, 1917.

drifts are reported to be driven on three levels, but they are largely inaccessible. Work has been carried on intermittently since 1870, but since 1901 it has been largely limited to the Boulder County tunnel, the portal of which is at Cardinal, about 800 feet below the collar of the shaft. The vein trends N. 70° W. and dips N. at 60°–70°. It has been traced for more than a mile on the surface. It is cut by the tunnel about 3,200 feet N. 18° W. of the portal and has been developed extensively. The vein ranges in width from a few inches to several feet but is commonly less than 3 feet wide. The schist, gneiss, granite, and biotite diorite porphyry wall rocks are strongly altered near the ore; next to the vein they are changed to a fine-grained intergrowth of quartz, sericite, calcite, and pyrite; outward from the vein the amount of introduced quartz diminishes rapidly, but the sericite, calcite, and pyrite persist for several feet. The vein itself is predominantly quartz, with substantial amounts of galena, sphalerite, pyrite, and chalcopyrite and appreciable amounts of gold and silver. Native gold and wire silver were visible in the oxidized zone, but the primary ore mined in the Boulder County tunnel level averaged only a few ounces of silver and about 0.6 ounce of gold to the ton.

OTHER MINES

Data on other mines are given briefly below. Detailed descriptions have been given by Bastin and Hill.[22]

COMSTOCK, EUREKA, GRAND COUNTY, I. X. L., KALAMAZOO, POOR MAN, AND WIGWAM

Development.—Several shafts, 160 feet to more than 215 feet deep.

Production.—Wigwam mine, $40,000 in 1874.

Veins.—Comstock, Eureka, Grand County, I. X. L., Kalamazoo, Poor Man, and Wigwam all strike east-west and dip steeply north; 6 inches to 3 feet wide.

Wall rock.—Monzonite porphyry and ultramafic rock.

Ore and sulfide minerals.—Chiefly argentite, galena, and native silver, some cerargyrite, cerussite, and sphalerite.

Changes in depth.—Ore not followed beyond 300 feet in depth.

Ore shoots.—Rich silver ore near junction with No-Name vein.

Tenor.—Rich silver ore; some 300 ounces of silver per ton.

SILVER POINT

Development.—Worked to a depth of 250 feet.

Vein.—Silver Point: Strike, N. 80° W.; dip, 75° N.; width, 3½ feet.

Ore and sulfide minerals.—Gold and silver minerals.

Changes with depth.—Strongly oxidized near surface.

Tenor.—In oxidized zone smelting ore averaged 2 ounces of gold and 100 to 200 ounces of silver per ton.

ELEPHANT

Development.—Shaft.

Vein.—Elephant: Strike, N. 80° W.; dip, 75° N.; brecciated zone, 2 feet wide.

Ore and sulfide minerals.—Lead-silver ore.

[22] Bastin, E. S., and Hill, J. M., op. cit., pp. 177–184.

IDAHO

Development.—Shaft.

Production.—3,000 tons of ore.

Vein.—Idaho: Strike, N. 80° E.; dip, vertical.

Ore and sulfide minerals.—Gold and silver minerals.

Changes with depth.—No ore below a depth of 90 feet. Ore probably concentrated by secondary or residual enrichment.

Tenor.—2 ounces of gold and 100 to 200 ounces of silver per ton.

ST. LOUIS

Vein.—St. Louis: Strike, N. 80° E.; dip, 65° N.; width, 3 to 4 feet.

Ore and sulfide minerals.—Gold.

Tenor.—Streak of high-grade ore averaged 5 ounces of gold per ton and contained very little silver. Average for 3,000 tons of ore was 0.75 to 0.90 ounce of gold per ton.

WARD DISTRICT

The Ward district[23] takes in the headwaters of Lefthand Creek and Fourmile Creek and, as defined in this report, includes the area near Sunset and Copper Rock. The town of Ward is 12 miles west of the mountain front and about 19 miles from Boulder by automobile road. It lies at an altitude of 9,200 feet, but the hills just to the west reach 10,400 feet, and the valley bottoms a few miles east range from 7,500 to 8,000 feet. The town of Sunset, at the junction of Fourmile Creek with Pennsylvania Gulch, is about 3 miles southeast of Ward and about 10 miles west of Boulder. It had a population of less than 20 in 1940, and Copper Rock, 1½ miles to the east, was uninhabited. The geology of this area was mapped by Worcester, who showed the location of the principal mines but did not describe the ore deposits. The mines nearby have not had a large output, but the area is of interest because of the variety of Laramide porphyries found in it and because of the wide mineralized zone in the vicinity of Copper Rock. The canyons of Lefthand Creek to the east of Ward and of Fourmile Creek to the south are moderately steep-walled. The interstream areas are rolling uplands that correspond to the Overland Mountain erosion surface.

The Ward district was one of the first discovered in Boulder County and has been one of its most productive. In 1861 gold was found by Calvin Ward, just east of Indiana Gulch on the hillside north of Lefthand Creek. In 1862 the Columbia vein was found by John Deardorf, and soon afterwards the town of Ward was founded. Before 1870 nearly all the important lodes in the district had been discovered, and oxidized ore was being treated in several mills, including the outstanding Niwot Mill, which was built in 1865 and was operated steadily for many years. Several attempts have been made to build a mill that would treat the primary low-grade pyritic gold ores economically, but so far none have been entirely satisfactory. Mining has con-

[23] Worcester, P. G., The geology of the Ward region, Boulder County, Colo.: Colorado Geol. Survey Bull. 21, 1920.

tinued from 1862 to the present day, with many fluctuations in the degree of activity. According to Worcester,[24] output of the camp from 1885 to 1919 amounted to about $3,000,000, and the total production may have been as much as $9,000,000. The output during the period 1938–43 was 12,794 ounces of gold, 15,081 ounces of silver, 155,300 pounds of copper, and 16,900 pounds of lead.[25]

GEOLOGY

The southern part of the district is chiefly in northward-dipping schists and gneisses of the Idaho Springs formation, but in the northern half much of the country rock is Silver Plume granite. Several moderately extensive stocks of diorite and monzonite porphyry formed during the Laramide revolution occur south and east of Ward, and a few small irregular masses of sodic andesite and diorite porphyry are present in the same region. Porphyry dikes are common throughout the district but are most abundant in the northern half. The predominant strike of the dikes is easterly, but northward and northwestward-trending dikes are common south of Ward. As shown on plate 7 and figure 12, the porphyries have a wide range in composition.

Pre-Cambrian rocks.—The most common rock of the Idaho Springs formation is garnetiferous quartz-mica schist, which is more abundant in the northeast part of the district than in the southwest. It contains some sillimanite, and, through an increase in this constituent and a decrease in the amount of quartz and garnet present, it grades into another facies, which may be termed a sillimanite schist. This variety is most abundant in the southeastern part of the district south and east of Sunset, and near Sunnyside in the southwestern part. A fine even-grained dark-colored quartz-biotite schist differing greatly in appearance from the sillimanite schist and the garnetiferous quartz-mica schist is locally abundant in the northeastern part of the district. Small lenses of hornblende schist are found at several places but are most common near Gold Lake in the northeast part of the district and at Sunnyside. Southeast of Copper Rock the northwest edge of the Boulder Creek granite batholith extends through the southeast part of the district. This gneissic gray biotite granite trends northeastward parallel to the foliation in the adjacent schist.

The Silver Plume granite in the Ward district is the southern part of a large stock that extends northward to the Thompson River. (See pl. 1.) Associated with it are numerous dikes and irregular masses of pegmatite and aplite.

Laramide intrusives.—Fourteen varieties of rocks intruded during the Laramide revolution have been recognized in the Ward district. Most of them occur in dikes, which vary greatly in width and range from a few hundred feet to more than 2 miles in length, but the greatest area of intrusives comprises six stocks of extremely irregular outline, which range from 0.1 to 1.8 square miles in surface extent.

Some of the felsites near Ward probably belong to group 1, but most of them apparently belong to group 7 (pl. 7 and fig. 12). Rocks of group 2 are represented by diabase dikes in the eastern part of the district.

The diabase is black or dark greenish-gray and consists of calcic plagioclase, augite, hypersthene, and black iron oxide, with the usual suite of alteration products. It occurs in a series of dikes trending north and northwest, which extend for a number of miles and cross the northeastern part of the Ward district near Gold Lake. Some of the dikes are 60 feet wide, but in most places they are not more than 25 feet wide. The diabase is definitely older than a monzonite dike that cuts it near Gold Lake.

The rocks of group 3 in the Ward district include quartz latite and the Modoc, Utica, Brainerd, and White Raven quartz monzonite porphyries of Worcester. The Modoc quartz monzonite porphyry occurs in a single dike at the Modoc mine half a mile north of Ward, and the Utica quartz monzonite porphyry is also represented by only one dike, which extends about half a mile southeast of the Utica mine. Both are moderately fine-grained gray porphyries. The Modoc quartz monzonite porphyry contains phenocrysts of feldspar and hornblende 2 to 5 millimeters long. The Utica quartz monzonite porphyry contains many inconspicuous phenocrysts of feldspar and biotite and rarely quartz. The Brainerd quartz monzonite porphyry occurs in two large dikes on the north side of Lefthand Creek, near the portal of the Brainerd tunnel a mile east of Ward. A third dike occurs to the north in Tuscarora Gulch. It is a coarsely granular rock in which biotite, hornblende, and orthoclase can easily be distinguished. It has a light-gray color with a pink tint and resembles an even-grained light-gray granite.

In contrast to the quartz monzonite porphyries described above, the White Raven monzonite porphyry occurs in many dikes, but it is restricted to a belt less than 2 miles wide extending westward from Sunset to Sunnyside and northward to Ward. In many places the contact of this porphyry with the country rock is highly mineralized. The White Raven mine and several others in California Gulch follow veins intimately related to dikes of this porphyry. The rock is locally known as "birdseye porphyry" and contains many prominent phenocrysts of andesine which are in sharp contrast to the gray and greenish-gray fine-grained groundmass. Locally the groundmass is glassy. In some places quartz phenocrysts are abundant, but even

[24] Worcester, P. G., op. cit., pp. 70–71.
[25] Data furnished by C. W. Henderson and R. H. Mote, U. S. Bureau of Mines.

in a single dike their distribution is sporadic. The chief constituents of the rock are andesine, orthoclase, and quartz. The orthoclase is confined to the groundmass. Apatite, magnetite, and pyrite are common accessories. Ferromagnesium minerals were originally present but are everywhere altered to chlorite, epidote, and zoisite. Their shapes suggest hornblende.

Quartz latite has been noted in three localities, and in each it is closely associated with its granular equivalent, quartz monzonite. Its composition is similar to that of the White Raven and Brainerd quartz monzonite porhyries of Worcester. It has been found at the White Raven mine associated with White Raven quartz monzonite porphyry, and in Tuscarora Gulch it borders the dike of Brainerd quartz monzonite porphyry. About a mile east of Sunnyside, on the north side of Fourmile Creek, three other dikes of quartz latite occur. All the quartz latites are distinctly porphyritic, but in nearly all of them the phenocrysts are small; the groundmass is dense and for the most part glassy. Orthoclase, andesine, quartz, and biotite are the most important minerals. The quartz latite of the White Raven mine has been impregnated with silver-bearing galena.

The only rock of group 4 described by Worcester in the Ward report is the "quartz monzonite" north of Rowena, but this rock is part of the large granodiorite stock of the Jamestown district described on p. 257. Rocks allied to the intermediate quartz monzonite porphyries of group 5 are represented by the biotite dacite of Worcester. Biotite dacite dikes are prominent north of Lefthand Creek in the eastern part of the district. The fresh rock is gray to greenish gray and has fine-grained locally glassy groundmass containing many prominent phenocrysts of feldspar, quartz, and biotite. Orthoclase is rare as a phenocrystic constituent but is common in the groundmass; andesine and quartz are common both in phenocrysts and groundmass.

Group 6 is apparently represented by the Mount Alto quartz monzonite, which forms a single dike in the Ward district. This dike occurs in the central eastern part of the district about a quarter of a mile north of Mount Alto Park and a mile east of Gold Hill. It is gray or brownish-gray and coarsly porphyritic. Single crystals of orthoclase 2 inches long are not uncommon, and a large number range from half an inch to 1 inch in length. Quartz phenocrysts are also conspicuous. Less prominent but more abundant crystals of andesine with some altered hornblende and biotite are also present as phenocrysts. The groundmass which makes up half the rock is chiefly much-altered orthoclase and quartz in a micropoikilitic intergrowth. Titanite and magnetite are abundant accessory minerals.

Representatives of group 7 include most of the rocks described as felsites by Worcester. Some of the dikes termed felsites in Worcester's report are probably the earliest in the region and belong to group 1, but most of them are alaskites and rhyolites of group 7 that have been mapped as felsites. They are definitely later than the pyritic ores of the district.[26] The early felsites include a large number of fine-grained, light-colored, partly glassy rocks composed chiefly of quartz and orthoclase with small amounts of hornblende and biotite. They occur near Ward and near the eastern edge of the district in dikes that range in length from a few hundred feet to more than a mile.

The rocks of group 8 include sodic diorite and alkalic monzonite porphyries. The diorite porphyry and monzonite porphyry described by Worcester grade into each other; their lithologic character and age relations indicate their equivalence to the alkalic syenite of the Idaho Springs-Central City district. They are earlier than the trachyte (bostonite) at Sunset and later than the breccia reefs. Most of the rocks mapped as diorite porphyry by Worcester are somewhat richer in hornblende and biotite than his monzonite porphyry. The diorite porphyry occurs in two stocks and several dikes a few miles southeast of Ward. It is brown to gray, coarsely porphyritic, and consists essentially of plagioclase and biotite but also contains hornblende and a little orthoclase, apatite, titanite, and calcite. It has abundant phenocrysts of plagioclase and biotite and some of hornblende; commonly phenocrysts make up more than half the rock.

Monzonitic rock has the greatest areal distribution of any of the Laramide intrusives and forms irregular stocks extending from the south side of Fourmile Creek nearly to Gold Lake. The largest of these stocks, north of Sunset, has a surface area of 1.8 square miles. As shown in plate 2, it extends southward from Lefthand Creek nearly to Sunset. Worcester called this rock a monzonite porphyry, but his description [27] and the appearance of the rock indicate that it is close to a syenite in composition. Worcester states that in places it grades into a diorite. Just east of the stock, between Todd Gulch and Spring Gulch, there is a small lenticular mass of diorite porphyry, which differs but little from the syenite (monzonite) porphyry. Dikes of similar porphyry occur on both sides of Fourmile Creek just west of Copper Rock. They strike in various directions, but their predominant trends are eastward and northeastward. The dioritic syenite porphyry has a pronounced porphyritic texture. It is dark-gray in a freshly broken surface but weathers rapidly to some shade of brown or greenish gray speckled by white feldspar and black hornblende phenocrysts. Pink to white phenocrysts of orthoclase and sanidine are abundant and are as much as an inch long. Small needlelike and stubby

[26] Wahlstrom, E. E., The age relations of the Ward ores, Boulder County, Colo.: Econ. Geology, vol. 31, p. 112, 1936.

[27] Worcester, P. G., op. cit., p. 40.

phenocrysts of hornblende are moderately prominent. Most of the syenite porphyry is coarsely porphyritic, containing prominent orthoclase and hornblende phenocrysts. Even-grained facies occur locally. Plagioclase, commonly andesine, is the most important mineral in the groundmass and also forms sparsely distributed phenocrysts. Biotite is common in the groundmass but rarely occurs as phenocrysts. Sphene and magnetite are also common in the groundmass, but orthoclase is only sparingly present.

Several masses of latite porphyry occur on the borders of monzonite porphyry dikes and stocks and may be related to the monzonite magma; they are therefore provisionally referred to group 8. There are several latite porphyry dikes scattered through the Ward district. Nearly all are mineralized at their borders, and some of them are mineralized throughout. The abundant pyrite locally contains appreciable amounts of gold, and for this reason most of the latite dikes are pitted with prospect holes. They show a wide range in color, texture, and condition of weathering but do not resemble other intrusive rocks of the Laramide revolution, with the possible exception of some of the andesites. The latite porphyries characteristically have a dense or glassy matrix with many phenocrysts. Feldspar phenocrysts are most common, but hornblende and biotite are locally prominent. Plagioclase is more abundant in the groundmass than orthoclase and is equally common in the phenocrysts. Hornblende is the most abundant ferromagnesian mineral in the fresh rock, but in many places it has been strongly altered to epidote and chlorite.

Rocks of group 9 are represented by the trachyte at Sunset. It occurs near the village of Sunset, about 4 miles southeast of Ward, in an irregular stock and in several dikes. The main body of trachyte is on Bald Mountain about a mile and a half west of Sugarloaf Mountain, and from it large dikes extend to the north. Fresh specimens are extremely rare. It commonly weathers to light brown, buff, red, or pinkish gray, with a pitted surface. It is much jointed and characteristically breaks up into sharp-edged plates 2 to 3 inches thick. The trachyte is conspicuously porphyritic, but the numerous phenocrysts are not large; they are chiefly of orthoclase, though some altered augite (?) is visible. Orthoclase is also the most abundant mineral in the groundmass, where it is accompanied by a small quantity of oligoclase and by characteristic alteration products indicating that a ferromagnesian mineral was moderately abundant. Augite has been reported in the trachyte by Breed.[28] Apatite is present as an accessory mineral. Between Sunset and Copper Rock the trachyte follows the eastern edge of the large stock of dioritic syenite porphyry for a short distance and cuts directly across the platy structure of the syenite porphyry body. The platy structure of the intruding trachyte is parallel to the contact.

The andesites described by Crawford are believed to be equivalent to the biotite monzonite of the tungsten belt and are therefore assigned to group 10. They form dikes, which attain a maximum length of approximately half a mile and are most common in the southeastern part of the district, east of Bald Mountain and Copper Rock. The andesites are light to dark gray and commonly contain feldspar, biotite, and hornblende or augite crystals about 2 millimeters in diameter, set in a very fine-grained groundmass. Plagioclase and the ferromagnesian minerals are the most abundant minerals, but some orthoclase and sphene are always present.

Intrusion breccia of group 11 has been found near Sunset by the writers. It is a fine-grained glassy rock containing fragments of schist, granite, and pegmatite, and locally of earlier porphyries. The breccia is dark gray where fresh, but in most places is considerably altered and is light gray. The groundmass is largely glassy and contains minute laths of feldspar and minute grains of magnetite. In places tiny crystals of biotite or hornblende are present. The breccia occurs in a small area on Fourmile Creek, half a mile west of Copper Rock, between the two lobes of trachyte shown on plate 2. It fills the space between the two lobes and contains numerous fragments of the trachyte, as well as some fragments of the syenite porphyry. On the east side of the east lobe is a narrower zone of intrusion breccia, which contains numerous spheroidal masses of actinolite (?) and abundant disseminated pyrite. Two small northwestward-trending dikes of intrusion breccia are exposed on the north side of Fourmile Creek just above Copper Rock. In the upper tunnel of the Free Coinage mine, about half a mile south of Sunset, irregular stringers and seams of intrusion breccia are exposed in a strong northwesterly fault on the east side of a trachyte dike.

Two small masses of olivine basalt occur about a mile north of Ward, but neither outcrop has a surface area of more than a few hundred square feet. The position of the basalt in the sequence of rocks of the Laramide revolution is unknown, but it probably belongs in either group 2 or group 12. The rock is very fine textured, but in the hand specimens many minute lath-shaped grains of feldspar and moderate-sized grains of green olivine are visible. The borders of one of the basalt bodies is vesicular and amygdaloidal. The rock is a typical olivine basalt and consists essentially of calcic plagioclase, augite, and olivine, with conspicuous amounts of a black iron oxide, probably ilmenite. The texture ranges from moderately fine-grained to porphyritic or coarsely holocrystalline.

[28] Breed, R. S., Sunset trachyte from near Sunset, Boulder County, Colo.: Colorado Sci. Soc. Proc., vol. 6, pp. 216–230, 1899.

STRUCTURE

The structure of the pre-Cambrian rocks is fairly uniform throughout the district. The schist, gneisses, and gneissic facies of granite trend eastward or northeastward and dip 45°–80° N. West of Sunset the foliation swings from a northeasterly to a more westerly trend, ranging from due west to N. 60° W., and dips 10°–60° N. In the extreme southeastern part of the district is the border of the Boulder Creek granite batholith. The contact has a general northeasterly trend, approximately parallel to the foliation. The structure and direction of emplacement of the stocks have not been ascertained, but some observations have been made on the trachyte and syenite porphyry stocks near Sunset.

That the trachyte is later than the monzonite porphyry is shown by the fact that platy structures in the trachyte are parallel to the contact, whereas those in the monzonite porphyry close to the contact are at right angles. However, the linear structure in both masses pitches from 45° to 60° SE., suggesting a common source somewhere between Bald Mountain and Copper Rock, on the east side of the trachyte body.

Most of the early ferromagnesian intrusives trend north-northwest. Most of the rocks belonging to groups 4 to 10 trend eastward, but several strike nearly due north. The eastward-trending dikes that are exposed in the mine workings commonly dip north parallel to the gneissic structure of the enclosing rock. A few dikes in California Gulch strike northwest.

The strike and dip of the veins near Ward are essentially those of the dikes. Most of the veins trend west-northwest and dip north. The majority dip at angles steeper than 60°, and abrupt changes of 15° to 30° in dip are common. The most productive veins belong to the "breccia reef" fault system formed during the early part of the Laramide revolution and are extremely persistent in the direction of the strike. (See pl. 3.) The deepest mines have followed veins more than 1,000 feet below the surface, and at this depth they are still strong.

The most noteworthy structural feature of the area near Sunset is the wide zone of fracturing and brecciation that extends along the east side of the trachyte stock. This zone has a general north-south trend, parallel to the east border of the trachyte stock, and is about three-quarters of a mile wide and more than a mile and a quarter long. It is marked by mild fracturing of the schist throughout and locally by strong fracturing and brecciation. The dominant trends of the fractures are northwest and northeast, approximately at 45° to the direction of the zone, but there are also some north-south fractures and breccia zones. Various dikes of porphyry follow the predominant trends of fractures. The strongest brecciation appears to have taken place on the cliffs, just north of Copper Rock. The whole brecciated zone has been mineralized, and copper stains on the cliffs above Copper Rock have given rise to its name. The occurrence of this wide zone on the eastern border of a porphyry stock and the abundance of porphyry dikes scattered through the zone seem to indicate that it was formed by the upward force exerted by the intrusion of either the trachyte mass or by another related porphyry mass that does not appear at the surface but may underlie it. This fractured and brecciated zone resembles in many respects the zone of brecciation that lies along the southwest side of the Jamestown sodic granite porphyry stock and was apparently produced by the intrusion of the stock.[29]

Another important structural feature of the area near Sunset is the strong fault of northwesterly trend exposed in the Free Coinage workings half a mile south of Sunset. It lies on the eastern side of the westernmost tongue of the trachyte stock, as shown on plate 2. The fault strikes about N. 30° W. and dips about 80° NE., and is known for some distance to the northwest and southeast. In the Nederland district a fault with similar dip and trend crosses Gordon and Upham Gulches about half a mile west of their junction and lines up directly with the Free Coinage fault; the two are believed to be the same, but their continuity has not been established. This fault as exposed in the Free Coinage workings consists of a zone of fractured and sheared schist 50 feet wide, with about 10 feet of gougy material on the footwall and 1 to 2 feet on the hanging wall. On the footwall is a trachyte dike 15 feet wide, and near the middle is a dike of intrusion breccia about 3 feet wide. The fault belongs to the system of northwestward-trending breccia reefs that are earlier than the porphyry intrusions of this part of the Front Range. Slickensides found on the wall of one of the slips pitch vertically in the plane of the fault, but the direction of movement could not be determined.

The fissures occupied by the veins of the district near Sunset strike both northwest and northeast. The only northeast vein studied, the Copper Glance, dips 65°–75° NW. The foot wall moved down to the southwest at about 55°, but the total displacement was only 5 feet.

ORE DEPOSITS

Gold, silver, lead, copper, zinc, and tungsten, in the order named, are the valuable constituents in the ores of the Ward district, and of them, gold, silver, and lead have been responsible for most of the output.

Nearly all the ore occurs in tabular shoots or in chimneys of roughly elliptical cross section that appear to be local enlargements of veins. The largest of the chimneys, in the White Raven mine, is about 30 feet wide and extends 200 feet along the vein. The most

[29] Goddard, E. N., The influence of Tertiary intrusive structural features on mineral deposits at Jamestown, Colo.: Econ. Geology, vol. 30, pp. 370–386, 1935.

productive veins have been found in the granite or the granite gneiss along dikes of quartz monzonite, quartz latite, latite, and felsite, but some of the dikes are later than the ore. The veins in the Idaho Springs formation are much less continuous and in general are of lower grade. In many places well-defined veins in granite and gneiss feather out in the schist. Post-mineral faulting is common, but the displacement of the veins is generally small, as most of the movement has occurred along the vein fissure. In nearly every place where such faults cut across the vein the faulted segments have been found with little difficulty.

Although there are approximately 200 mines in the Ward district that have supplied some ore, probably not more than 50 have supplied ore having a gross value of more than $5,000 and probably not more than 15 have had an output valued at more than $100,000. Of this group the Baxter, Columbia, Niwot, Madelaine, Sullivan No. 5, and Utica are on the Columbia vein. Among the other productive mines are the Celestial, Celestial Extension, and Morning Star on the Celestial vein. The output of the Big Five property came from the White Raven vein system and the Columbia vein. The B. and M., the Ruby, the U. P. group, the Ward Rose, and the White Raven are the other mines credited with an output valued at more than $100,000 each.

Pyritic gold-silver ore.—The gangue minerals of the pyritic gold-silver ores are chiefly quartz with some fluorite and sericite. Most of the quartz is early and is massive and white, but druses of colorless quartz crystals are late. Nearly all the gold mined in the district has been found in the quartz veins associated with pyrite or chalcopyrite or both. Ore containing chalcopyrite is commonly richer in gold than ore containing only pyrite. Silver occurs with the gold and chalcopyrite but is most abundant in the galena ore. Many assays of the pyritic gold-silver ore indicate that the average proportion of silver to gold is about 10 : 1 by weight; the two are apparently alloyed. Although chalcopyrite is generally much less abundant than pyrite, locally the reverse is true. Molybdenite and wolframite are economically unimportant but are present in most of the pyritic gold veins and seem most abundant in the deep workings. Wolframite is earlier than chalcopyrite and most of the pyrite.

Enrichment of the pyritic gold ores in the oxidized zone above the water table has been responsible for all the rich free-milling gold ore in the region. The level of ground water in the Ward district ranges from 50 to 250 feet below the surface of the ground but in general is not more than 100 feet. The enriched zone is clearly defined in all the pyritic veins. Near the surface the vein minerals are oxidized, and limonite is abundant. The iron-stained quartz is loose and honeycombed and contains drusy cavities lined with late quartz crystals. This "rotten quartz" is well known for high values in gold. Below the water level the gold tenor of the pyritic gold ore is commonly 0.1 to 0.5 ounce to the ton, but in the oxidized zone much of the ore contains 3 or more ounces of gold to the ton.

Lead-silver ore.—The lead-silver ore is largely limited to the White Raven vein system. The gangue minerals are calcite and barite. Galena is abundant and is usually in large well-formed crystals. Silver alloyed with gold occurs as a primary mineral included in the galena. Sphalerite is not abundant except locally. Gray copper (tennantite) occurs sparingly below the 700-foot level. Galena, primary silver, and gold are apparently contemporaneous with some calcite and are earlier than barite and a second generation of calcite. Later than all these minerals is abundant supergene wire silver, which has been found between level 6 and the top of the water table in the White Raven mine. In the oxidized zone the silver content is somewhat lower than immediately below the water table. Gold is not an important constituent of the silver-lead ore. Zinc is commercially unimportant and where found is a minor constituent of the ore.

Copper ore.—In most of the mines of the Ward region copper-bearing ore has been valuable chiefly for its gold content, but both chalcopyrite and chalcocite are sufficiently abundant to be of commercial interest. From the Sunset area, in the southeastern part of the district, chalcopyrite ore has been shipped in which the content of gold and silver were of less value than that of copper, which approximated 20 percent. Chalcopyrite is everywhere the most important copper mineral and occurs chiefly with pyrite in pyritic gold-copper ore.

Gold-telluride ore.—Gold-telluride ore has been found locally in some of the mines. It is common on the eastern side of the Ward district and has also been reported from the Morning Star mine in Spring Gulch.

Tungsten ore.—Wolframite intimately associated with quartz and pyrite and with a small amount of chalcopyrite is widely scattered through the veins of the Ward district. It is not found far south of Ward and is most abundant north of town (see p. 211) and in the eastern part of the district near Gold Lake.

Deposits near Sunset.—Gold with minor amounts of copper is the chief metal produced in the Sunset area, but some ores also contain silver. The ore deposits may be divided into two classes, those occurring as strong veins limited largely to the vicinity of Sunset on the western side of the trachyte stock and those associated with the strong fracture zone on the eastern side of the trachyte stock. They are similar mineralogically though quite different structurally. The veins in the vicinity of Sunset belong to the pyritic gold type and are almost identical with those of Ward; beneath a shallow oxidized zone they are in general of low grade.

They occur both in northeasterly fractures dipping steeply to the northwest and in northwesterly fractures dipping steeply to the northeast. The veins observed range from about 6 inches to 1½ feet in width. The greatest depth to which they have been exposed is 300 feet, in the Dolly Varden mine. The chief ore mineral in the veins is chalcopyrite accompanied by minor amounts of pyrite, but argentiferous galena and gray copper occur locally in the Free Coinage mine. The chief gangue mineral is coarse milky to glassy quartz. The gold in the primary ore is apparently contained in the chalcopyrite. All the minerals appear to be approximately contemporaneous, but some of the chalcopyrite is later than the pyrite. Locally there is some fine-grained hematite in the quartz of the Dolly Varden vein. According to A. L. Edmonds, of Sunset, the ore shipped from these veins had a gold content of 2 to 3 ounces to the ton and a copper content ranging from 2 to as much as 35 percent. Mr. Edmonds reports that good silver ore was taken from the Free Coinage mine and from the Bismarck mine. The ore from the Free Coinage mine is said to have assayed $125 per ton and to have consisted chiefly of galena, gray copper, and pyrite in a quartz gangue. This ore was not seen by the writers. Mr. Edmonds also reported the presence of telluride ore on the 60-foot level of the Dolly Varden mine.

The wide fractured and brecciated zone on the east side of the trachyte stock in the vicinity of Copper Rock has been unevenly mineralized. The biotite schist is chloritized and locally sericitized and silicified. In the cliff just north of Copper Rock there are numerous small breccia zones about 10 feet wide and 30 to 50 feet long, trending either northwest or north-south, but throughout much of the zone the rock is merely fractured. Pyrite is disseminated along the fractures and foliation planes of schist throughout this zone, and locally some chalcopyrite is also present, as indicated by the copper stains on the cliffs at Copper Rock. The fractures are spaced from a few inches to more than a foot apart. Numerous pits and small tunnels have been dug, but on the whole the zone was apparently of too low grade to be of commercial value. One part of it, however, was of higher grade and was opened in the Orphan Boy mine, about 500 feet from the eastern border of the mineralized zone, about half a mile south of Copper Rock. Here there are many nearly vertical fractures striking about N. 50° E. and a few prominent ones striking about N. 25° W. In places the fractures contain small seams of vuggy quartz and coarse free gold, but these seams are rarely more than an inch wide, and many are less than half an inch. The free gold is limited to the oxidized zone, which extends from 50 to 75 feet beneath the surface. Below the oxidized zone there are merely seams of pyrite along fractures locally associated with quartz. It seems clear that the rich free gold in the Orphan Boy mine, like that of so many other pyritic gold deposits, is due to secondary enrichment. Much of the quartz in the high-grade seams is "honeycomb quartz, and some of the cavities left by the removal of the pyrite during oxidation are partly filled with free gold. Some of this free-gold ore was very rich, small lots containing as much as an ounce of gold to the pound of ore, but the average was between 5 and 10 ounces of gold to the ton. Assays of samples taken from various surface cuts scattered over the hill in the vicinity of the Orphan Boy through a width of about 700 feet were kindly furnished the writers by Mr. More, owner of the property. The samples were reported to have been taken over a width of 4 to 5 feet and should therefore give a fair idea of the average tenor of the rock in the mineralized zone. The tenor of these samples in the oxidized zone ranged from 0.01 to 0.04 ounce of gold to the ton. Unoxidized rock in the mineralized zone in the vicinity of the Orphan Boy commonly contains 0.01 to 0.02 ounce of gold to the ton.

CELESTIAL VEIN SYSTEM

The Celestial, Celestial Extension, and Morning Star mines are on the northernmost of the highly productive veins of the Ward district. The Celestial vein is on the northern side of Spring Gulch, northeast of Ward, at an altitude of slightly less than 9,000 feet. It is a typical representative of the pyritic gold-copper ores of the district, but the ore is said to be more continuous and less pockety in this vein than in many others. The country rock of the vein is chiefly granite gneiss, but lenticular masses of schist are rather common. In places the vein follows the walls of felsite porphyry dikes and in other places cuts them. It strikes N. 80° E. and dips steeply to the north. On the 300-foot level of the Morning Star mine a rich sulfide body containing gold telluride and native gold was found, but most of the smelting ore contains less than 4 ounces of gold to the ton, and the ore milled has ranged in value from 0.17 to 0.70 ounce of gold to the ton.[30]

B. AND M. VEIN

The B. and M. mine is on the crest of the hill about a quarter of a mile east of Ward. The vein strikes N. 57° W. and dips about 45° N. for a slope distance of 750 feet; at greater depth it is much steeper. The vein has been followed 900 feet down the dip by the B. and M. shaft. Although the vein is known to extend for a long distance east and west of the B. and M. property, nearly all the output has come from this mine. The country rocks along most of the vein are schist and gneiss, but near the B. and M. shaft the vein cuts an eastward-trending felsite dike at a low angle. The ore shoot from

[30] Worcester, P.G., The geology of the Ward region, Boulder County, Colo., Colorado Geol. Survey Bull., 21, pp. 65–66, 1920.

which nearly all the output has come extended about 400 feet along the strike and was apparently localized by the broken dike. The ore shoot is said to have been limited to that part of the vein where one or both walls are felsite. Postmineral movement has caused the vein filling to become somewhat loose and broken. The ore is typical of the pyritic gold-copper veins of the district. The so-called smelting ores averaged about 3 ounces of gold to the ton.

COLUMBIA VEIN

The Baxter, Boston, Columbia, Madelaine, Niwot, Sullivan No. 5, and Utica mines are all located along the strong, continuous Columbia vein,[31] which strikes about N. 70° W. and passes through the southern part of the town of Ward. The deepest shaft on the Columbia vein is the Niwot inclined shaft, 950 feet long, which reaches a vertical depth of 800 feet. The collar of the Niwot shaft is at an altitude of approximately 9,400 feet. The vein in the Niwot ground is also tapped by an adit tunnel the portal of which is in California Gulch at an altitude of approximately 9,000 feet.

The country rock of most of the vein is gneissoid granite containing occasional lenses of schist. In much of the most productive ground, however, the vein follows the contact of white felsite porphyry dikes with the granite. The vein is commonly 4 to 6 feet in width, but locally it attains a width of about 14 feet. The most abundant vein minerals are quartz and pyrite with subordinate amounts of chalcopyrite. In the oxidized zone much free gold alloyed with silver was found. Below the ground-water level the gold is combined with the sulfides, and the silver content is comparatively low. The productive ore bodies on the Columbia vein are said to have occurred in five shoots, which pitched steeply to the east and were separated by zones of low-grade material.

The Columbia vein strikes about N. 70° W. and dips from 45° to 80° N., most commonly about 65°. In 1932, when the Columbia mine was visited by the writers, the shaft was in bad condition but was descended to the 300-foot level. The lower part of the shaft, said to be 300 to 400 feet deeper, had been filled with waste. The Columbia vein system on the 300-foot level consists of several subsidiary fractures either parallel to the vein or branching from it at small angles. The "shaft vein" is the most persistent; it strikes from east-west to N. 70° W. and dips 65°–70° N. The vein consists largely of quartz, pyrite, and chalcopyrite.

On the 300-foot level there is a hard nearly barren layer of massive bluish-white quartz about a foot thick along the footwall, but it was apparently of too low grade to be mined. The vein material mined was commonly about 4 feet wide and in places somewhat wider. Parts of the stopes suggest that it attained a width of about 6 feet. There are many smaller veins 1 to 3 feet wide that branch from the "shaft vein." Good ore was obtained in these smaller veins in the steeper parts away from the junction with the shaft vein. In the hanging-wall fractures the ore pinches notably where the vein flattens, but the best ore was found just below the segments of low dip. The hanging-wall fractures invariably tighten and become poorer as they approach their junctions with the shaft vein. A few similar fractures are known in the footwall, but are not nearly so abundant; they were not seen by the writers. Smelting ore ranging from 0.70 to 4.0 ounces of gold to the ton was found in some of the subsidiary veins. High-grade ore occurred only above the 300-foot level. On the Adit or 400-foot level the vein is said to consist largely of hard, massive, fine-grained bluish-white quartz 1 to 3 feet thick. Below the Adit level in the Niwot winze, west of the Columbia claim, the vein is said to dip 45° N. The walls of the vein are much grooved by repeated movement. The earlier movements were not far from horizontal; the later movements apparently dropped the hanging wall towards the west at about 60°.

In the lowest levels of the Niwot mine, chiefly those well below the Adit level, the vein contained considerable wolframite, but this mineral was rare on the higher levels.

In the Baxter mine, some distance east of the Columbia shaft but on the Columbia vein, work was progressing on the 140-foot level in 1933. There the vein dips about 70° N. and follows the hanging wall of an andesite dike about 14 feet thick. Mineralized fault breccia is exposed on both sides of the dike and is in part of postmineral origin. Faulting apparently occurred before and after the intrusion of the andesite as well as before and after mineralization. Most of the grooves on the hanging wall of the dike are nearly horizontal, and the north wall moved eastward relative to the dike. The drag along the footwall fracture, however, shows that there the hanging wall dropped almost straight down the dip. A late cross fault striking east-northeast and dipping 65° S. has offset the vein and the porphyry dike east of the shaft, the southeastern side apparently having moved northeastward.

WHITE RAVEN-DEW DROP VEIN[32]

The White Raven mine is on the north side of California Gulch about three-quarters of a mile south of Ward. The country rock of the White Raven vein is chiefly a gray coarse-grained granite, but a large quartz monzonite porphyry dike, in places 15 feet wide, cuts the granite and forms the hanging wall of the White Raven ore shoot (pl. 19). The dike strikes nearly east-west and dips 45°–80° N. and can be traced for more

[31] Worcester, P. G., op. cit., pp. 9, 63.

[32] Idem, pp. 53, 58, 62.

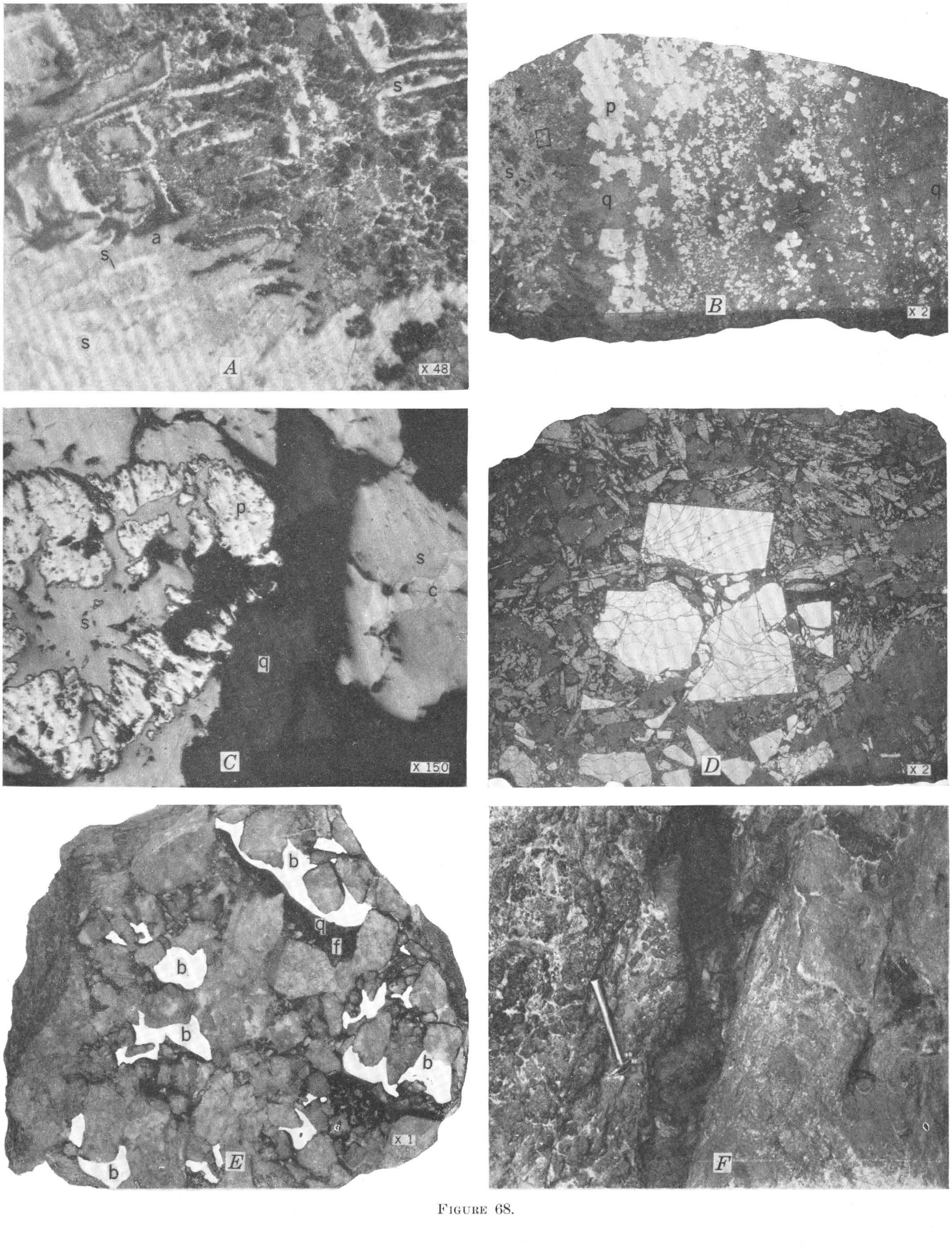


FIGURE 68.

than a mile. The main vein strikes nearly east-west and at the surface has an average dip of about 60° N., but below level 3 the dip commonly decreases to 45°. The fracture that the vein follows is roughly parallel to the dike, and in most places the vein and the dike wall coincide. Brecciation of the dike and the country rock was extreme. In most places the vein ranges in width from 2 to 12 feet. Both the hanging wall and the footwall are cut by many subsidiary fractures, and in places mineralized rock extends out from the main vein for some distance along the minor fractures.

Most of the ore in the White Raven mine came from a single chimneylike shoot, which was approximately elliptical in cross section. This shoot extended about 200 feet along the strike of the vein, attaining a maximum width of about 30 feet. The filling of the ore shoot comprises fragments of schist, granite, and porphyry, which are covered with layers of sulfide an eighth to three-quarters of an inch thick. The prominent sulfide is galena, which is in part contemporaneous with calcite. Resting on the galena is a thin coating of calcite and barite, and resting on these minerals is wire silver. Some secondary chalcopyrite is apparently contemporaneous with the native silver. Primary gold is apparently included with primary silver in the galena, but the total value of gold recovered has not been high. Nearly all the gold was limited to that part of the vein that lies east of the shaft. Most of the silver was obtained from above level 7. The tenor of the shipping ore has been 100 ounces of silver to the ton and about 10 percent of lead. Sphalerite is not abundant, but locally ore containing 30 percent of zinc was found above the 500-foot level. Gray copper (tennantite) occurs sparingly in the lower levels and is almost entirely limited to that part of the vein that lies below the 700-foot level. In the vein adjoining the chimneylike shoot the sulfide ore occurs as cementing material of a fault breccia.

On the Dew Drop property, some distance to the west on the same vein system, the vein strikes N. 70°–80° W. and dips about 65° N. The walls are said to be of gneissic granite. The longest ore shoot in the Dew Drop vein is reported to have been an irregular shoot of pyritic copper-gold ore 700 feet long, which extended from the surface to a depth of 300 or 400 feet. Similar ore was found in the Adit tunnel level and to a depth of 100 or 150 feet below; it assayed approximately $10 per ton.[33] This ore shoot is said to pitch west at a low angle. At its eastern end a pyritic copper ore graded into nearly barren quartz and gougy fault material.

QUEEN MINE

The Queen mine is in the northern part of the district half a mile northeast of Ward, at an altitude of 9,225 feet. The workings consist of a shaft 250 feet deep with four levels. The mine has had a substantial output of gold ore in recent years.

The chief wall rock in the Queen workings is Silver Plume granite, but schist is exposed in the western part of the workings. The foliation of the schist has a general strike of N. 80° W. and a steep dip to the north.

The Queen vein has an average strike of N. 75° W.; it dips 70° N. in the upper levels but steepens to 80°–90° in the lower levels. Grooves on the wall of the vein pitch 20° W., and displacement on the schist indicates that the north wall moved westward.

The vein is 6 inches to 3 feet wide but averages about 12 inches in its productive parts. The ore shoot being mined in 1934 was about 190 feet in stope length and persisted from the surface to the 250-foot level.

The ore is mined for its gold content. It is chiefly made up of coarse-grained pyrite in a gangue of glassy quartz, with minor amounts of sphalerite and chalcopyrite. (See fig. 68, *B* and *C*.) The gold seems to be chiefly associated with the pyrite and chalcopyrite, but sooty chalcocite is present on the 250-foot level, and there may have been some supergene enrichment to this depth. On the 250-foot level there is a 2-inch seam of milky quartz containing abundant bladed crystals of wolframite, which borders the pyritic gold vein and is plainly later (fig. 68, *D*).

On the 250-foot level the ore had a tenor of 2.5 ounces of gold to the ton and contained less than 1 percent of copper. On the 150-foot level the tenor was 1.5 ounces of gold to the ton and 5 percent of copper. It would seem that here the gold content was not so closely related to the chalcopyrite as it is in the primary ore of most pyritic gold mines of the Front Range, but it is probable that a substantial part of the chalcopyrite above the 250-foot level is of supergene origin in the Queen mine. The localization of ore in the vein seems due to the irregularities in the vein fissure formed

[33] Worcester, P. G., op. cit., p. 62.

EXPLANATION OF FIGURE 68

A, Photomicrograph of high-grade silver ore from Caribou vein 100 feet below surface. Native silver (*s*) replaces argentite (*a*) in the zone of secondary sulfides.

B, Typical coarse-grained quartz-pyrite-sphalerite ore of the Ward district from 200-foot level of Queen mine. Bands of pyrite (*p*) and quartz (*q*) are earlier than the sphalerite (*s*). Area included in *C* shown by small rectangle.

C, Photomicrograph of part of field shown in *B* enlarged to show centrifugal replacement of pyrite (*p*) by sphalerite (*s*). Chalcopyrite (*c*) replaces sphalerite in small irregular veinlets. *q*, Quartz.

D, Ore from the Queen mine, Ward district, showing wolframite (light gray) and quartz (dark gray) cutting coarse pyrite (white).

E, Photomicrograph of low-grade ferberite ore from Quaker City mine. Horn quartz and fine-grained ferberite (*f*) were deposited in the bottoms of open spaces in a breccia and coated successively by limonite-stained horn quartz (*q*) and the clay mineral beidellite (*b*).

F, Looking east at a barren part of the main Clyde vein at the east end of the stope on the tunnel level.

during the movement of its walls. As the right-hand wall moved ahead, ore would be expected where the vein turns to the left and has a more westerly trend, and this condition holds true where the ore occurs. The ore shoot is limited on the east by a sudden bend of the vein to the southeast and on the west by a change in wall rock from granite to schist. The maximum width of ore coincides with a "flat" cross fracture striking N. 75° E. and dipping 9° N.

ORPHAN BOY MINE

The Orphan Boy mine, located on the northeast slope of Bald Mountain, about a quarter of a mile south of Copper Rock, is of particular interest because of the coarse free-gold ore found there. The relation of this mine to the wide alteration zone has already been described. According to Mr. Edmonds of Sunset the Orphan Boy has yielded several hundred thousand dollars worth of ore. The development consists of three tunnels and numerous open pits and small shafts. The upper tunnel, at an altitude of about 8,000 feet, trends S. 20° E. for about 200 feet. The middle tunnel is about 100 feet beneath it and is also about 200 feet long, trending S. 15° E. The lower tunnel trends nearly due south and is driven from a point near Fourmile Creek for a distance of about 800 feet. The wall rock is all schist except for two hornblende andesite dikes about 60 feet apart trending about N. 30° W. The western dike is exposed in the upper tunnel workings, where it strikes N. 15° W. and dips 65° E. The schist strikes N. 50°–70° E. and dips 60°–80° NW.

Most of the ore has been taken from the upper tunnel. It consisted of free gold in honeycomb quartz and occurred in narrow veinlets commonly an eighth to a quarter of an inch wide and rarely more than an inch wide. In places these veinlets show only the honeycomb quartz with abundant limonite. The upper tunnel is driven on two parallel veinlets 2 to 5 feet apart, which trend N. 20° W. The eastern one dips 75°–85° E. and the western one about 75° W. to vertical. These N. 20° W. veinlets are crossed by a group of four fractures, which contain veinlets in places and strike N. 45°–55° E. and dip 56°–78° NW. Minor fractures trend from N. 30° W. to N. 20° E. and are fairly steep. There has been very little displacement along the fractures. On the northeasterly fractures the southeast side has moved southwest, and one of this group has displaced an andesite dike about a foot. The ore occurs in various places along the fractures but is most abundant along the N. 20° W. fractures, particularly where they are crossed by the northeast fracturing. The ore is very pockety, occurring in small bunches a few feet to 15 feet in length.

Complete oxidation extends to a depth of about 40 feet and partial oxidation to a depth of about 100 feet below the surface. Below this depth no commercial ore has been found. One specimen of high-grade ore showed a quarter of an inch seam of vuggy quartz with considerable limonite containing numerous irregular masses of gold as much as a tenth of an inch in diameter, but most of the gold was in small flakes and wires. The limitation of this high-grade ore to the oxidized zone implies that it is largely due to secondary enrichment. The veinlets are believed to have originally contained auriferous pyrite and quartz. As the material was oxidized, pyrite was leached out, leaving behind minute grains of gold. Some of the gold, however, was apparently dissolved and redeposited on the minute grains of gold at lower levels, building up wires and irregular grains visible to the unaided eye.

Some of the ore was of very high grade, small lots containing as much as an ounce of gold to the pound, but most of it ranged from 1 to 10 ounces of gold to the ton. Mr. More, the owner, kindly allowed the writers to copy a large number of assay returns from samples taken in the tunnel and over a considerable area on the surface. One sample from the upper tunnel, 26 feet from the portal, contained 10.56 ounces of gold to the ton over a width of 5 feet 4 inches. Other samples from the tunnel, taken over a width of 18 inches to 5 feet, ranged from 0.02 to 0.32 ounce. Samples taken on the surface over an area about 300 feet wide and 150 feet long, from various open cuts and shallow shafts near the upper tunnel, ranged from 0.01 to 0.36 ounce to the ton, and one contained 6.38 ounces to the ton. These samples were not taken along single seams but over widths ranging from 4 to 10 feet, in order to give a fair idea of the general tenor of the mineralized zone. The lower Orphan Boy tunnel did not disclose any ore of value but did cut many small fracture zones containing seams of pyrite.

On the basis of this sampling it does not seem probable that the entire mineralized zone would average a high enough tenor to be worked, even on a large scale; however, it is quite possible that there are certain local zones of high enough grade to be profitably worked so long as gold is worth $35 an ounce. Apparently the Orphan Boy mine is the only place in the mineralized zone where high-grade free gold has been sufficiently concentrated to be worked.

FREE COINAGE MINE

The Free Coinage mine, on the southeast side of Pennsylvania Gulch, three-tenths of a mile south of Sunset, is developed by two tunnels and a shaft. The tunnels are partly crosscuts and partly drifts, one being about 75 feet and the other about 250 feet below the shaft. The upper tunnel comprises about 800 feet of workings and the lower tunnel about 1,400 feet. The upper tunnel was the only one accessible in 1934. According to Mr.

Edmonds of Sunset the value of the mine's output is more than $50,000, represented chiefly by lead-silver ore.

The outstanding feature of the mine is a strong fault zone about 50 feet wide, which strikes N. 30° W. and dips 65°–82° NE. The zone consists of fractured and sheared schist with a strongly sheared, gougy zone about 10 feet wide along the footwall and a similar one about a foot wide along the hanging wall. On the upper tunnel level the wall rock is chiefly schist. A 3-foot mass of intrusive breccia occurs in the middle of the fault and a 2-inch seam on the hanging wall. Small slips extend out from the hanging wall, trending about N. 10° W. and dipping 70°–75° E. On the footwall is a trachyte dike about 15 feet wide, which dips approximately with the fault zone. Throughout the 10-foot zone of strong shearing on the footwall there are numerous seams, lenses, and bunches of quartz and pyrite. In places these seams follow the hanging wall of the strong shear zone and in places lie along the footwall.

The footwall has been stoped on for a distance of more than 75 feet southeast of the crosscut and to a height of more than 30 feet in places. This ore is of the pyritic gold type, and, according to Mr. Edmonds, one sample taken in 1934 contained 3.15 ounces of gold to the ton. On the west side of the dike there is a zone about 35 feet wide of irregular slips and fractures, which vary in strike from N. 25° E. to N. 15° W. and in dip from 50° to 80° E. In general the zone strikes nearly due north. These slips and fractures contain variable amounts of quartz and pyrite as much as 2 inches in width. This zone on the tunnel level apparently represents the vein that in the shaft contained the lead-silver ore. Mr. Edmonds said that the silver vein was 6 inches to 2 feet wide and extended to the porphyry dike and spread out against it but did not cut through it. The lead-silver ore taken from this vein consisted chiefly of galena, gray copper, and pyrite in a quartz gangue. Ore taken out in 1911–16 averaged about $125 per ton. Samples taken in 1933 showed 0.65 to 0.85 ounce of gold and 65 to 85 ounces of silver to the ton. No lead-silver ore was noted on the upper tunnel level by the writers.

DOLLY VARDEN MINE

The Dolly Varden mine, in Pennsylvania Gulch, about three-quarters of a mile southwest of Sunset, is developed by a shaft about 300 feet deep, with levels at depths of 60, 110, 186, and 250 feet. The Dolly Varden vein strikes N. 77° W. and dips about 80° NE. Slickensides on the walls pitch 12° SE. and indicate that the north wall moved west. The wall rock is entirely schist, which strikes N. 52° E. and dips 55° to 65° N.

According to Mr. Edmonds the vein ranged from 2 inches to 6 feet in width. It is made up of white glassy quartz, with considerable chalcopyrite and small amounts of pyrite and hematite. The gold seems to be contained in the chalcopyrite. According to Mr. Edmonds, the smelting ore assayed about $35 or $40 a ton in gold and contained 2 to 7 percent of copper. On the 186-foot level a drift extends east for 300 feet to its junction with the Lolla Rook vein. At this junction there was an ore shoot about 90 feet long. Not much ore was taken from below the 186-foot level. Mr. Edmonds reported that some telluride ore was found on the 60-foot level. This level extends 80 feet east and was stoped to the surface. According to Mr. Edmonds the total value of the mine's output exceeded $40,000.

COPPER GLANCE MINE

The Copper Glance mine, on Fourmile Creek about half a mile west of Sunset, is developed by a tunnel 500 feet long, of which 400 feet is along the vein. The wall rock is chiefly schist containing numerous lenses of pegmatite, the foliation trending from N. 60° W. to due west and dipping from 8° to 48° N. The vein ranges in strike from N. 50° to 75° E. and in dip from 55° to 75° NW. Slickensides and displacements of pegmatite dikes indicate that the southeast wall moved southwest and down at about 55° with a total displacement of about 5 feet. The vein ranges from a few inches to 15 inches in width and where productive is made up of quartz, pyrite, and chalcopyrite. The quartz is coarse grained, white, glassy, and vuggy in places, the vugs containing minute crystals of siderite. The wall rock is sericitized for 1 to 2 feet on either side of the ore shoot, but along the barren stretches it is only chloritized.

According to Mr. Edmonds the ore taken from this mine ranged in value from $36 to $68 per ton in carload lots, and some shipments contained as much as 35 percent of copper. In the tunnel, 50 feet east of the crosscut, there is a stope extending for 100 feet along the drift and, Mr. Edmonds states, to the surface. Another small stope 225 feet east of the crosscut extends 40 feet along the drift and is stoped upward for 25 feet. According to Mr. Emonds, the mine has yielded about $18,000 worth of ore.

RUBY MINE

The Ruby mine is at Sunnyside, on Fourmile Creek, about 3 miles west of Sunset. The workings consist of a shaft 274 feet deep with about 1,000 feet of drifts on the vein. Up to 1920 the output had amounted to about $120,000. The country rock is coarse-grained gneissoid granite, which is cut by a dark-gray felsite dike.

The vein is 2 to 4 feet wide and contains pyrite, chalcopyrite, and quartz with some gold and silver. The best-grade ore had a value of between $60 and $90 a ton at the old price of $20 an ounce for gold. The low grade had a value of $2 to $14 a ton.

BOULDER COUNTY TUNGSTEN DISTRICT [34]

LOCATION AND HISTORY

The Boulder County tungsten district extends in a narrow southwesterly belt 9½ miles long from Arkansas Mountain, about 4 miles west of Boulder, to the Sherwood Flats, a mile northwest of Nederland. Throughout most of this distance the belt is 1 to 2 miles wide, but near its western end it flares out to a width of approximately 3 miles (pl. 3). Boulder is the nearest railroad shipping point, but the district is well served by good automobile roads.

The abundant float of a heavy black mineral throughout the tungsten belt was known in the days of the earliest prospecting in Boulder County and was called "heavy iron," "barren silver," and "black iron" and was assayed again and again for silver and gold. Its identity was not recognized until about 1899, when W. H. Wanamaker, who was familiar with the tungsten ore of the Dragoon Mountains of Arizona, recognized the ferberite float as a tungsten mineral. Wanamaker and his partner, S. T. Conger, obtained a lease on a part of the Boulder County land where the float was abundant, about a mile northwest of Nederland, and 40 tons of high-grade ore were taken from the surface in 1900. In the same year Conger discovered the Conger vein, which proved to be the most productive vein in the entire district. The discovery of the tungsten ore coincided with the period during which tungsten steel was first introduced in the manufacture of high-speed cutting tools, and prospecting throughout the district was encouraged by the consequent demand for tungsten ore. In spite of the fact that during the first few years following the discovery the price of tungsten ore was as low as $1 per unit,[35] there was much activity throughout the tungsten belt, and most of the productive veins were discovered before 1907. The price paid per unit, which ranged from $2 to $3 in 1903, gradually rose to as much as $14 during the next decade and reached a peak of $100 per unit in 1916 because of the urgent demand during World War I. As early as 1904 the potentialities of the district were recognized by some of the large steel corporations of the East, and a number of well-financed corporations entered the district and acquired property. From this time on the larger companies, such as the Wolf Tongue Mining Co., subsidiary of the Firth-Sterling Steel Co., the Primos Mines Co., subsidiary of the Primos Chemical Co., the Vasco Co., subsidiary of the Vanadium Alloy Steel Co., and later the Vanadium Corporation of America dominated the mining of tungsten in Boulder County. These large companies erected concentration plants, bought ore from small operators, and mined ore on properties of their own. The problem of satisfactorily concentrating ore was difficult because of the marked tendency for the ferberite to slime during the crushing process. It is probable that the mills have not recovered more than 75 percent of the tungsten contained in the ore, though constant efforts were made to increase the recovery, and the slimes were passed over canvas in the larger mills. As shown in the record of output (fig. 69), the district was entering its most productive stage about 1910, when 1,221 tons of concentrates containing 60 percent of WO_3 were produced. The demand for high-speed steels during World War I greatly stimulated the production of tungsten all over the world and resulted in a boom of unparalleled proportions in the Boulder County tungsten district.

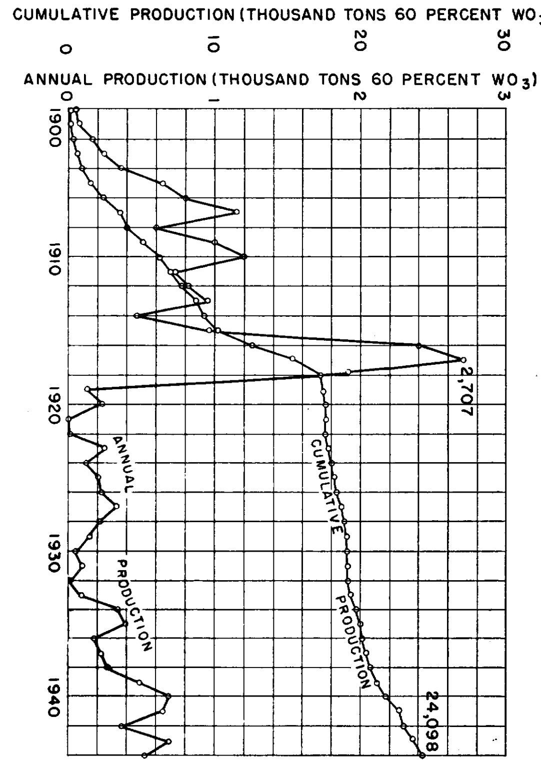


FIGURE 69.—Graph showing production of tungsten in Boulder County, 1900–1944.

In 1915 the price rose from $5.60 per unit in the early part of the year to $45 at the end of the year. The price continued to rise rapidly during the first two months of 1916, and by the first of March prices quoted in published schedules reached $90 per unit, and some tungsten was sold for as much as $100. Late in March the price began to fall and was as low as $10 in September. By the end of the year, however, the price had risen to $15, and in 1917 it rose to $18 and in 1918 to $20. The rise to boom prices in 1915 came too suddenly to affect the production substantially for that year, but it spurred mine development, with the result that 2,401 tons of 60

[34] The writers are indebted to Mr. Ogden Tweto for critically reviewing this section and adding valuable material from his work in the district during World War II.

[35] A unit is 20 pounds of tungsten trioxide, or 1 percent of a short ton; the standard grade for which prices are quoted is material containing 60 percent by weight of WO_3 (tungsten trioxide); if the ore is of high grade a bonus is paid and deductions are made if the quality is below standard.

percent concentrates was produced in 1916, and a peak output of 2,707 tons of 60 percent concentrates was reached in 1917, when the price was less than $20. By 1918 the effects of boom prices were waning, and output fell substantially. In 1919 the price fell as low as $6 per unit, and the district entered a doldrums from which it did not begin to recover until 1939.

In 1918, immediately following World War I, a statement was made by a number of the operators to the United States Tariff Commission[36] in which it was agreed that all the cheaply mined ore had been extracted and that it was doubtful whether more than a few operators would be able to continue if the price dropped below $20 per unit. Answers made by the majority of operators to a questionnaire from the Tariff Commission indicated that most of them felt that a price of $30 to $40 per unit was essential if they were to obtain a reasonable profit in operation. From 1918 through 1938 the output of the district was small, averaging less than 200 tons of 60 percent concentrates per year for the 20 years. Most of this was produced by the Wolf Tongue Mining Co. and the Tungsten Production Co. and their lessees. The great decline in output was due in part to the increased cost of mining in Boulder County, where, according to Mr. William Loach,[37] ores cannot be mined for less than $12 per unit, but the decline was mainly due to the introduction of cheap Chinese ores, which could be landed in New York and London for less than $10, including the tariff of $7.14 per unit.

The effect on the tungsten district of World War II and the world-wide rearmament preceding it was felt as early as 1937, when the price of tungsten rose to $20 per unit for a short time. Although the price again fell as low as $12 per unit in 1939, the 1937–38 price spurt caused inception of mine development that was of great importance in increasing the wartime output. Thus the Wolf Tongue Co. began development of the Illinois mine, and the Vanadium Corporation of America, which had acquired the property from the Primos Chemical Co. in 1920, reopened the Conger mine, the largest in the district. From 1939 to 1943 the price of tungsten rose gradually to a peak of $30, paid by the Metals Reserve Co. from July 1, 1943, to March 31, 1944.

The price of $30 per unit for 60 percent WO_3 was far less attractive than the peak price in World War I, especially so considering the greater depletion of the district, but nevertheless production of tungsten was greatly stimulated because of the relatively good prices paid for tungsten in low-grade ores. Prior to 1942, ore containing 1 percent of WO_3, or one unit per ton, was commonly quoted at $1 to $3 per ton, or 10 to 20 percent of the theoretical value, and during World War I quotations commonly were not given for ore containing less than 5 percent of WO_3. In 1942 Boulder Tungsten Mills, Inc., buying on a $23 schedule for 60 percent ore, offered $7 per ton for 1 percent ore, that is, $7 per unit for WO_3 in ore containing 1 percent of WO_3. When the Government-owned Metals Reserve Co. entered the market in 1943 it paid the unprecedented price of $20.50 per ton for ore containing 1 percent of WO_3. For a while it accepted ore running as low as 0.50 percent of WO_3, but the minimum was later changed to 0.80 percent of WO_3. This price subsidy, in addition to Government exploration and loans, greatly stimulated tungsten mining, and in 1943 about 50 tungsten mines were in operation. Upon withdrawal of the Metals Reserve Co. from the market the local price fell to $20 per unit. Owing to the wartime increase in costs, most mines could not be operated at this price, and by the end of 1944 only two mines, the Conger and the Forest Home, were in operation.

The wartime output of the Boulder County district was considerably increased by the product from the combined gravity and flotation mill of the Boulder Tungsten Mills, Inc. This mill, which was completed in 1942, handled a large tonnage of accumulated mill tails from the gravity mills, producing a considerable tonnage of low-grade concentrates suitable as feed for the chemical plant of Metals Reserve Co. at Salt Lake City.

The output of the Boulder County district increased almost threefold, from the equivalent of 240 tons of 60 percent concentrates in 1938 to 693 tons in 1940. In 1941 the output amounted to 646 tons, but in 1942, a year of development, it fell to an estimated 365 tons. The peak output for World War II was about 700 tons and was reached in 1943. In 1944, with production largely limited to the first few months of the year, an estimated output of 529 tons of 60 percent concentrates was made. It is significant that at the time of the price drop in 1944 the district appeared in better shape than at any time during World War II. From this and the record of output during the war it may be inferred that the district is still capable of producing a few to several hundred tons of concentrates a year under proper price conditions, but that the time lag between the impetus caused by increasing price and the actual increased production is becoming steadily greater.

GEOLOGY

Formations present.—Most of the tungsten district lies within the batholith of Boulder Creek granite that extends eastward from Hurricane Hill to the edge of the Front Range; a small but very productive part lies within the area of metamorphic rock bordering the batholith on the west (pl. 2). West of Hurricane Hill most of the terrain is underlain by the Idaho Springs

[36] Mineral resources U. S., 1918, pt. 1, pp. 981–983.
[37] Idem, 1923, pt. 1, p. 242.

formation, which has been thoroughly invaded by aplite and pegmatite related to the Boulder Creek granite and by small masses of the granite itself. East of Hurricane Hill the Boulder Creek granite is seamed by many dikes of gneissic aplite and pegmatite related to the granite. Along the western border of the batholith there is a zone half a mile to 1½ miles wide made up largely of aplite or pegmatite. The outer edge of this zone where these late differentiates of the granite feather out into the metamorphic rocks is extremely uneven. All the intrusives are irregular in outline, but in general their long dimensions trend north-northwest parallel both to the foliation in the Idaho Springs formation and to its contact with the Boulder Creek batholith. Tertiary dikes of hornblende monzonite porphyry and hornblende diorite porphyry are common in the western half of the district but are much less abundant in the eastern half. Dikes of biotite monzonite porphyry and the associated intrusion breccias of biotite latite have been found in several localities in the eastern part of the district but are uncommon in the western half.

STRUCTURE

The foliation of the Idaho Springs formation strikes north-northwest and dips about 60° ENE. in most places, but locally it may vary 90° from the average strike and nearly as much from the average dip. Most of the intrusives in the schist are sill-like, but near the edge of the batholith the larger bodies of aplite are cross breaking in part and have comparatively flat floors, which cut sharply across the foliation of the underlying Idaho Springs formation. Most of the aplite dikes and sills in the schist areas have a well-developed gneissic structure, which appears only rarely in the pegmatite.

The Boulder Creek granite has a strong primary gneissic structure everywhere, but it is most conspicuous close to the edge of the batholith. The primary banding strikes nearly parallel to the edge of the granite mass for a distance of about a mile. Farther east the structure swings from north-northwest to nearly east-west and maintains this general strike to the eastern end of the tungsten belt. Near the western edge of the granite the gneissic structure dips 50°–70° E., and both dip and strike are nearly parallel to the foliation of the bordering Idaho Springs formation. Where the primary structure has an easterly strike it dips 50°–70° N. and is roughly parallel to the regional dip and strike of the schists that lie a short distance to the north (pl. 2). The linear structure is almost independent of the platy structure and throughout the tungsten belt pitches 35°–60° N. A regional study suggests that the Boulder Creek granite mass was emplaced from a center near Gold Hill.

Most of the aplite and pegmatite dikes within the batholith strike from east to east-northeast. Although northwestward-trending aplite dikes are not uncommon in the border zone, they are less abundant than northwestward-trending pegmatite dikes within the main mass. Some of the aplite dikes crosscut the gneissic structure locally, especially near the border of the batholith.

At two localities, Hurricane Hill and Arkansas Mountain, persistent northwestward-trending masses of aplite and pegmatite can be followed for several miles. These northwesterly structures were the loci of fracturing during the Laramide revolution and were probably instrumental in determining the course of the Hurricane Hill and Hoosier breccia reefs. The gneissic structure of the granite and the trends of the minor aplite and pegmatite dikes were also determining factors in directing the course of the easterly and northeasterly fracturing in Laramide time that produced many of the vein fissures.

The earliest of the structures formed during the Laramide revolution in the district is marked by the northwesterly Iron dike, an extensive diabase dike, near the eastern end of the tungsten belt. It is offset by branches from the northwestward-trending Livingston breccia reef, which is subparallel to it, and all are earlier than the easterly and northeasterly faults and veins. It is probable that the northwesterly fractures marked by the hematitic silicification of the breccia reefs are not everywhere simple fault fissures; in places some seem due to the silicification of brecciated material intrusive into a simple fissure the walls of which show little or no movement (see p. 248). The major zones of early silicification along the northwesterly fissures are spaced 2 to 3 miles apart and include, from west to east, the Hurricane Hill, Rogers, Livingston, and Hoosier breccia reefs. All these silicified zones are earlier than the main period of movement along the east-west and northeast fractures that include most of the tungsten veins.

As shown on plate 3, there are three rather marked zones of east-northeasterly fractures, the strongest of which extends eastward from Hurricane Hill through the Dry Lake district to Comforter Mountain and thence eastward along the north slope of the valley of Middle Boulder Creek to the eastern edge of the district. This zone is characterized by the most persistent east-northeasterly fissures within the tungsten belt. Many minor fractures diverge from this general zone to the northeast. On both the easterly and the northeasterly fissures the movement of the walls was nearly horizontal; commonly the north walls of easterly fractures moved downward and to the west at low angles, while the walls of the northeasterly fractures were moving in nearly the opposite direction, their southeast walls moving downward and to the southwest at low angles. These movements suggest that the series of westward-pointing wedge-shaped blocks bounded by intersecting fissures moved downward and to the west in response to nearly horizontal compressive forces.

A zone of much less persistent easterly and northeasterly intersecting fractures occurs half a mile to a mile north of the Dry Lake-Comforter Mountain system. The most conspicuous veins in this zone are found east of Gordon Gulch and include the Quaker City, Oregon, Howard, and Bummer Gulch group of tungsten veins. The movement along the fractures of this zone was similar to that of the corresponding fractures in the Dry Lake-Comforter Mountain zone.

For half a mile west of Hurricane Hill the interlacing masses of aplite and pegmatite between Sherwood Gulch and Middle Boulder Creek are cut by many productive easterly and northeasterly veins, which end abruptly where they enter the main body of schist to the west. Many nonpersistent veins striking north-northeast occur in a zone that extends west-southwest from the north end of Hurricane Hill along Sherwood Gulch to the Sherwood Flats at the western limit of the tungsten belt; a substantial proportion of the output of the district has come from these veins. Very little tungsten has been found between Nederland and the Beaver Creek district, 1½ miles to the southeast, where another easterly zone of tungsten veins is found. The veins in the Beaver Creek district strike from east to northeast.

The unusually mafic Tertiary intrusive rocks of Caribou Hill are only a few miles west of the tungsten district. It is probable that some of the mafic rocks in the western part of the tungsten district are closely related to the Caribou stock magma, but the two dikes of hornblende monzonite that persist for more than 2 miles east of Nederland were intruded much later in the tectonic history of the region and probably belong in group 8 (pl. 7 and fig. 12). Farther east porphyries are uncommon and occur chiefly in short dikes too small to be shown on plate 2, but limburgite dikes, only one of which is shown on plate 2, are found in an east-northeasterly zone extending from Comforter Mountain to Arkansas Mountain. Nearly everywhere the linear structure of the porphyry dikes pitches 50° to 80° W.

Nearly all the porphyry masses found in the eastern half of the tungsten belt and not included in the limburgite (group 12) and diabase (group 2) clans are biotite monzonite porphyries or the related biotite latite intrusion breccias of groups 10 and 11. A study of the Logan and Yellow Pine mines (p. 248) indicates that the biotite monzonite and the intrusion breccia were emplaced relatively late in the structural history of the region and immediately preceded the deposition of the gold-telluride and tungsten ores.

In most localities the alteration that immediately followed the intrusion of the breccia converted the igneous matrix of the breccia into aggregates of sericite, calcite, silica, and chlorite, masking its original igneous character. Where movement occurred along the walls of the intrusive breccia after its emplacement and alteration, the altered igneous matrix was immediately reduced to a gouge, and its intrusive character may not be suspected.

The general relations in the Yellow Pine and Logan mines suggest that the Hoosier breccia reef in this locality was the site of recurrent intrusions of porphyry and intrusion breccias, each accompanied by a definite type of alteration. It seems very probable that the widespread silicification that marks the northwesterly faults is the result of a process affecting a brecciated mass of country rock that rode up on an underlying dike. At the Yellow Pine mine the horstlike movement of the Hoosier breccia reef suggests the brecciation of rock between two walls during the upward push of an underlying magma that followed the general course of the breccia reef. The successive injections of different intrusion breccias show the common tendency of igneous activity and orogenic movement to recur at the same localities after periods of quiescence. The irregular course and the lack of offsets in the intersected pre-Cambrian aplites suggest that parts of some other northwesterly breccia reefs are due to the intrusion of a hidden magma at depth. Although the hematitic silicification is characteristic of the earliest mineralization in the Front Range and is largely limited to the northwestward-trending fractures, it is possible that some of the silicified zones represent alteration above intrusions much younger than the period of northwest faulting.

ORE DEPOSITS

The mineral composition of most of the veins in the tungsten belt is very simple. Except in the eastern part, tungsten is the only metal sought. In the eastern part gold-telluride veins are present, and in the extreme northeastern part a substantial amount of high-grade silver-lead ore was taken from the Yellow Pine mine. Some lead-silver-zinc deposits occur along the northern and southern borders of the tungsten belt but little or no sulfide ore has been mined within it. The total output of the belt is valued at approximately $24,000,000.

Mineralogy. — Although many minerals have been found in the tungsten veins, only a few are common. The gangue is microgranular quartz locally known as "horn," and the only ore mineral is ferberite. Sericite and the clay minerals dickite and beidellite are common throughout the district, barite in small quantity is widely distributed, and in certain veins iron sulfides are sufficiently abundant to lower the grade of the ore. Hematite and magnetite occur with some of the ferberite ore at scattered localities in the tungsten belt but are not common. Pyrite, marcasite, galena, and sphalerite are rare but are locally associated with the ferberite as late minerals. Calcite and ankerite occur as early minerals in some of the veins, and adularia is present locally in the veins and wall rocks. The fine-grained quartz gangue in many places contains minute crystals of goyazite ("hamlinite"), dickite, kaolinite, beidellite, hematite, magnetite, and goethite, each mineral giving a characteristic color to the quartz in which it is disseminated. Opal and chalcedony are late minerals in most of the veins and are usually intimately associated with kaolinite or beidellite (fig. 68, *E*). Dickite, the moderately high temperature form of the kaolin group, is very common in vuggy ferberite ore and seems to be nearly contemporaneous with the ferberite. In the eastern part of the district some ferberite is associated with the sylvanite ores (fig. 74, *A*, *B*) but the sylvanite veins were formed before the tungsten mineralization took place.

Nearly all the tungsten ore mined in Boulder County contains so little manganese that it must be classed as a ferberite, but some ore from Gordon Gulch contained sufficient manganese to be designated wolframite.[38] Much of the ferberite in the Beaver Creek area is coarsely crystalline and vuggy and shows comb structure. In the Sherwood Creek zone and in the region near the Hurricane Hill fault, although vuggy medium-grained to coarse-grained ferberite is common, much of the ore consists of massive medium-grained ferberite, which occurs as a matrix to country rock fragments. The ferberite becomes finer and finer grained to the east. Scheelite in druses and veinlets in the ferberite ore and in minute veinlets and grains in the late light-colored "horn" is not uncommon in the northern and eastern parts of the district. The ferberite from different areas shows marked differences in color. Much of that in the western part is shiny black, except where it has been somewhat decomposed and in part converted to limonite. Some of the coarsely crystalline ore is highly iridescent. At many localities, especially in the central part of the district, the ferberite has a brownish cast and is distinctly softer than the black ferberite. Hess and Schaller[39] suggest that the brown ferberite may have contained specular hematite which has broken down to a hydrous oxide of iron imparting a brownish cast to the fresh ferberite.

Rock alteration.—The wall rock near most of the important tungsten veins was first strongly argillized—altered to the clay minerals dickite and beidellite—through a distance of 10 to 50 feet from the vein and later partly converted to quartz, sericite, and hydromica. In most places the argillized wall rock next to the vein was sericitized and slightly silicified prior to the deposition of the ferberite ore, giving the appearance of a band or casing of fresh rock separating the vein from highly altered country rock. Extensive argillization evidently preceded tungsten deposition by an appreciable period of time, as it is not everywhere related to the tungsten mineralization. Many of the minor ferberite veins occur in almost unaltered country rock, and some strong veins with thoroughly argillized walls contain fine-grained quartz but no ferberite. Unlike the simple sericitic alteration of the gold veins, the beidellite-dickite alteration results in an altered granite that soon slacks on exposure to the air, yielding heavy ground that sloughs and caves, closing many of the workings of abandoned mines within a few years. A detailed discussion of the alteration has been given by Lovering.[40]

Paragenesis.—The earliest minerals of the tungsten veins are fine-grained varieties of quartz, the introduction of which was probably accompanied by alteration of the wall rock to beidellite. Immediately preceding deposition of the ferberite, and accompanying its early stages, hematite and magnetite were deposited in small quantities. The ferberite in turn was succeeded by chalcedonic to opaline quartz and locally by barite. The solutions that deposited the barite and opaline silica were no longer in equilibrium with the ferberite, which was extensively replaced in the localities where these minerals are abundant. Small quantities of the sulfides, pyrite, marcasite, galena, and sphalerite, followed the deposition of barite, and the meager sulfide-bearing solutions apparently dissolved some ferberite in nearly all places where they came in contact with it. Dickite, an abundant mineral, was deposited shortly after the main period of ferberite deposition. Clay minerals were also formed during the later stages of vein formation.

The extensive formation of beidellite, the intergrowth of dickite and ferberite, and the local intergrowth of marcasite and ferberite all point to the presence of acid solutions of moderately high temperature. Recent work[41] suggests that dickite is formed in the temperature range of 225° to 365° C. and that nacrite is stable at higher temperatures than dickite. The immediate impoverishment of ferberite ores where gouge is abundant in the vein suggests deposition at comparatively low pressure, and the vein minerals suggest deposition at moderately high temperatures. The tungsten veins are believed to fall in the group discussed by Buddington and classed by him as xenothermal.[42]

Enrichment.—Ferberite ore is commonly less soluble than the surrounding country rock, and supergene enrichment of the tungsten ore bodies is negligible. Residual enrichment took place to an important degree and accounted for much of the surface ore, the so-called

[38] Hess, F. L., and Schaller, W. T., Colorado ferberite and the wolframite series: U. S. Geol. Survey Bull. 583, pp. 30–34, 1914.

[39] Idem., p. 16.

[40] Lovering, T. S., The origin of the tungsten ores of Boulder County, Colo.: Econ Geology, vol. 36, pp. 229–279, 1941.

[41] Morey, G. W., and Ingerson, Earl, The pneumatolitic and hydrothermal alteration and synthesis of silicates (a critical summary of work done prior to 1937): Econ. Geology, vol. 32, pp. 751–752, 1937.

[42] Buddington, A. F., High temperature deposits formed at shallow to moderate depths: Econ. Geology, vol. 30, p. 209, 1935.

"float" and "potato" ore, mined in the early days of the camp. Many of the gulches on the plateau north of Middle Boulder Creek have been placered for this type of tungsten ore, and in 1943 a substantial amount of tungsten was obtained from a relatively large-scale dry-land dredge operation in the gulch below the Cold Spring mine.

Tungsten veins.—The primary tungsten ore is found in veins, most of which are vertical or dip steeply. The ore is almost entirely a fissure filling and shows little or no replacement of the country rock. The ferberite mineralization occurred at a late stage in the orogenic history of the mineral belt; most of the larger veins have preserved a record of repeated shearing, some prior to deposition of the ferberite and some at the time of its deposition. Postore movement was uncommon, except in the western part of the district, and there most of the late movement caused a reopening of the ferberite vein. Displacement of ferberite veins along cross-breaking postmineral faults is rare.

In the southwestern part of the district ores have been mined between altitudes of 8,200 and 8,800 feet, in the northwestern part ores cropping out at the surface at an altitude of 8,700 feet have been mined to a vertical depth of 700 feet, and at the extreme eastern edge of the district ores have been mined between altitudes of 6,400 and 7,100 feet. In general it may be said that throughout the district the vertical range in which ores have been found is approximately 700 feet, but it should be pointed out that this depth corresponds rather closely to the topographic relief. The majority of the individual ore shoots have been followed to a depth of less than 100 feet, though a few, such as the Conger, Clyde, Vasco No. 6, and the Cold Spring, have been followed much deeper. The shape of ore shoots depends almost entirely on the shape of the open spaces available within a vein at the time of the tungsten mineralization. As shown by the longitudinal section of the Cold Spring mine (pl. 21), the ore shoots in cross section may be chimneylike, elliptical, or highly irregular in a given vein within a short distance. Many important ore bodies have been found during underground development, though no sign of the ore was known at the surface. The productivity of the district during World War II was largely dependent upon such ore bodies, and the success in finding blind ore shoots is evidence that many still exist in the district. An increasingly greater dependence upon blind shoots is inescapable, but the costs of exploration and development are high, and unless tungsten prices not only compensate for mining and milling costs but also leave a substantial margin to cover discovery costs little mining will be done.

The small size of most of the individual ore shoots and the fact that by far the greatest number of ore bodies mined cropped out at the surface suggest that the correspondence between the depth range of the ore and the topographic relief largely reflects the ease with which ore bodies could be discovered rather than the actual thickness of the zone of deposition of the ferberite. The deepest continuous ore shoot, that found in the Conger mine close to the western edge of the district, had a vertical depth of 700 feet, but though a winze was sunk 200 feet deeper little exploration was carried on below the pay ore. If exploration in the Cold Spring mine had been similarly restricted, three profitable blind ore shoots would have been missed.

The width of the average tungsten vein ranges from 6 inches to 3 feet, but in places ore bodies 12 to 16 feet in width have been exploited. The grade of ore as mined commonly ranges between 2 and 20 percent of trioxide of tungsten (WO_3). Replacement and impregnation of the country rock or of broad shattered zones by ferberite rarely took place, and no extensive bodies of low-grade ore are known in the district. In parts of the veins the ferberite is very finely disseminated in the horn quartz that makes up the bulk of the vein material; such material may assay from 0.5 to 2 percent of WO_3, but the difficulties of milling it have generally prevented its use. Even bodies of this type are not especially abundant; the only one exploited extensively is a moderately large deposit of black ferberite-bearing horn quartz in the Copeland mine, 2½ miles south of Magnolia.

No change in the character of the ferberite with depth has been observed, except that ore in some of the deeper shoots becomes slightly more "horny" near the bottom. Some veins, however, differ slightly in other features above and below ore shoots. Red hematite stain, earthy hypogene hematite, and occasional specularite are common in the tight parts of veins both above and below ore shoots, but hematite is more common below the shoots. Carbonate veinlets often accompany the hematite above ore shoots but are less common below, where they occur chiefly in nonhematitic horn veins. Fluorite and sulfides of iron, copper, zinc, and lead may accompany hematite below ore shoots, but the sulfides are found with hematite above ore shoots only when carbonate is also present. Above and below many ore shoots the veins are "horny" and brecciated, but the openings in brecciated and vuggy horn veins are commonly much larger below ore shoots than above them. Below ore shoots the openings contain pockets of white clay, which is largely beidellite. Above ore shoots openings may contain crusts of chalcedony, opal, and barite. The horn quartz below ore shoots on some of the larger veins is coarser grained than the "horn" accompanying ore or above it. Pyrite and other sulfides when unaccompanied by hematite are perhaps a little more common in the upper than the lower parts of ore shoots, but the distribution of sulfides in individual shoots is commonly erratic. In many veins "spots" of ferberite are irregularly distributed in horn quartz, rock or horn quartz breccia, or gouge below ore shoots. Similar "spots" are found above ore shoots but are commonly less abundant, and there is a greater tendency for the little ferberite present to be distributed as thin veinlets of black horn or ferberite in banded horn veinlets. The vein is generally more open near an ore shoot than elsewhere, and this condition is reflected in a heavier flow of water here than in the tighter parts of the vein. Many of the ore shoots and many of the bodies of horn quartz terminate abruptly downward or along the strike against gouge filling.

The principal factor determining the localization of an ore shoot was the relative permeability of the different parts of the fissure during mineralization, and this depended on the character of the wall rock and the displacement of the irregular walls of the vein fissure. Schist and altered granite readily broke down to impermeable gouge, whereas silicified rock, horn quartz vein filling, fresh granite, and pegmatite were reduced to open rubble. In the area of metamorphic rocks west of Hurricane Hill the tungsten ores are rarely found between walls of pure schist but commonly occur where schist containing many injections or a rib of pegmatite or aplite has been broken by a premineral fault. Within the Boulder Creek batholith the granite is more extensively altered than aplite or pegmatite, and movement of fissure walls tended to create more gouge in granite than where the fissure crossed an aplite or pegmatite dike; this condition is reflected in the occurrence of the ore.

Nearly all the ore shoots show a structural control directly related to the movement of the fissure walls and the course or the dip of the fissure. In most of the tungsten veins there is a strong horizontal component of movement, and in those veins in which the right-hand wall moved ahead there is a marked tendency for ore to occur where the vein course swings to the left (pl. 21 and fig. 70). Similarly, in a normal fault the ore occurs in the steeper parts of the vein (fig. 28), and in a reverse fault it occurs in the more gently dipping parts. The narrow wedge formed at the intersection of two veins or where a branch vein diverged from the main vein was more permeable than other parts of the vein. Several ore shoots are localized at the intersection of branch veins or of crossing veins (fig. 33). Unfortunately it is difficult to anticipate changes in dip and strike in advance of exploration, and where favorable structure can be located ahead of penetrations there is no way of foretelling whether it will carry ore, horn quartz, or barren gouge.

CONGER MINE

The Conger mine is about a mile northwest of Nederland, close to the western edge of the district. It is the deepest mine in the district, having been developed to a depth of almost 1,000 feet in the plane of the vein. It is opened by several adits and two shafts from which extensive levels are turned. The main or New shaft is vertical and was sunk 600 feet to level 7, from which an inclined winze was sunk 400 feet to level 11, which is 320 feet lower in elevation. Four levels were turned from the winze, 100 feet apart on the incline. The Old shaft, an incline extending to level 6, has been caved for many years.

The Conger mine has been the most productive mine in the Boulder County district. It was operated steadily by the Primos Chemical Co. and its predecessors from 1900 to the end of 1918; in 1938 it was reopened by the Vanadium Corporation of America and was operated until May 1945. The total output of the Conger mine is not known accurately, but incomplete records indicate that it has been at least 500,000 units of WO_3. The Bettig vein, which was worked largely through the Conger mine, has produced an additional 50,000 or more units of WO_3.

The Conger vein strikes N. 10° E. and dips about 65° E. and lies within a narrow irregular mass of pegmatite and Boulder Creek granite striking northwest. (See pl. 2). The vein is unproductive where it passes into the schist to the south and to the north. The Jumbo vein, which is 50 to 300 feet east of the Conger at the surface, dips 65°–70° E.; the Beddig, about 300 feet to the west, dips less than 50° E. All three veins fill fault fissures that were the site of repeated movement before, during, and subsequent to the ferberite mineralization. Though differing in amount, the direction of movement is the same, the east walls having moved down and to the south at an angle of about 35° or 45°. The Conger and Jumbo veins are in two eastward-dipping master fissures connected by several productive westward-dipping tension fractures lying between them. Within the mine the strongest vein between the Conger vein and the Jumbo is known as the Middle or Oregon vein. The veins are irregular in strike and dip, and the width of the fractured zone varies. The ore seems localized by the changes in course and dip favorable to the creation of openings in the vein; as the left-hand wall moved forward, ore shoots tend to occur where the vein swings to the right. The net slip on the Conger vein is approximately 27 feet and on the Middle vein about 18 feet.

Dikes of hornblende monzonite porphyry and of felsite are cut and displaced by the Middle vein, but as shown on pl. 20 the felsite was intruded after much of the movement had occurred along the vein. The felsite dike strikes west-southwest, but at its intersection with the vein it turns and follows it for a short distance. In two places felsite dikes are offset about 8 feet, suggesting that they were intruded when about half the total movement of the vein had occurred. A wide hornblende monzonite porphyry dike is cut and displaced by both the Conger and Middle veins.

The ore found in the Conger mine occurred in large lenticular masses separated by barren gougy zones. The largest ore body found was limited on the south by the contact of schist with pegmatite, but its northern limit was an irregular line that seemed to bear no relation to the distribution of the formations or to the intersection of the Conger and Middle veins. It coincided with the appearance of a gougy filling within the vein and a slight swing to the right. Most of the ore shoot was above level 5, and the vein was almost barren directly below the ore shoot on level 6, except close to the intersection with the Middle vein. According to G. W. Teal, who was superintendent of the mine during World War I, much ore was found in the Conger vein under Sherwood Gulch on level 5 of the mine. The richest ore was found on level 2 in a stope about 100 feet long, 100 feet deep, and 8 to 16 feet wide. Although not continuous, ore was found below this mass down to level 6, which was 550 feet below the collar of the New shaft. Below level 6 little ferberite was found, and the vein, according to Mr. Teal, consisted of pink horn quartz about 8 feet in width. The ore was medium-grained crystalline and massive ferberite, which occurred as a matrix to brecciated fragments of pegmatite, granite, monzonite, and horn quartz. Over considerable areas, however, brecciation of the vein matter occurred after deposition of the ferberite and resulted in ore that consisted of a breccia of ferberite and earlier vein matter cemented largely by the comminuted fragments and to a less extent by late chalcedony and horn quartz.

The ore in the Beddig, Conger, Jumbo, and connecting veins is of similar character and grade. It is reported that the Beddig ore shoot was localized by the intersection of the hornblende monzonite porphyry dike and the vein and that it pitched to the northeast at a low angle.

CLYDE MINE

The Clyde mine, about 1½ miles northeast of Nederland and 2,000 feet west-northwest of Hurricane Hill, is one of the more productive mines of the tungsten district. As shown in cross section (fig. 28), the ore shoots were found on two closely related overlapping veins—the Clyde main vein, which crops out at the surface, and the blind Footwall vein. The main vein was followed by an inclined shaft from the surface to a vertical depth of 253 feet. The third level of this shaft, at a depth of 211 feet, is known as the tunnel level and is worked through an adit, the portal of which is about 600 feet north of the shaft, on the south side of Sherwood Gulch. Two underground shafts 140 feet apart were sunk from the tunnel level on the Footwall vein. The eastern winze follows the vein to a vertical depth of 405 feet and the western winze to a vertical depth of 503 feet. Both winzes and the shaft are inclines. Only the tunnel level was accessible when the mine was studied by Lovering in 1930.

The country rock throughout the mine above level 4 is a medium-grained gneissic biotite aplite facies of the Boulder Creek granite cut by fine-grained dikes of alaskite and by irregular seams and masses of pegmatite. The aplite and pegmatite are much altered near the vein, but the alaskite is not. Near the vein the aplitic granite and pegmatite are much less abundant than alaskite, but where present they show a silicified casing enclosing the vein bordered by a soft bleached argillized envelope extending to distances of 15 to 30 feet from the main vein. Below level 4 schist of the Idaho Springs formation appeared in the eastern part of the workings, and on each succeeding level the schist was found farther west. From data given by Mr. Will Todd, superintendent of the mine, it is probable that the schist-granite contact dips about 32° W. below level 4 but has a much gentler dip above it.

Both the main Clyde vein and the Footwall vein follow well-defined premineral faults striking N. 70°–78° E. and dipping north. The main vein dips 78°–90° N. and overlaps the Footwall vein, which is found about 15 feet south of (below) it on the tunnel level near the shaft. At this level the main Clyde vein feathers or "horsetails" to the right as it is followed east, and in the crosscut adit 100 feet east of the shaft the only indication of its presence is a small group of northeasterly fractures in a broad sheeted zone along the strike of the vein. On the tunnel level the course of the Footwall vein is N. 70°–75° E., but in the lower workings the eastern part of the vein swings to N. 50° E. The swing to the northeast is coincident with a marked decrease in the dip and occurs about 50 feet above the schist-granite contact. On the tunnel level the Footwall vein is vertical throughout the 60 feet exposed in the stopes. It is probable that the Footwall and the main Clyde vein merge in a sheeted zone a short distance above the stope, but no conspicuous junction exists. As the Footwall vein was followed downward below the tunnel level its dip was at first steep to the north, but it gradually decreased until on the lowest level it was only 50°.

The veins follow premineral faults, which have been reopened many times by successive movement. The earliest movement was nearly horizontal, the right-hand wall moving forward. Later movements were progressively steeper, and during the movement that immediately preceded ore deposition the north wall moved westward and downward at about 45°. The total displacement of the walls is approximately 25 feet. These movements tend to produce openings where the vein steepens or strikes northeast.

The Clyde vein and the Footwall vein may be regarded as filling overlapping master fissures in different parts of the same fault zone. To the east of the main shaft the Clyde vein dies out, and the Footwall vein becomes the dominant fracture, but to the west, so far as it is exposed in the main tunnel level workings, the Clyde vein becomes stronger and the Footwall vein weaker. A similar overlapping takes place with depth, the main vein feathering out and giving place to the strong Footwall fracture. At the lowest level the Footwall vein has been followed 300 feet west of the western winze and is still a strong vein. Many nonpersistent seams diverge from the veins and are marked by seams of horn quartz and ferberite, and a few show molybdenite.

One ore shoot was worked on the main Clyde vein and two on the Footwall vein. Only a few narrow stringers of ferberite ore cropped out at the surface above the Clyde vein. The seams were vertical, half an inch to an inch wide, and trended northeastward diagonally across the vein. About 10 feet below the surface they passed through a northward-dipping seam of soft white material, below which the width of the ore shoot abruptly increased to as much as 6 feet and consisted of brecciated aplite and alaskite cemented by ferberite. The ore shoot reached a depth of 95 feet and extended 100 feet along the strike; the ore mined from it contained as much as 20 percent of WO_3 and probably averaged 5 percent. It bottomed abruptly on a flat seam of soft reddish-black material locally called graphite, though it was probably a mixture of hematite and clay. The vein continued with undiminished width to a depth of 300 feet, but no ore was found below this seam. This shoot lies directly above one of the important shoots found on the Footwall vein, not far above the place where the two veins probably merge in a sheeted zone.

The ore shoot cut on the tunnel level directly below the main Clyde shoot was 165 feet long and extended from 50 feet above the tunnel level down to the fourth level, 40 feet below. Its lower eastern tip joins the central part of another ore shoot, which pitches west at about 30°. The ore in both shoots was 3 to 6 feet wide, and near the upper end of the lower gently pitching shoot a maximum width of 14 feet was reported. Both ore shoots occur in steeply dipping parts of the vein, and the pitch of the lower shoot is controlled by the decreasing dip of the vein, which in turn seems related to the appearance of schist 50 feet below. The barren zone between the upper part of the gently pitching ore shoot and the western vertical shoot is not clearly related to any structural feature. This part of the vein is 5 feet wide and contains openings as much as 12 inches wide and several feet long coated with chalcedony, quartz, barite, clay, and a few thin crusts of ferberite (fig. 68, *F*). Apparently it marks a dead space between two diverging streams of solutions that deposited ferberite but became depleted of tungsten before all available space was filled. The gently pitching shoot was stoped for 55 feet above the tunnel level and through a vertical depth of 300 feet below the tunnel level, but the ore obtained at the bottom level was of lower grade than that near the top. The ore shoot, which extended beyond the Clyde property, was followed to the end line.

The vein filling of the Footwall vein is chiefly brecciated horn quartz cemented by later fine-grained quartz, chalcedony, and ferberite. Mr. Todd reported that outside the ore shoot on the levels below level 4 the vein filling was horn quartz as far east as the schist contact, where it changed to a soft gouge. Within the main ore shoot the ferberite occurred as a matrix to the horn quartz breccia, as solid veinlets and to a small extent as rounded masses in a loosely cemented breccia. Above the vertical ore shoot on the Footwall vein, the vein filling consisted of several generations of horn quartz cut by a seam of open friable breccia loosely cemented by fine-grained chalcedony. In the many crevices of the vein in this locality barite crystals coated with kaolinite and other clay minerals are abundant. Some late opal is also present, and pyrite is common, forming thin veinlets and disseminated grains through a dark horn quartz with which it is commonly associated.

COLD SPRING MINE

The Cold Spring mine is 3 miles northeast of Nederland and half a mile northeast of Hurricane Hill. It is the second or third largest producer in the district and was worked with less interruption than any other mine in the region until 1935, when it was closed. In 1943 a 75-foot shaft, the Cold Spring No. 4, was sunk a few hundred feet west of the Old shaft on a footwall vein. A small amount of stoping on the Cold Spring vein was done through this shaft before the workings broke into the Scogland stope, the upper western Cold Spring stope (fig. 70).

The Cold Spring mine is opened by two inclined shafts, the Old shaft, at an altitude of 8,365 feet, and the New shaft, 365 feet to the east, at an altitude of 8,329 feet. Six levels have been turned from the Old shaft and seven from the New shaft, the bottom level being 480 feet vertically below the collar of the New shaft. The fifth level, 327 feet below the collar of the Old shaft, is the most extensive in the mine, extending 1,750 feet east of the Old shaft and 400 feet to the west. A crosscut from level 7 extends southeastward for 507 feet from a point near the new shaft to the Orange Blossom vein, where it is connected to the bottom level of the Orange Blossom mine by a raise 134 feet high.

The country rock of the entire mine is dark-gray Boulder Creek granite. It is cut by a few small seams of pegmatite and aplite, but the walls of most of the drifts are of the uniformly coarse-textured gneissic Boulder Creek granite. The gneissic structure strikes northwest and dips about 40° NE. in most of the mine, though local variations in strike and dip are common.

The country rock on both sides of most of the veins is moderately hard and fresh in appearance for 2 feet or less. The hard "casing," as it is called by the miners, is generally thinner than the vein filling; for example, where the Cold Spring vein is 5 feet thick the hard casing commonly is 15 to 20 inches thick. The casing is bounded sharply by an envelope of soft altered rock, which may be as much as 30 feet thick. Although the change from the hard casing to the soft envelope is sharply marked, the outer edge of the envelope grades into fresh unaltered rock through a transition zone of appreciable width. There is little difference in the appearance of the altered rock in the inner half of the envelope, but the maximum alteration is generally found about a third of the distance out from the casing. The plagioclase crystals are the most conspicuously altered minerals; they are changed to chalky white pseudomorphs, which contrast strongly with the fresh black biotite. The orthoclase crystals are much less altered than the plagioclase crystals but are dull and less lustrous than in the hard casing. The quartz is unaltered.

When first opened, the envelope of altered rock stands well, but after a time it gradually disintegrates and begins to slough into the crosscuts. The alteration of the envelope is almost solely argillic; beidellite is abundant in the outer part of the zone, and dickite is prominent close to the casing. The magnetite of the granite is changed to hematite in the inner part of the argillized envelope and to pyrite in the sericitized zone. The hard casing is moderately silicified, and the clay is largely replaced by sericite and hydromica; locally adularia, goyazite, and pyrite are present.

The Cold Spring vein strikes about N. 75° E., dips steeply north, and follows a premineral fault the north wall of which moved west and downward at about 30°. The vein is a strong well-defined fissure as far west as it has been explored in the Cold Spring mine and continues unbroken for nearly 600 feet east of the New shaft. Farther east it continues in a zone of overlapping fissures, which are found farther and farther north as the vein zone is followed eastward (pl. 21). Throughout its length branch veins diverging at small angles from the main vein are common. Almost all these branching veins trend slightly more northeastward than the main vein and are more common in the hanging wall than in the footwall. Although its average strike is about N. 75° E., the course of the vein ranges from N. 83° E. to N. 68° E. west of the Old shaft, and farther east it ranges from N. 80° E. to N. 57° E., much of it being close to N. 67° E. In most places the dip of the vein is 65°–85° N., but locally it is vertical or steep to the south. The many branching minor veins or "feeders" generally strike from N. 45° E. to N. 55° E. and dip steeply north. Some minor veins in the hanging wall strike approximately parallel to the Cold Spring vein but are vertical or dip steeply south.

There are few faults in the mine later than the Cold Spring vein, but some of the repeated movements recorded by brecciated vein filling locally followed diverging fissures for short distances and then broke back into the main vein. As a result the main vein is in some places apparently faulted by fissures that prove to be only branches elsewhere. On the fifth level, 310 feet east of the New shaft, the Cold Spring vein is offset by a fault that parallels the northeasterly branch veins nearby. The eastern segment of the vein is offset 5 feet northeast of the western segment. The fault flattens greatly near the shaft, where the north side apparently moved down, a movement similar to that on the Cold Spring vein.

Nearly all the branch veins formed in response to the same stresses and approximately at the same time as the main vein. In one branch vein, about 30 feet north of the main Cold Spring vein on the third level, the north wall moved down and east. As this vein contains ferberite ore in fresh unaltered rock, the fissure that it fills was probably formed later than the main period of movement responsible for opening the Cold Spring fissure.

Three general types of vein filling are present in the Cold Spring vein—the barren unmineralized unsilicified gouge, the barren fine-grained horn quartz, and the ferberite and quartz filling of the ore shoots. Commonly the barren and unsilicified parts of the vein are marked by one or more seams of clay gouge 3 to 12 inches thick. Most of the gouge is light gray, but thin seams of brick-red clay gouge are common, which owe their color to finely disseminated hematite. This red gouge is somewhat more common near ore shoots than in other parts of the vein. The horn filling shows a great variety in its color and occurrence. In some places only one kind of quartz is present, but in most places the repeated movements have brecciated the filling several times, and many generations of fine-grained quartz can be seen. The most common types are the early gray and early white "horn." Locally the less common green, red, brown, or black "horn" is abundant, and in a few places early ankerite is present. The various types of quartz are not directly related to ore occurrence, although the later varieties, such as the green (goyazite) and black (ferberite or pyrite) horn quartz, are more common near ore shoots than at other places. The ore occurs as moderately fine grained branching masses cementing a breccia of horn quartz and wall rock. It filled open spaces with almost no replacement of breccia fragments or country rock. Some well-crystallized ferberite occurs in vuggy openings, but the bulk of the ore is compact massive ferberite, which completely fills the openings of the vein. Dickite, kaolinite, and banded chalcedony also occur with the ore, resting on it in druses or veining it and the nearby country rock.

Four ore shoots have been found on the main Cold Spring vein and several small ones on nearby branch veins and related fissures. Only one of the four cropped out, the other three remaining unknown until discovered during underground development (fig. 70). All four shoots occur in segments of the vein that trend more to the northeast than those at either end of the ore shoot, and all have a moderately steep dip. As noted earlier, the north wall moved downward and westward, making the steeper parts of the vein more open than the rest and the segments that trend northeast of the average course more open than those striking more nearly due east.

Branch veins are much more common in the barren sections of the vein than along the productive parts. The presence of many minor fissures diverging from the main vein at a small angle suggests that the faulting was distributed between the main fissure and the minor fissures in these places, whereas the movement along those parts of the vein devoid of branches was concentrated along a single fissure, thus resulting in greater displacement of the walls. The ore shoots tend to occur where changes in the strike and dip of the vein are such that the movement of the walls would create open spaces and where much of the movement was concentrated along the vein fissure.

The vein filling below the Cold Spring ore bodies is generally tighter than above, but it is more open than in the barren parts of the vein at the sides. In some places the ore bottoms on gouge containing very little horn quartz, but more commonly a drift under an ore body exposes a wide seam of brecciated horn quartz through which surface water flows easily, making a wet drift. In the drift about 30 feet below the 1927 ore shoot small spots of ore appeared in the "horn." These spots were small and widely spaced in the drift but became more and more abundant as the ore was approached, finally merging into one another and forming the bottom of the ore shoot.

Above an ore body the vein is commonly open and vuggy and generally shows a late seam of brecciated "horn" cemented by white friable fine-grained quartz. In the vugs of the vein over some of the ore shoots banded chalcedony, kaolinite, and some clays with low refractive indices occur. Spots of ore are common above the ore shoots and are irregularly distributed through a considerable distance (fig. 70). The spots over the 1918 shoot were no more abundant close to the ore shoot than they were 100 feet above it; locally they were so abundant as to form low-grade ore for several feet, but this concentration was haphazard and had no relation to the proximity of the underlying ore shoot.

There was no gossan over the ore shoot at the Old shaft, although the horn quartz breccia at the sides of the open pit was iron stained and slightly porous, and limonite crusts were abundant. The iron-stained country rock graded into fresh rock about 150 feet below the surface, but signs of oxidation persisted to slightly greater depth. The ore shoot itself did not come to the surface but pinched to a feather edge of bright fresh ferberite about 12 feet below. It thickened rapidly as it was followed downward, and at a depth of 40 feet it contained a 4-foot thickness of 18 percent WO_3 ore. The "horn" was as iron-stained as the nearby country rock, but the ferberite crystals were apparently fresh. It is probable that the iron stain was caused by the de-

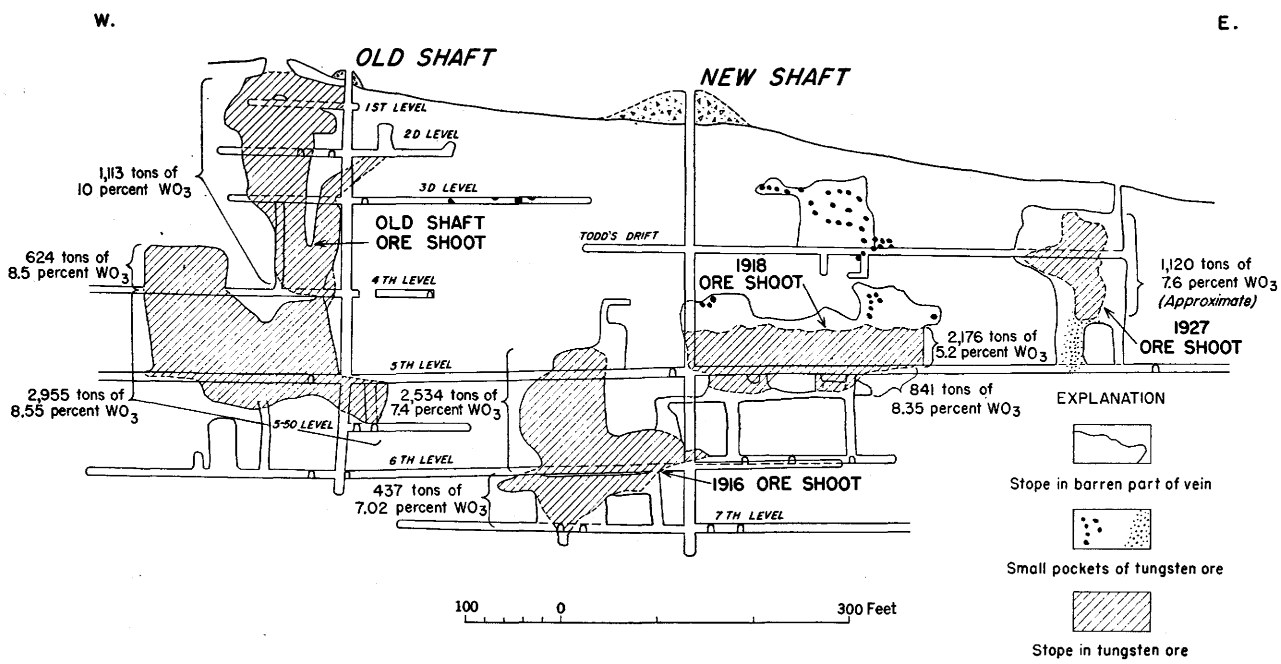


FIGURE 70.—Longitudinal section of the Cold Spring vein, Boulder County tungsten district.

composition of the ferruginous minerals in the granite and of the small amount of disseminated pyrite found in the sericitized casing and in some of the "horn."

In the westernmost part of the mine schist is more prominent and gneissic aplite less prominent than to the northeast. As the vein swings to a more westerly course, the dip becomes less than normal, and the vein appears to be weaker than to the east. In the northeastern part of the mine the vein is very strong and has a more northerly course than the average of the barren parts; the possibilities of finding ore by further exploration in this direction are therefore encouraging.

ROGERS NO. 1 AND ROGERS NO. 11 MINES

The Rogers No. 1 and Rogers No. 11 mines are in the central part of the tungsten belt. They are situated on the south side of North Boulder Creek, not far west of Gordon Gulch, and are approximately 1,500 feet south-southwest of Switzerland Park at altitudes of about 8,075 and 7,800 feet. The Rogers No. 1 mine is one of the more productive mines of the district, and the two mines together have had an output of nearly 40,000 units of WO_3.

As shown in figure 35, the Rogers No. 11 vein is reached by a 140-foot crosscut tunnel, from which a drift extends 450 feet to the west and 50 feet to the east. In the eastern part of the mine the strike of the vein is N. 75°–85° E., and the dip is 67°–88° N.; in the western part the strike swings to N. 65° E., and the dip is steeply southward. Displacement of a flat pegmatite indicates that the north wall is downthrown, and grooves suggest that it moved down and westward at 25°–30°, but because of two periods of movement on the vein correlation between the displacement and the grooving cannot be safely made.

The Rogers No. 11 vein is an example of the large and relatively unproductive horn quartz veins rather common in the Boulder County district. It is a composite vein consisting of 2 to 3 feet of gray horn quartz that was fractured and brecciated by later movement, after which a thin vein of black horn and ferberite was introduced. The younger vein winds through and along the older gray horn vein. The black horn and ferberite filled only part of the openings in the gray horn, and open cavities several feet long and as much as a foot wide are common in the younger vein. Small kidneys of galena were found in one or two of these cavities. The wide and persistent early quartz vein and the weak ferberite vein associated with galena suggest that the Rogers No. 11 fissure was open and had connection with the mineralizing solutions only during an early and a late stage of the mineralization period. After deposition of the gray horn the fissure was apparently dammed off from channels of supply, and although later movement produced ample openings only a little ferberite and black horn was available to fill them.

The Rogers No. 11 mine has supplied a relatively small amount of tungsten in horny ore difficult to mill.

The Rogers No. 1 mine consists of two tunnels 300 and 600 feet southwest of and 140 and 275 feet above the Rogers No. 11. The entire production has come from the upper tunnel and from open cuts above it. The vein strikes N. 35° E. and dips 74°–80° N. in the upper tunnel and dips 80°–88° N. in the lower tunnel. It follows a normal fault, the north wall of which moved down and northeast at about 30° for about 20 feet. As shown in figure 35, the Rogers No. 1 vein and a branch of the Rogers breccia reef intersect near the portal of the upper tunnel and near the southwest end of the lower tunnel. The north-northwestward trending reef is a wide sheared or brecciated silicified zone that contains disseminated pyrite near the Rogers No. 1 vein and abundant hematite beginning about 100 feet southeast of the vein. The reef is, in general, older than the vein and is clearly offset by the vein in the lower tunnel, but later movement on the reef broke the vein, offsetting the northeastern segment 15 to 25 feet to the south. With renewed movement on the Rogers No. 1 vein a new connection across the reef was made between the offset segments of the vein by a split from the vein on the southwest side of the reef. A small amount of late reverse movement on the reef has displaced the No. 1 vein about 12 inches in a direction opposite to the first movement in the upper tunnel.

Near the portal of the lower tunnel the Rogers No. 1 vein is gougy, but it becomes horny after it is joined by a horn vein that comes in from the east about 40 feet from the portal and remains a strong horn vein through most of the lower workings. The horn vein that comes in from the footwall has the strike and appearance of the Rogers No. 11 vein and is approximately on its projection. Although the main horn quartz seam turns and follows the Rogers No. 1 fracture, an actual crossing of the Rogers No. 1 and No. 11 fractures may be represented by a smaller vein that branches from the Rogers No. 1 in the hanging wall 100 feet from the portal. Southwest of the junction with the Rogers No. 11 vein the Rogers No. 1 vein contains 1 to 3 feet of gray to dark gray horn quartz breccia, with local seams and pockets of black horn, and a trace of ferberite, pyrite, and copper stain. Southwest of the Rogers breccia reef in the lower tunnel the vein is less "horny" and contains veinlets of black horn and a little ferberite.

In the upper tunnel the segment of the Rogers No. 1 vein northeast of the Rogers reef is gougy and locally indistinguishable in the crushed pegmatite near the reef. Immediately southwest of the reef the wide brecciated zone between the new split of the vein and the end of the faulted segment is gougy but contains brecciated black horn and a little ferberite. The main Rogers No. 1 ore shoot began about 50 feet southwest of the reef and extended about 200 feet southwestward along the vein. The richest part of the shoot was near the surface, where the vein steepens to a vertical dip and locally dips steeply southward. The flatter dip in the tunnel is associated with leaner ore, and stopes below the tunnel extend to a maximum depth of only 40 feet. The cuts or open stopes near the surface indicate that ore was mined through widths of as much as 12 feet, and the richness of the ore is attested by the fact that 33,280 units of WO_3, probably worth about $300,000, were obtained from only 3,277 tons of ore mined prior to 1926. Southwest of the ore shoot the Rogers No. 1 vein, as shown by bulldozer trenches, swings to a more southerly course. This swing to the left on a vein along which the left-hand wall moved forward causes the vein to tighten and the ore to disappear.

The barren or nearly barren character of the Rogers No. 1 and No. 11 veins northeast of the Rogers breccia reef is in marked contrast to the richness of the Rogers No. 1 vein southwest of the reef. Both of the veins northeast of the reef are strong "horn" veins, but the Rogers No. 11 vein shows clearly that the horn represents an early stage of mineralization and that the veins were dammed off during the later ferberite-depositing stage. Considering the contrast in the veins on the two sides of the Rogers reef and the postvein movement on the reef, it seems probable that the late movement on the reef accounted at once for the damming off of the veins to the northeast and for the opening of the Rogers No. 1 vein to the southwest. If this is true, it is improbable that any large ore bodies are present on the Rogers No. 1 and No. 11 veins in the area between the Rogers reef and the Rogers No. 11 mine. On the other hand, the Rogers No. 1 vein southwest of the reef in the lower tunnel seems a worthy prospect, and the presence there of banded black and gray horn and a little ferberite rather than massive horn breccia is encouraging.

The Rogers No. 11 vein intersects an eastern branch of the Rogers breccia reef in a covered and unexplored area about 500 feet east of the Rogers No. 11 mine. The relation of the vein to this reef is analogous to that of the Rogers No. 1 vein to the western branch of the Rogers reef, and exploration of the Rogers No. 11 vein near its intersection with the reef is therefore warranted.

OTHER MINES

Data on other mines in the district are given briefly below:

BETTIG

Development.—Shaft and levels; 5th level joins 3d level of Conger.

Production.—Prior to 1914: 250 tons of concentrates worth $90,000. Subsequent to 1914: "Considerable tonnage."

Veins.—Bettig: Strike, N. 30° E.; dip, 45° SE.; width, 1 inch to 3 feet. Joins Conger vein at 5th level and is mined at depth through Conger mine. Sperry: Strike, southerly; branch of Bettig.

Wall rock.—Pegmatite, granite, and schist, cut by dikes of felsite and hornblende monzonite porphyry.

Ore and sulfide minerals.—Chiefly ferberite, a little marcasite and sphalerite.

Gangue minerals.—Wall rock breccia and chalcedonic quartz.

Changes with depth.—Sperry vein barren below 5th level of Bettig.

Ore shoots.—Pitched northeast at a low angle. Localized by intersection of hornblende monzonite porphyry dike and vein.

Tenor.—Sperry vein contained good ore near surface.

EUREKA

Development.—Two tunnels, one at least ¾ mile long.

Vein.—Eureka: Strike, N. 55°–75° E.; dip, 75°–80° N., locally 85° S.; 1–2 feet wide in barren parts, 3 to 8 feet in productive parts. Vein is sheeted zone in soft chloritized and kaolinized granite. In productive parts sheeted granite seamed with ore consisting of granite and horn quartz fragments cemented by ferberite. On vein fissure south wall moved east and down at 15° to 20°.

Wall rock.—Boulder Creek granite and pegmatite. One wall marked by gouge. Strong kaolinic alteration. Biotite monzonite porphyry dike later than vein fissure.

Ore and sulfide minerals.—Ferberite and a little pyrite.

Gangue minerals.—Altered granite and horn quartz.

Ore shoots.—Ore in parts of vein having more northeast trend than average, as right-hand wall moved ahead.

MAMMOTH

Development.—Short tunnel and shaft 157 feet deep.

Vein.—Mammoth: Strike, turns from N. 25° E. to N. 80° E. in upper levels and from N. 25° E. to N. 40° E. in lower levels; dip, 50°–70° NW. Ore in veinlets in brecciated hornstone. Vein fissure a normal fault; north wall moved down and southwest at 40° Vein seems to continue into Milly vein south of Mammoth workings.

Wall rock.—Pegmatite and schist of the Idaho Springs formation, which strikes northwest and has synclinal structure. Pegmatite kaolinized and schist chloritized.

Ore and sulfide minerals.—Ferberite.

Ore shoots.—Best ore where vein had steepest dip. Stope on 150-foot level. Ore limited to those parts of vein where one or both walls are of pegmatite.

Tenor.—A little high-grade ore produced. Most of ore, when roughly sorted, contains about 13 percent of WO_3.

PEEWINK MOUNTAIN TUNNEL

Development.—Crosscut extending 500 feet northwest.

Veins.—Several veins cut by tunnel strike N. 55°–85° E., and dip south; 3 feet wide. Wall-rock alteration probably related to narrow but persistent northwest fractures that dip 65°–70° SW. These are offset by vein near breast of tunnel and are probably continuation of sheeted zone marked by breccia reef mineralization a few hundred feet to north on surface. Main northeast vein follows normal fault whose south or hanging wall first moved up and north at 45° for 15 feet, then straight down dip for 3 feet.

Wall rock.—Boulder Creek granite extensively altered near veins and in zone nearly coinciding with major part of tunnel. Silicified casing close to ore zones, with kaolinized envelope outside.

Ore and sulfide minerals.—Ferberite.

Gangue minerals.—Chalcedonic quartz.

Ore shoots.—Swing of vein to left, such as northeast course in lower level, highly favorable to occurrence of ore. Two veins near breast of tunnel extensively stoped.

PEEWINK "TUNGSTEN BLOWOUT"

Development.—Open pit and adit 35 feet below pit.

Veins.—Silicified north-south breccia reef few hundred feet to west. Strongly altered gougy zone associated with eastward-dipping reverse fault cut by adit. To south this fault is marked by silicified quartz breccia. Several small nonpersistent minor faults and slips parallel to reverse fault; these strike north and dip 20°–65° E.

Wall rock.—Boulder Creek granite, little altered except close to main fault zone.

Ore and sulfide minerals.—Ferberite.

Gangue minerals.—Quartz, some barite and kaolinite.

Ore shoots.—Open pit ore body 75 feet long, as much as 40 feet wide, and bottomed abruptly at not more than 60 feet below surface. Ore localized in zone of east to northeast fracturing between main fault and breccia reef. Ore solutions rose along main fault and spread into fissures of northeast fracture zone.

RAKEOFF MINE AND LILY TUNNEL

Development.—Inclined shaft 320 feet deep; Lily tunnel cuts vein at 325 feet from portal.

Production.—Reported to be large.

Vein.—Rakeoff: Strike, N. 80° E.; dip, 60°–75° N. North wall moved down and to west at 35° to 40°; vein and fault zone strong, but surface geology suggests vein fissure follows granite-schist contact of pre-Cambrian age. A second vein cut by Lily tunnel at 130 feet from portal strikes northeast and dips 50°–70° NW. A third vein cut by tunnel at 185 feet strikes northeast and dips nearly vertically. Ore in veins is brecciated granite cemented by ferberite.

Wall rock.—Boulder Creek granite and aplite, strongly kaolinized close to vein near both barren and mineralized parts.

Ore and sulfide minerals.—Ferberite.

Changes with depth.—Ore bottomed at depth of 200 feet.

Ore shoots.—Localized at intersection of Rakeoff vein and a northeast cross vein; most of ore occurring in fractured ground between the two veins just southwest of junction. Intersection of two veins pitches steeply northwest.

TUNGSTEN

Development.—Shaft 369 feet deep vertically, 396 feet on incline. Drift levels at 80, 180, 220, and 396 feet.

Production.—1907–9, $175,000.

Vein.—Tungsten: Strike, No. 50° E.; dip, 65°–75° N.; less than a foot to several feet wide. Vein follows normal fault; north wall moved down and southwest at 45° to 50°; displacement, 10 to 50 feet. Vein is straight gouge-filled fissure in barren parts. In western part of mine more schist and less aplite than to the northeast; in western part vein swings to more westerly course, dip flattens, vein appears to feather out. Northeast part of vein is strong and has more northerly course.

Wall rock.—Biotite gneiss of Idaho springs formation, containing layers of aplite and pegmatite. Near ore shoots walls are kaolinized for several feet from vein.

Ore and sulfide minerals.—Ferberite.

Ore shoots.—Occur where vein is a sheeted zone several feet wide and dips steeper than 68°. Best ore where course of vein is more northerly than average.

Tenor.—1907–9: Ore averaged 32 percent of WO_3, crude. 1917–18: Ore mined from stope on 180-foot level averaged 5 percent of WO_3.

MAGNOLIA DISTRICT

LOCATION AND HISTORY

The Magnolia mining district lies about 5 miles due west of Boulder and about a mile south of Middle Boulder Creek. The district is about 1,400 feet above the valley bottom. As shown on plate 22, most of the productive veins crop out in an area of less than a square mile, and the outcrops range in altitude from approximately 7,000 feet at the Graphic vein to about 7,700 feet at the Kekionga shaft a mile to the southwest. The district is accessible over a good automobile road from Boulder. The geology was described and the history given in a thesis by Wilkerson[43] in 1937, and descriptions and maps of most of the mines accompany his report. The descriptions of the mines given on pages 229–234 are largely taken from this thesis.

Gold-telluride ore was found on the Magnolia vein in 1875, and during the next 2 years nearly all the veins now known in the district were discovered. Because of the high tenor of the ore and its erratic distribution in rich pockets, company mining and mining by absentee landlords has seldom been successful, and the district does not have a large output on record. Monroe and Wolff[44] credit it with a total output valued at $2,815,000 through 1905, of which $1,000,000 is ascribed to the Keystone and Kekionga mines, as shown in the table below.

Reported value of output, 1875–1905, of mines in the Magnolia district

American	$125,000
Cash	150,000
Dardanelle	40,000
Graphic	40,000
Kekionga	500,000
Keystone	500,000
Lady Franklin	160,000
Lamon, Ward H	50,000
Little Pittsburg	40,000
Lowell, Ben C	50,000
Magnolia	400,000
Mountain Lion	250,000
Pickwick	50,000
Poorman	60,000
Sac and Fox	150,000
Senator Hill	250,000
Total	2,815,000

The writers feel that the figures given above may be somewhat optimistic but are of real use in presenting the relative values of output from the different mines. From 1906 to 1936 the district has yielded ore valued at a little less than $200,000, bringing the total to about $3,000,000.

GEOLOGY

The country rock of the district is Boulder Creek granite, the gneissic structure of which strikes northeast and dips northwest. The Livingston breccia reef, one of the early persistent northwesterly faults whose influence on the ore deposits has already been described,

[43] Wilkerson, A. S., Geology and ore deposits of the Magnolia mining district, Boulder County, Colo.: Thesis, University of Michigan, 1937.

[44] Monroe, Edward, and Wolff, J. R., History and production of the gold fields of Boulder County, Colo., p. 5, 1906.

passes through the district about a quarter of a mile west of the town of Magnolia, trending about N. 25° W. (pl. 22). In this region the breccia reef is paralleled by an early diabase dike known as the Iron dike. A similar but more ferromagnesian dike is reported as striking in an easterly direction from Magnolia to a point near Boulder, about 2½ miles southwest of the University of Colorado,[45] but neither the writers nor Wilkerson were able to find it.

ORE DEPOSITS

All the ore deposits in the Magnolia district are fissure fillings; mineralization has been chiefly of the gold-telluride type, but some tungsten ore has been mined. Gangue minerals are present in only minor quantity and consist of little but light-colored to dark-colored varieties of extremely fine grained quartz or "horn." The sheared and brecciated granite in the veins is locally silicified or cut by thin closely spaced branching veinlets of horn quartz, but in many places the gold-telluride ore is in little-altered granite along a premineral fault unaccompanied by gangue minerals. The district is noted for the variety of telluride minerals found and for the unusual association of gold telluride with tungsten, molybdenum, and vanadium minerals. Native gold, native tellurium, tellurite, ferro-tellurite, melonite, sylvanite, hessite, petzite, coloradoite, altaite, calaverite, lionite, magnolite, nagyagite, henryite, ferberite, molybdenite, and roscoelite and some galena, sphalerite, pyrite, marcasite, calcite, and fluorite have been found in the district. The chief ore mineral is sylvanite.

The presence of alunite in the ferberite veins and of marcasite in the telluride veins has led Wilkerson to suggest that the ore-forming solutions were originally acid in character and deposited the metallic minerals when they became neutral or alkaline.

According to Wilkerson[46] the telluride minerals commonly occur in small blades that average between 1.5 and 2.5 millimeters in length and about 0.5 millimeter in width, but in many places the small blades are so abundant and closely intergrown that they resemble single large prismatic crystals. Ferberite is the only tungsten mineral found. It forms blades averaging 0.2 millimeter in length and 0.1 millimeter in width.

A study of the paragenesis indicates several periods of mineralization during which the following minerals were deposited in approximately the following order: (1) Sericite, quartz, pyrite; (2) quartz; (3) quartz and hematite; (4) quartz; (5) molybdenite; (6) fluorite; (7) quartz-pyrite-alunite, ferberite, sylvanite, calaverite, petzite, hessite, coloradoite-altaite, native gold; (8) quartz, ferberite; (9) quartz-pyrite-marcasite, sphalerite, chalcopyrite; (10) chalcopyrite, bornite; and (11) calcite. The relations of ferberite to sylvanite are shown in figure 74, *A*, *B*.

Silicification and sericitization are locally prominent along the walls of veins, but wall-rock alteration has been relatively slight in the Magnolia district. In the wall rock of the telluride veins silica has been introduced close to the veins and makes up as much as 10 percent of the rock in the form of small veinlets extending a few inches to about 3 feet from the vein. Small stringers and finely disseminated pyrite accompany the quartz in some places, but the two zones are not necessarily coextensive. Sericite is found within and beyond the limits of silicification, and the bulk of the sericite is within 3 or 4 feet of a vein. In the zones of most intense sericitization the microcline has remained unattacked, although plagioclase has been completely altered. Carbonatization is coextensive with sericitization outside the zone of quartz.

Silicification is more prominent in the wall rock of some tungsten veins than along the telluride veins; locally 80 percent of the immediate wall rock consists of introduced quartz, but in few places does this quartz extend into the wall for more than 1 or 2 feet. The sericitic alteration zone is similar to that along the telluride veins but is largely outside the zone of silicification.

The strongest veins in the district trend between due west and N. 70° W. and include the Graphic, Beggar, Senator Hill, Keystone-Mountain Lion, and Kekionga-Magnolia. The Interocean and American Eagle veins are short important cross veins with a northeasterly trend. The distribution of the veins is indicated on plate 22.

Most of the gold-telluride veins strike west or northwest. Northeastward-trending telluride veins are not common and are commercially unimportant, but most of the tungsten veins trend east or east-northeast and dip steeply north or south. Many veins are only a few hundred feet long, and only a few persist for a thousand feet along the strike, but the longest vein in the district, the Kekionga, has been traced for 6,000 feet. The premineral faults in which the veins formed had a strong horizontal component of movement, and throughout the district the right-hand walls moved ahead. With the exception of a little gold-telluride and ferberite ore in the Copeland fault, 2½ miles south of Magnolia, the ore deposits all lie in a zone about a mile and a half long and half a mile wide, which extends northeastward through the town of Magnolia, beginning a little west of the Livingston breccia reef southwest of town and ending at another breccia reef half a mile northeast of town. This reef is probably an offshoot of the Hoosier breccia reef, which lies a mile and a half east of Mag-

[45] Whitaker, M. C., An olivinite dike of the Magnolia district and the associated picrotitanite: Colorado Sci. Soc. Proc., vol. 6, pp. 104–109, 1898.

[46] Wilkerson, A. S., op. cit.

nolia. The ore zone trends nearly at right angles to the strike of its component veins. It is probable that the veins reflect the presence of a deep underlying northeasterly cross channel, but if such a fissure is present it is quite probable that it lies below the zone of ore deposition.

The greatest proved vertical range of gold ore in a single shoot is about 400 feet, but the gold ores of the veins of the Acme mine lie at an altitude of approximately 6,200 feet, and similar ore has been found in the Kekionga vein at an altitude of about 7,800 feet—a vertical range of 1,600 feet. Tungsten ore has been mined in the Dove vein at an altitude of 6,400 feet and in the Kekionga vein at about 7,650 feet, a vertical range of about 1,250 feet, although ferberite has not been found to persist in a single ore shoot for as much as 100 feet vertically.

Oxidation effects extend locally to a depth of at least 200 feet but in most places are not well developed below 50 feet. In the upper part of the oxidized zone much rusty gold was found. This gold was invariably very fine grained and in part not visible to the naked eye. It was probably formed by the leaching of tellurium and silver and the residual concentration of gold close to the outcrop. No change in the primary minerals with depth has been noted in the district, but the workings have all been relatively shallow.

Although most of the persistent veins have comparatively steep dips, many of the smaller fractures that contain rich pockets have dips of only 30° or less. The best ore bodies have been found close to intersections with cross veins or at the junction of two veins converging at small angles. Both the gold and ferberite are localized in shoots and pockets that show a marked lack of persistence. Many of these shoots have no visible limit, and the ore can be blocked out only by careful sampling. Ore deposition was most common at the intersections of fissures, especially where the junctions are not marked by much gouge. The ore shoots in the Acme-Audophone, Ben C. Lowell, and Poorman veins are localized at the junctions of fissures. Ore shoots in the Kekionga and Keystone mines are in part related to branch fissures but are largely controlled by the presence of open parts of the vein due to premineral movement of the walls. An ore shoot in the Ben C. Lowell vein lies just under the diabase Iron dike, which apparently acted as a guide to solutions rising in the vein. The largest individual ore shoot in the district is in the Keystone vein. This shoot is reported to be 500 feet in pitch length, 150 feet in stope length, and as much as 20 feet wide. It pitches 55° SE. Most of the ore shoots are less than 250 feet in pitch length and less than 3 feet in width, and a great many range from 20 to 60 feet in pitch length, 10 to 30 feet in stope length, and are less than a foot in width. The general ratio of pitch length to breadth varies from 3 : 2 to 4 : 1. Nearly all the shoots are lenticular and pitch about 55° SE. The tungsten deposits are generally much smaller than the telluride ore shoots. Most of the ferberite mined has come from pockets less than 40 feet in pitch length, 15 to 20 feet in stope length, and no more than 5 feet in width.

FORTUNE MINE

The Fortune mine is a quarter of a mile N. 35° E. of the Magnolia school house, at an altitude of approximately 7,400 feet. Much of the stoping was done in the eighties immediately after discovery of the ore-bearing vein, but a few hundred tons of ore containing a quarter of an ounce to 1½ ounces of gold to the ton were mined between 1932 and 1936. The mine is opened by a shaft, from which levels have been turned at depths of 66, 130, and 180 feet. The vein follows a fissure zone in granite along the contact of a narrow chloritized hornblende syenite dike striking about N. 50° W. and dipping 50° NE. (See fig. 71.) The average width of the vein is about 12 inches, and the syenite dike that forms its footwall is 8 to 18 inches thick. A few feet southeast of the shaft on the 130-foot level the vein is displaced approximately 12 feet by the Elephant shear zone, which is here 3 to 18 inches wide and is gougy and barren. The intersection of this shear zone and the vein pitches southeastward at a low angle and is probably the controlling factor in localizing the ore shoots. The principal gold-bearing mineral is sylvanite, which normally occurs in small quartz-lined vugs and is invariably accompanied by pyrite. Small amounts of free gold have been found on all the levels, and rusty gold is reported to be present to a depth of 140 feet.

GRAPHIC MINE

The eastern part of the Graphic vein trends N. 65° W., and west of the Graphic shaft it strikes N. 80° W. It dips steeply south everywhere. It is commonly 1 to 3 feet wide and locally contains pockets of silicified material reported to assay from 1¼ to 5 ounces of gold to the ton. According to George,[47] ore from the Graphic mine contained ferberite that was distinctly later than sylvanite and quartz; it formed a drusy crust on porous quartz that contained disseminated sylvanite well below the surface.

POORMAN MINE

The Poorman vein is a short distance south of the Graphic mine and about four-tenths of a mile N. 8° E. of the Magnolia school. It supplied some high-grade ore in the seventies.[48]

[47] George, R. D., The main tungsten area of Boulder County: First Rept. Colorado Geol. Survey, p. 76, 1909.

[48] Bradford and Myers, Mining notes from the Magnolia district, Colo.: Eng. and Min. Jour., vol. 23 pp. 188–189, 1877.

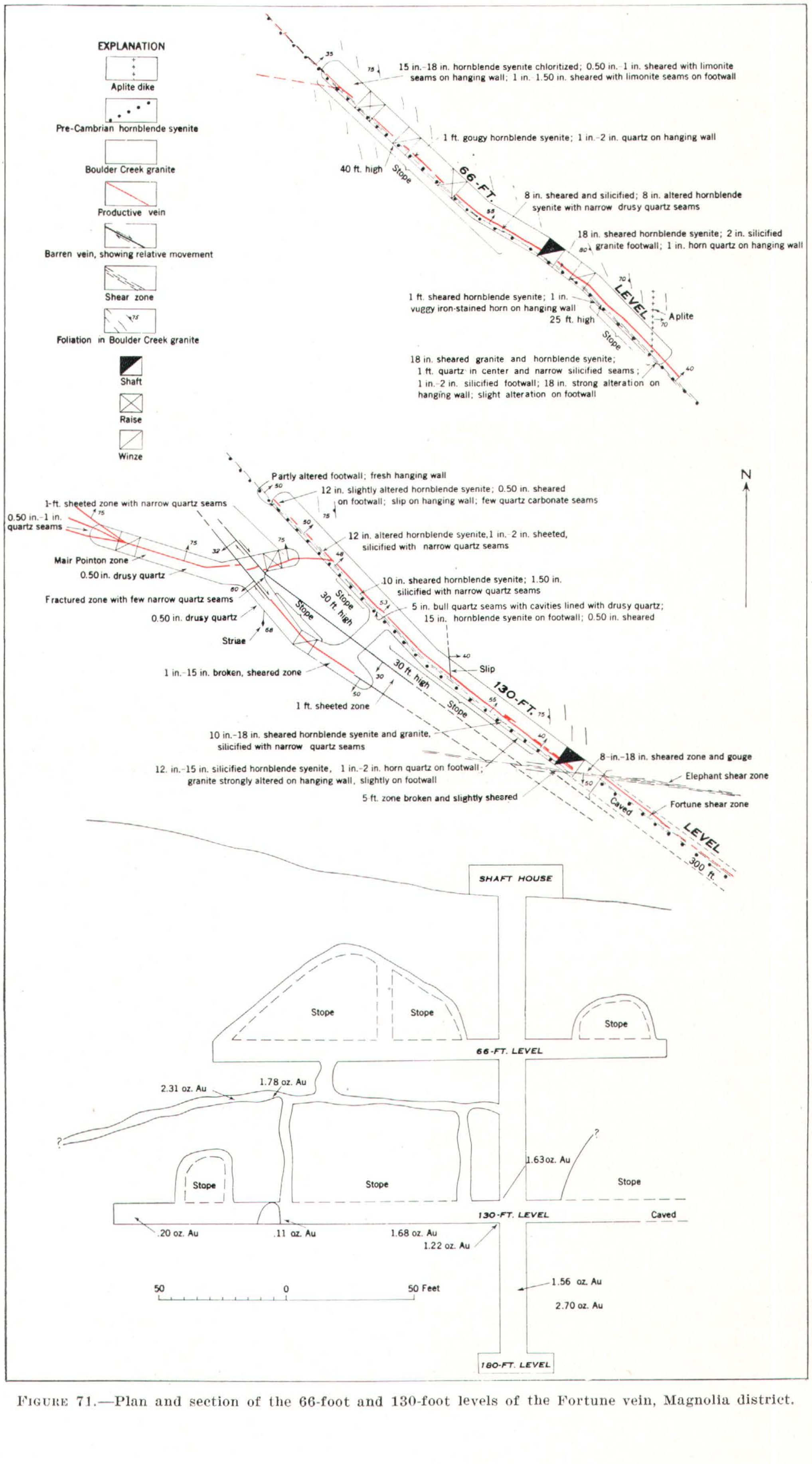


FIGURE 71.—Plan and section of the 66-foot and 130-foot levels of the Fortune vein, Magnolia district.

Wilkerson [49] estimates the value of its total output to be in excess of $200,000 (approximately 10,000 ounces of gold). It has been worked intermittently since its discovery in 1876. The tenor of the ore sent to the Boulder Sampling Works from 1904 to 1933 commonly ranged between 1.5 and 5 ounces of gold and 0.1 to 4 ounces of silver to the ton, but small lots of exceptional ore contained several hundred ounces of gold to the ton. The total gross weight of these shipments was 737 tons, from which 2,174 ounces of gold were recovered; thus the tenor of the ore was 2.95 ounces of gold to the ton.

The mine is opened by a shaft and two adits at altitudes of 7,050 and 7,252 feet. The strike of the Poorman fissure zone ranges from west to N. 35° W. but averages N. 45° W. The dip is 75° to 80° S. In most places the vein is 1 to 4 inches wide but locally attains a width of 3 feet. It is gougy and poorly mineralized throughout much of its length. The Pensacola vein strikes N. 25° E., dips 70° S., and cuts the Poorman vein about 80 feet southeast of the Hallett shaft. Most of the ore taken from the mine has come from the Poorman vein close to its intersection with the Pensacola, but some ore has been stoped in the Pensacola itself, just northeast of its intersection with the Poorman. In the upper levels most of the ore has been found east of the Pensacola vein, but in the winze sunk from the lower adit, 90 feet deep, nearly all the ore has come from northwest of the intersection with the Pensacola. The high-grade ore is said to be 1 to 4 inches wide and to have yielded 30 to 250 ounces of gold to the ton. The vein on either side of the high-grade streak is mineralized through a width of 1 to 3 feet.

SENATOR HILL AND OPHIR VEINS

At Magnolia the Senator Hill vein strikes about N. 75° W., and is joined by the Ophir vein, which strikes N. 87° E. In each of these veins the ore ranges from 2 to 20 inches in width and occurs in lenses separated by barren segments of the vein. According to the Colorado Mining Directory of 1883,[50] the output of the Senator Hill and Ophir veins, in which the ore occurred in rich pockets, was valued at $75,000 prior to August 1882. This mine has been one of the most productive in Magnolia and is credited by Wilkerson with an output valued at more than $250,000 in gold.

The mine is opened by two shafts, the Ophir and the Senator Hill, from which three levels are turned at depths of 40, 80, and 140 feet. The property includes four veins, the Senator Hill, Ophir, Half Circle, and Fortune. The Ophir vein strikes N. 87° E., and dips 70° N. and is about 8 inches wide. The Senator Hill vein, which is probably the eastern extension of the Elephant vein of the Fortune mine, strikes N. 75° W. and dips 80° N. The Fortune vein strikes N. 42° W. and dips 60° N., and is about 2 feet wide. The Half Circle vein strikes N. 70° W. in the vicinity of the Senator Hill shaft and swings to N. 40° W. about 125 feet west of the shaft; it dips 60° N. Both the Ophir and the Senator Hill shafts are on the Ophir vein, and the Fortune vein intersects the Ophir a short distance east of the Ophir shaft. The Senator Hill vein, the Half Circle vein, and the Ophir vein all joint at the Senator Hill shaft, and the most important ore shoot is reported to have been at this intersection. Another ore shoot was localized at the intersection of the Ophir and Fortune veins.

AMERICAN EAGLE-INTEROCEAN VEIN

The American Eagle and Interocean claims are probably on the same northeastward-trending cross vein just east of Magnolia. In the American Eagle claim the vein trends N. 50°–65° E., but just south of the Interocean it bends northward and strikes N. 15° E. According to Bradford and Myers [51] the vein in this claim has a pay streak 14 inches wide, shown by mill runs to have a value of $80 to $160 to the ton in 1877. According to Burchard,[52] a shipment of 2,865 pounds had a value of $507.40.

LADY FRANKLIN MINE

The Lady Franklin mine is just south of the main Magnolia highway near the place where the 7,200-foot contour crosses the road. The Lady Franklin vein was found in 1875 and was developed intermittently during the next two decades. According to Wilkerson [53] the value of the mine's output between 1896 and 1901 was about $51,000, and the entire output probably amounts to about 8,000 ounces of gold.

The mine is opened by an inclined shaft with levels at depths of 80, 140, and 200 feet, with a total footage of approximately 850 feet. The vein trends northwestward and in general dips about 70° NE., but its strike ranges from N. 45° W. to N. 80° W. and its dip from 55°–80° NE. (fig. 72). Striations on the walls pitching 58° NE. indicate that the left-hand wall moved ahead. The telluride seams have widths ranging from a small fraction of an inch to slightly more than 1 inch and are found in a fissured zone about 2 feet wide. The ore shoot seems to dip eastward at an angle of about 50° and is apparently related to changes in the dip of the fissure zone and to changes in the direction of foliation in the gneissic granite walls (fig. 72). The shoot has a pitch length of at least 200 feet with an average stope length of about 120 feet and locally attains a width of 10 feet.

[49] Wilkerson, A. S., Geology and ore deposits of the Magnolia mining district, Boulder County, Colo. Thesis, University of Michigan, p. 170, 1937.

[50] Corregan, R. D., and Lingane, D. F., Colorado Mining Directory for 1883, Denver, Colorado Mining Directory Co.

[51] Bradford and Myers, op. cit., p. 189.

[52] Burchard, H. C., Report of the Director of the Mint for 1882, p. 329.

[53] Wilkerson, A. S., op. cit., p. 151.

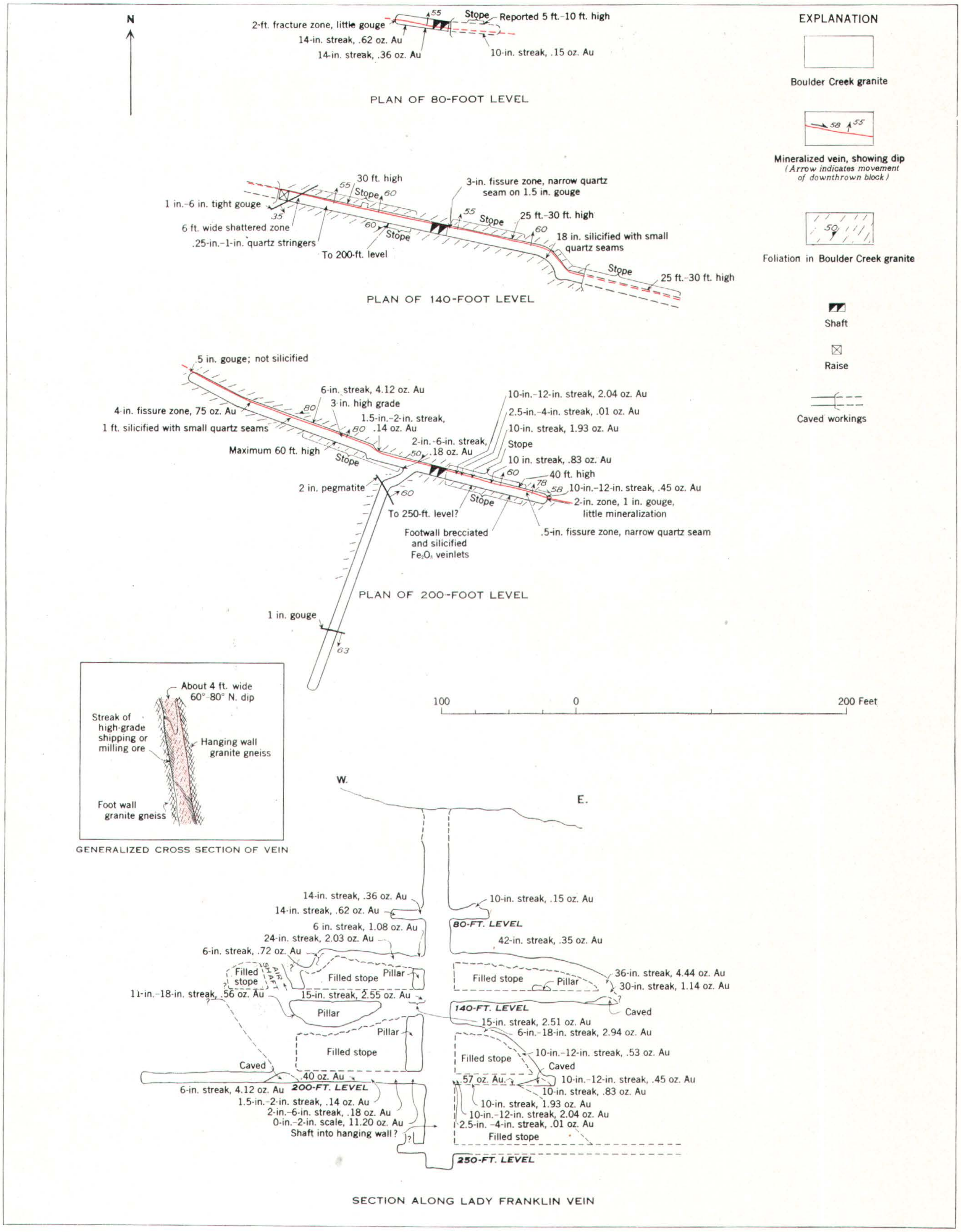


FIGURE 72.—Plan of 80-foot, 140-foot, and 200-foot levels and longitudinal section of the Lady Franklin mine, showing relation of ore to structure in the granite gneiss.

It is reported that commercial primary ore appears at a depth of 100 feet beneath the surface where the dip of the fissure zone steepens.

Studies of polished sections indicate that sylvanite is the dominant telluride and that it is replaced by a small amount of calaverite, hessite, petzite, and coloradoite. A little free gold is present, and rusty gold is found to a depth of about 80 feet.

MOUNTAIN LION-KEYSTONE VEIN

Two of the best-known mines in the district, the Mountain Lion and the Keystone, are on the same vein. The Keystone shaft is on the south slope of Magnolia Hill, about 2,000 feet east-southeast of the Magnolia school, at an altitude of 7,160 feet, and the Mountain Lion shaft is about a quarter of a mile north-northeast of the school, at an altitude of about 7,300 feet. It is reported that several shallow levels were turned from the Keystone shaft in the early days of mining in the district, but at the present time the chief levels are at depths of 150, 200, 260, 300, 400, and 450 feet. Although the general course of the vein is northwesterly, its course changes from N. 50° W. to N. 70° W. on the 150-foot level and from N. 32° W. to N. 60° W. on the 260-foot level—the levels mapped by Wilkerson.

In 1876, according to Raymond,[54] rich ore had been found as deep as the bottom of the shaft, which at that time was at a depth of 75 feet. The high-grade ore was confined to a seam 2 to 7 inches wide, the tenor of which, as indicated by a mill run, was about $600 to the ton. In 1876 the average value of the ore shipped was estimated to be about $700 to the ton. According to Fossett,[55] the Keystone mine had yielded $45,000 up to the end of August 1876. In 1877, according to Bradford and Myers,[56] the Keystone shaft was at a depth of 210 feet, the total width of the vein was 3 to 8 feet, and the mine was yielding 8 to 10 tons of ore a day. According to Burchard,[57] the mine was reported to have yielded $250,000 through the year 1882, and the width of the pay ore had commonly ranged from half an inch to 6 inches. The Mountain Lion mine had a shaft 178 feet deep in 1877. The total width of the vein ranged from 10 to 36 inches, and the width of the high-grade ore averaged about 12 inches and assayed $600 to $2,200 per ton. The average value of several shipments was approximately $1,200 per ton. The second-class ore shipped to the mills in 1877 yielded approximately $200 per ton. Monroe and Wolff credit the property with an output valued at $500,000 prior to 1905; since that time the output has been relatively small.

[54] Raymond, R. W., Mines and mining west of the Rocky Mountains: U. S. Treasury Dept., 8th Ann. Rept., pp. 311–312, 1876.

[55] Fossett, F., Colorado—Gold and silver mining region, p. 405, Denver Daily Tribune Printing House, 1876.

[56] Bradford and Myers, op. cit., p. 188.

[57] Burchard, H. C., op. cit., p. 339.

In most places the dip of the fissure zone ranges from 45° to 50° N. but locally decreases to 30°; it is reported that the disappearance of ore at the 400-foot level coincided with a decrease of the dip to 30°. Several small branch fractures join the vein at small angles but do not persist from one level to the next. The ore seams range from a sixteenth of an inch to 2 inches in width, and at places the tellurides are frozen to the wall. The Keystone ore shoot pitches southeastward at an angle of about 55° and has a pitch length of 450 to 500 feet, a depth of 150 feet, and a maximum width of nearly 20 feet. The ore shoots coincide with the intersection of branch fissures with steeper parts of the vein, which occupies a premineral normal fault.

According to miners working in the Mountain Lion mine the shaft has levels turned at depths of 80, 147, 230, 300, and 350 feet. The only level accessible to Wilkerson in 1937 was the 230-foot level, as the upper ones had caved and those below were under water. The ore shoot is reported to pitch steeply to the east. The main fissure zone is 6 inches to 1½ feet wide. It trends N. 50° W. southeast of the shaft and about N. 18° W. northwest of the shaft and dips 40° to 60° N. Striations on the walls indicate that the ore occupies a premineral normal fault, the hanging wall of which moved almost straight down the dip.

The vein continues west from the Keystone property through the Mountain Lion property into the Ward H. Lamon mine to the northwest and is one of the most persistent in the district. It has been traced nearly 4,000 feet southeast of its junction with the diabase Iron dike near the Livingston breccia reef.

Nearly every mineral reported in the district is represented in the Mountain Lion-Keystone vein. The two mines are particularly well known for the unusual oxidation products of the many telluride minerals and for the unusual masses of crystalline native tellurium. To a minor extent telluride minerals occur intergrown with quartz, roscolite, and pyrite, but the richest ore minerals, such as calaverite, occur chiefly in thin seams distinctly later than the quartz. The relation of the molybdenite pockets in the Mountain Lion mine to the telluride mineralization is not known.

KEKIONGA-MAGNOLIA VEIN

The first vein discovered in the district has been extensively worked in the Magnolia and Kekionga mines. The Magnolia mine is about half a mile southwest of Magnolia, at an altitude of about 7,500 feet. West of the Magnolia claim the vein trends nearly due east, but within the Magnolia claim its swings slightly to the southeast. As it is followed farther to the east it swings from S. 70° E. near the eastern end lines of the claim to S. 45° E. as it is followed southeast into the Sherry claim. It is the most persistent vein in the district and has been traced for more than a mile along the surface. It was discovered by Fuller, Stewart, and Wilson in 1875 and has been responsible for much of the output of the district. Like the Keystone-Mountain Lion vein, it is well known for the unusual variety of tellurides and their oxidation products. As early as 1877 [58] the Magnolia mine was noted for the rich narrow high-grade streaks commonly less than 1½ inches wide that assayed from $18,000 to $60,000 per ton in places but averaged about $200 per ton. The shipping and milling ore in the vein ranged from 8 to 36 inches in width and averaged between 3 and 4 ounces of gold to the ton.

According to Wilkerson, the tenor of the ore between 1881 and 1892, as shown by shipments to the Boulder Sampling Works, ranged between 2 and 12 ounces of gold and 1 and 6 ounces of silver and averaged 4½ ounces of gold and 2 ounces of silver to the ton. In recent years, the ore shipped has averaged a little less than half an ounce of gold to the ton. As shown in figure 73, the mine is opened by an inclined shaft, from which levels have been turned at 80, 135, 185, 270, and 400 feet.

In the Kekionga claim the vein dips about 80° N. According to Mr. Snider, who worked as lessee in the Kekionga mine for many years, the high-grade ore occurred in lenticular masses from the surface to the deepest levels. The width of the lenticular masses was commonly 1 to 8 inches, and some of them were followed vertically for as much as 100 feet. Few of them exceeded 30 feet in strike length, however. The ore mined by Mr. Snider averaged about 3 ounces of gold to the ton.

Vanadium is associated with the ore, and in 1910 some ore was shipped for its vanadium content. Although the mineral containing the vanadium was not definitely ascertained, it was probably roscoelite. According to Wood,[59] some of the ore contained as much as 6.28 percent of vanadium oxide, and a moderate tonnage averaging 2 percent of vanadium oxide was blocked out. The ore with a marked vanadium content extended for a distance of 1,500 feet along the surface and to a depth of 400 feet. The average of a large number of tests, including a sample taken from a carload of 20 tons, was 4.3 percent of vanadium oxide.

The ore of the Kekionga and Magnolia mines is also unusual because of the presence of ferberite. Specimens of ore from the Kekionga claim given to the writers consisted of brecciated medium-grained granite cemented and seamed by fine-grained quartz, much of which was vuggy. Calaverite and sylvanite are in large part contemporaneous with the quartz, but veins of fine-grained ferberite are distinctly later and cut both the tellurides and the quartz seams. (See fig. 74, *A*, *B*.) Ferberite was also observed encrusting sylvanite and quartz crystals in vugs.

In most places the Kekionga vein zone is about 2 feet wide, and where it contains ore the telluride seams range in width from a mere film frozen to the wall to rich masses 3 inches wide. The chief mineral is sylvanite. It is found in small blades in horn quartz, accompanied by pyrite and some sphalerite. With the sylvanite there is generally a small amount of hessite, petzite, and calaverite. Nearly all the tungsten ore is found in a shear zone that joins the Kekionga vein near the west end of the 185-foot level (fig. 73). It is reported to average 2 percent of WO_3 and 0.04 ounce of gold to the ton. The Kekionga vein in the same stope averages about 0.25 ounce of gold to the ton.

Slickensides on the footwall of the vein near the east end of the tungsten stope pitch 14° SE., and apparently the left-hand wall moved ahead.

Although the shoots of high-grade ore are lenticular, narrow, and nearly vertical, much of the lower-grade rock between them was also removed; the resulting stope as shown in the longitudinal section of figure 73, suggests an ore shoot that had a general pitch of about 40° E. This shoot as exposed in the upper levels had a pitch length of more than 315 feet, and if, as reported, it extended to the lower level, it may have been as much as 500 feet long. Its breadth was more than 250 feet and its maximum thickness about 8 feet. The stope from which the tungsten was removed is about 75 feet long, 15 feet wide, and 20 feet high.

The value of the total production of the Kekionga is probably more than $500,000.

GOLD HILL DISTRICT

The Gold Hill mining district comprises about 12 square miles in the central part of Boulder County, 3 to 8 miles northwest of Boulder and 30 miles northwest of Denver. The district includes several small mining camps or settlements, the largest of which is Gold Hill. Others comprising only a few houses each, are Rowena and Glendale on Lefthand Creek, Sunshine in the eastern part of the district, and Wallstreet, Salina, and Crisman on Fourmile Creek. The district ranges from 5,900 to 8,400 feet in altitude and is well watered by Fourmile Creek, Lefthand Creek, and their tributaries.

The geology of the area was mapped in 1906 and 1907 by Crawford,[60] and his map was incorporated in Worcester's report [61] on the Ward region, but no detailed work was done on the ore deposits or on the structural fea-

[58] Bradford and Myers, op. cit., p. 188.

[59] Wood, J. R., Rare metals in Boulder County: Mining Sci., vol. 62, p. 11, 1910; New vanadium fields: Mining Sci., vol. 65, pp. 74–75, 1912.

[60] Crawford, R. D., Geology and petrography of the Sugar Loaf district; Colorado Univ. Studies, vol. 6, no. 2, 1909.

[61] Worcester, P. G., The Geology of the Ward region, Boulder Co., Colo.: Colorado Geol. Survey Bull. 21, 1920.

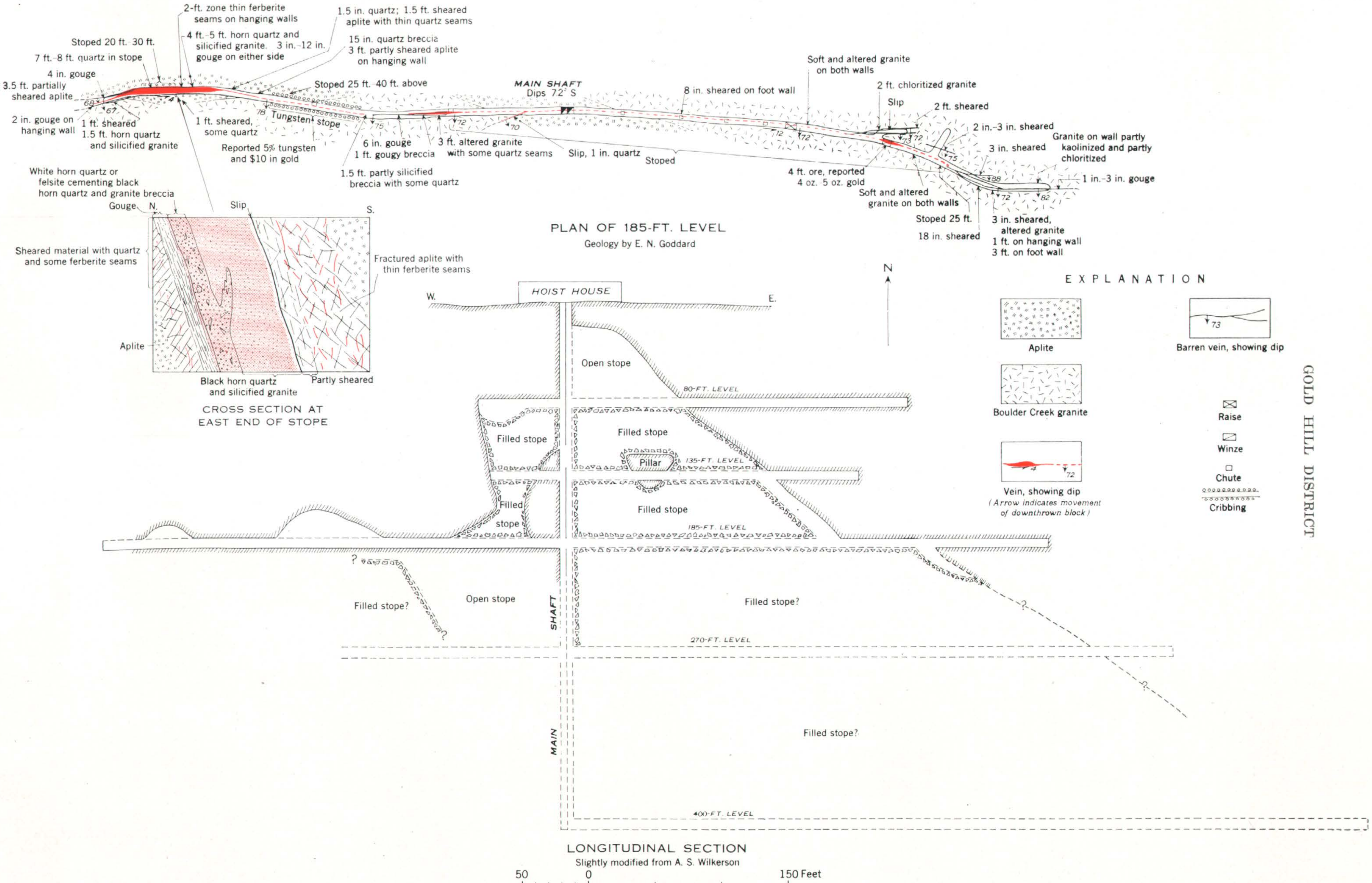


FIGURE 73.—Plan of the 185-foot level and longitudinal section of the Kekionga vein, Magnolia district.

tures. In the fall of 1931, Lovering,[62] assisted by L. B. Graff and Bert Stegeman, traced the system of strong northwesterly faults known as breccia reefs through the Gold Hill region. During the summers of 1934 and 1935 the writers visited several of the more important mines of the district and mapped some of them in detail. In the summer of 1937 an excellent topographic map of the district was prepared by S. G. Lunde of the Topographic Branch of the Geological Survey. Using this map as a base, Goddard,[63] assisted by Stanley Jerome and L. A. Warner, mapped the geology in detail and studied the ore deposits during the field seasons of 1937, 1938, and 1939.

HISTORY AND OUTPUT [64]

Placer gold was discovered near the present site of Gold Hill in January 1859, and during the following summer some of the veins were located. Between 3,000 and 5,000 people flocked to the district during the first few seasons. After 1860 mining in the district rapidly declined but suddenly became active again in 1872, when gold-telluride ore was discovered at the Red Cloud mine and very rich ore was mined on many properties. Mining was further stimulated in 1898 by the completion of a railroad from Boulder to Ward, which lay 3 miles west of Gold Hill.

During the early part of the twentieth century there was a gradual decline in activity in the district, lasting until the fall of 1933, when the sudden rise in the price of gold caused a great increase in activity. During 1934 the Slide, Ingram, Klondike, Interocean, Emancipation, Wood Mountain, Poorman, Grand Republic, and many other mines were reopened and actively worked. As a result, the value of the gross production of the district jumped from $79,368 in 1933 to $450,995 in 1934 and to $816,929 in 1939.[65] This activity continued until 1942, when nearly all gold mining ceased because of World War II.

Few figures are available on the output in the early days, but from 1904 to 1944 the Gold Hill district (including the Sugarloaf district) produced 706,293 tons of crude ore having a value of $8,498,233.[66] The total value of the output is estimated to be between $12,000,000 and $14,000,000.

GENERAL GEOLOGY

The Gold Hill district is in the northern part of the batholith of Boulder Creek granite that underlies about 100 square miles of the east slope of the Front Range (pls. 2 and 4). At the northern edge and in the western part of the district schists of the Idaho Springs formation wrap around this stock and interfinger with the granite. Two to three miles east of the district, the Pennsylvanian "red beds" of the Fountain formation lie unconformably on the granite and dip about 35° E. The pre-Cambrian rocks were invaded during the Laramide revolution by a series of porphyry dikes, which range in composition from diabase to alaskite.

Pre-Cambrian rocks.—The rocks of the Idaho Springs formation include biotite and quartz-biotite schist and small amounts of injection gneiss. In the western and northwestern parts of the district, the foliation ranges in strike from N. 15° W. to N. 50° E. and dips 50°–85° NW. Along the north border of the granite the foliation of the schist swings more toward the east, striking N. 50°–70° E. and dipping about 60°–80° SE. This structure has been influenced both by the Boulder Creek granite and by a stock of Silver Plume granite to the north.

The Boulder Creek granite ranges from a very coarse grained mottled pink and black biotite granite near Big Horn Mountain east of Gold Hill to a medium-grained quartz monzonite gneiss at the borders of the stock. The platy and linear structures throughout this stock seem to indicate that the magma came up from the vicinity of Big Horn Mountain just east of Gold Hill and spread out fan shape to the south. An extensive dike of Silver Plume granite with gentle easterly dip cuts the Boulder Creek granite on the east side of Big Horn Mountain, and dikes and lenses of pegmatite and aplite are abundant throughout the Boulder Creek granite and the schist. Most of the dikes trend northeastward parallel to the platy structure of the granite, but some cut across it in various directions.

Laramide igneous rocks.—The earliest of the intrusives formed during the Laramide revolution is a diabase dike of group 2 (pl. 7 and fig. 12) called the Iron dike. This dike extends N. 30° W. brokenly for nearly 30 miles from Magnolia to Estes Park and passes about half a mile west of Gold Hill. It is 20 to 60 feet wide, and in many places its outcrops form small but prominent ridges.

Intermediate quartz monzonite porphyry of group 5, which Crawford[67] described as a dacite, forms an extensive system of northwestward-trending dikes in the southeastern part of the district and occurs as sills in the sedimentary rocks near Boulder. Irregular dikes of alaskite of group 7 occur in a zone trending N. 75° W. through the central part of the district; one of these dikes cuts the Iron dike just west of Gold Hill. On the south side of Fourmile Creek, near Wallstreet, a group of latite dikes trends N. 80° E., and one of them

[62] Lovering, T. S., Relations of ore deposits to geologic structure in Boulder County, Colo.: Colorado Sci. Soc. Proc., vol. 13, no. 3, pp. 77–88, 1932.

[63] Goddard, E. N., Preliminary report on the Gold Hill mining district, Boulder County, Colo.: Colorado Sci. Soc. Proc., vol. 14, no. 4, pp. 103–139, 1940.

[64] Fosset, F., Colorado—Gold and silver mining region, Denver Daily Tribune Printing House, 1876. Montgomery, M. G., A Story of Gold Hill, Colo., privately published, May 1930.

[65] Data furnished by C. W. Henderson, U. S. Bureau of Mines, Denver, Colo.

[66] Idem.

[67] Crawford, R. D., op. cit., pp. 97–131, 1909.

cuts the Iron dike. The lithologic character of this latite seems to indicate that it belongs in group 8.

Bostonite of group 9, called trachyte by Crawford, occurs in a number of dikes in the northern part of the district. These dikes range in strike from N. 10° E. to nearly due east. Andesite probably belonging in group 10 forms a strong dike that extends northeastward from Sugarloaf Mountain and cuts the Iron dike near Fourmile Creek. Small dikes of biotite monzonite of group 10 and of biotite latite intrusion breccia of group 11 are exposed in the Logan and Yellow Pine mines in the southwestern part of the district and are scattered in the northwestern part of the district.

All the porphyry dikes dip steeply and with the exception of the Iron dike range from a few feet to 30 feet in width. Seams of intrusion breccia are only a few inches wide. Few dikes can be traced continuously for more than a mile, and many are short segments of groups that extend for 1½ to 2 miles.

STRUCTURE

The pre-Cambrian structure of the district is described briefly on page 236. The most outstanding structural features formed during the Laramide revolution are the strong northwesterly faults known as breccia reefs (pl. 2). Although these faults occur throughout the northern part of the Front Range, they are best developed in the Gold Hill district. The recognition by the Gold Hill miners of a relation between them and the ore deposits led to geologic studies that seem to establish them as one of the most important factors in regional localization of ore. The more persistent of these faults form a nearly vertical system trending N. 25°–50° W. Faults of a less persistent system trend N. 60°–85° W., dip gently to steeply, and break across between faults of the more northward-trending system. The breccia reefs are commonly marked by silicified sheared or brecciated rock, which is pink, red, or purple. The color is due to finely disseminated hematite. In places there are large veins of bull quartz 5 to 25 feet wide, and in other places the faults consist of narrow zones of strongly sheared rock or wide zones of slightly sheared rock.

In the eastern part of the district the Maxwell reef trends about N. 28° W. through Orodel and Glendale and dips steeply to the east. It is 50 to 150 feet wide and is characterized by reddish-colored sheared and more or less silicified granite and gneiss. The Hoosier reef trends N. 35° W. through the central part of the district, extending across Arkansas Mountain and just east of Gold Hill, where it dips 80°–88° W. It is 5 to 50 feet wide and in many places is made up of bull quartz, which forms wall-like outcrops. In the southwestern part of the district the Livingston reef trends about N. 45° W., lying just west of Wheelman on Boulder Creek and just east of Sugarloaf Mountain. It is a shear zone much like the Maxwell, but of less width and extent. The Blue "vein," a relatively small breccia reef in the north-central part of the district, strikes N. 70°–75° W. and dips 80° N. It is 3 to 5 feet wide and is made up of sheared and silicified granite containing some quartz. The Poorman reef strikes N. 85° W., dips 58° to 90° N., and breaks across from the Maxwell to the Hoosier reef in the southeastern part of the district. It is 10 to 20 feet wide and consists of sheared and strongly silicified granite, which stands up in prominent wall-like outcrops. The Fortune reef trends N. 70° W. across the central part of the district from the Maxwell to the Hoosier reef, dips 30° N., and forms a shear zone 3 to 15 feet wide.

In general the displacement along the northwesterly reefs has been large, ranging from 50 feet on the Hoosier reef to more than 600 feet on the Maxwell reef, but it may have been less along the more westerly reefs. In most places the southwest wall has moved down and to the southeast at an angle of 50° or less.

In some of the mines strong gouge-filled fault fissures 1 to 5 feet wide are exposed, which strike northwest and dip 20°–50° NE. These faults, called flat veins by the miners, are apparently earlier than the vein fissures, though they have been reopened several times; they also may have originated during the breccia-reef period of faulting. Though barren for the most part, they seem to have had a very important influence on the distribution of ore in some of the veins. They apparently were too tight and gougy to allow the free circulation of ore solutions and acted as dams or baffles to cause deposition of ore in vein fissures just below or above their intersection. This group includes the Flat and Mud veins of the Yellow Pine and Logan mines and the Flat vein in the Poorman mine.

The fissures occupied by the porphyry dikes, which were intruded after the formation of the breccia reefs, are irregular but seem to belong to two general systems. In the western and southern parts of the district they have a general trend of N. 70° E. and in the eastern part of the district a general trend of N. 60° E.

Most of the fissures occupied by the ore deposits strike N. 30°–45° E. and dip steeply. In the northern part of the district some strike about N. 60° E. and dip steeply northwest, and a few, notably the Poorman and Gladstone veins of the Poorman group in the southeastern part of the district and the Zopher vein of the Wood Mountain group in the southwestern part, strike nearly east and dip 50°–85° N. The productive veins filling these fissures are chiefly limited to the vicinity of the breccia reefs, but many low-grade veins and barren fissures are scattered in other parts of the district.

The displacement on the vein fissures has not been large, in most places ranging from 2 to 10 feet, but in a few places is as much as 20 feet. On some of these fissures there have been three or more periods of movement. On most of the fissures trending N. 30°–45° E., the southeast wall moved southwestward and downward at low angles. On those trending N. 60° E., the early movement was the same, but commonly in a second period of movement the northwest wall moved downward and to the southwest. Along the fissures of easterly trend, where the direction of movement could be determined, the south wall moved westward almost horizontally.

ORE DEPOSITS

VEINS

Gold is the chief metal mined in the Gold Hill district, although in most veins minor amounts of silver are associated with the gold. In a few of the mines silver has been the chief product, and some lead and copper have also been produced. Moderate amounts of tungsten ore have been taken from the Logan gold mine in the southwestern part of the district. A pre-Cambrian deposit of nickel ore containing cobalt has been opened near Gold Hill but has had only a small production. This deposit is described in the chapter on pre-Cambrian ore deposits, page 70.

All the ore shipped from the Gold Hill district has come from fissure veins. Most of the veins are of the gold-telluride type, but there are some important pyritic gold veins and a few important silver-lead veins. The silver-lead veins appear to be the oldest; those of the Yellow Pine mine, which have been the most productive in the district, may even be related to the breccia reef period. Some of the pyritic gold veins, particularly those of the northern part of the district, are later than the telluride veins, but some may be earlier, as are those in the Jamestown district. The tungsten ore in the Logan mine is thought to be the latest of all the ores.

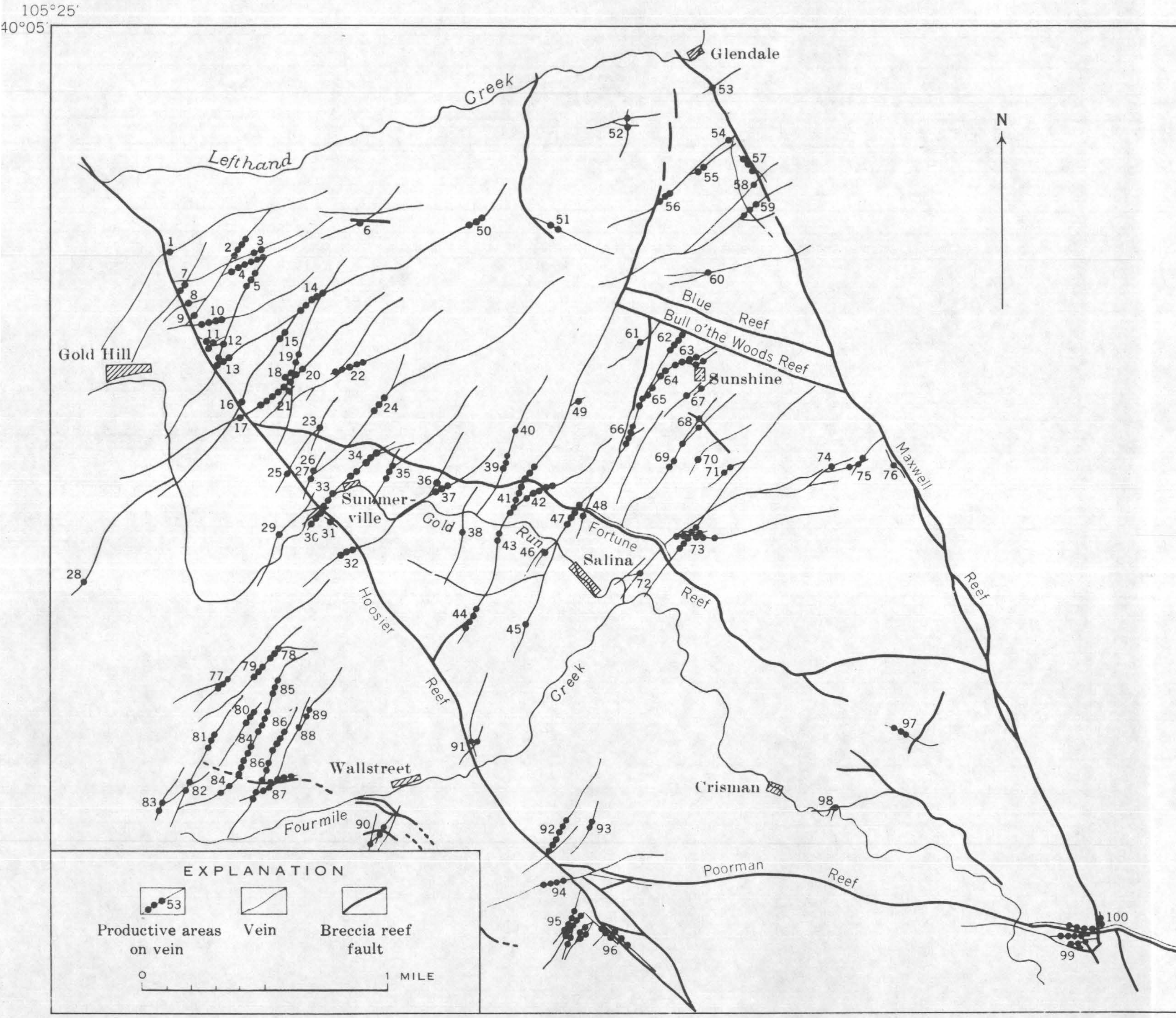
Gold tellurides are by far the most important ore minerals in the district. Petzite, sylvanite, and calaverite or krennerite are the most abundant, but small amounts of hessite and altaite are common. In most of the telluride ores, two or more of the telluride minerals are so finely intergrown that they cannot be distinguished by the naked eye. The tellurides occur in groups of small blades, in small irregular masses, or in tiny veinlets in horn quartz associated with finely disseminated pyrite. Very small amounts of galena and sphalerite are found with the tellurides in places. In many of the veins free gold is a valuable constituent of the ore. Rusty gold is common in the oxidized parts of the telluride veins, and in several rich primary deposits free gold is found either associated with the tellurides or in separate seams. The Logan mine is well known for its rich free-gold ore, and free gold has been found associated with tellurides in the Slide, Cold Spring, and Red Cloud mines.

In the pyritic gold veins, pyrite and chalcopyrite are the chief ore minerals, but galena, sphalerite, and gray copper are common and locally are abundant enough to form silver-lead ore. The gold appears to be most closely associated with the chalcopyrite, though in places fine-grained pyrite contains a very appreciable quantity of gold. In some of the pyritic gold veins rich pockets of free gold have been found.

In the lead-silver veins, the chief ore minerals are argentiferous galena and gray copper, and in places they are accompanied by some pyrite, chalcopyrite, and sphalerite. Ferberite is the only ore mineral in the tungsten ore and is associated with small amounts of fine-grained pyrite.

The chief gangue mineral throughout the district is quartz. In the lead-silver veins it is sugary to glassy; in the pyritic gold and telluride veins it is sugary to very fine grained (the horn quartz of the miners) but is rarely glassy; and in the tungsten ore it is of the very fine grained horn variety. In places the quartz gangue takes the form of silicified wall rock. Ankerite of variable composition is common in many of the pyritic gold and telluride veins and appears to be the latest mineral present.

The veins in the district are in general not as persistent as those in the central and southwestern parts of the mineral belt. Only a few can be traced as much as a mile along the strike, and most are less than 2,500 feet long. Many have been followed to depths of 300 and 600 feet, and a vein mined through the Slide shaft has been followed to a depth of 1,080 feet. In most mines the depth of mining has been determined not by the pinching out of the veins but commonly by water problems and other operative difficulties that have made exploration unprofitable. The veins range from a few inches to 5 feet in thickness for the most part, but at junctions they locally widen to as much as 15 feet. The ore minerals are not uniformly distributed but are likely to be limited to narrow irregular stringers of quartz scattered throughout the entire width of the vein. In mining the telluride veins it is common practice to sort out these high-grade stringers from the rest of the vein material, which is relatively barren. Almost all the important veins of the district are in the immediate vicinity of the breccia reefs (pl. 23). Some have broken to or nearly to the reefs and others cut through them. Ninety percent of the productive veins lie between the Hoosier and Maxwell breccia reefs. Many productive veins border the northeast side of the Hoosier reef and the southwest side of the Maxwell reef, and there are several along the Fortune reef, the Blue "vein," and the Poorman reef. In the southern part of the district the Logan, Yellow Pine, and Grand Republic veins crop out on the southwest side of the Hoosier reef. The Wood Mountain group is exceptional, lying more than half a mile southwest of the Hoosier, the nearest breccia reef. In general the veins cut across the gneissic structure of the Boulder Creek granite at acute angles.



LIST OF MINES

1. New Discovery
2. Prussian
3. Twin
4. Klondike
5. Slide
6. Helena
7. Cold Spring and Red Cloud
8. Alturas
9. Gold Ring
10. Alamakee
11. Times
12. Winona
13. White Cloud
14. Horsefal
15. Columbus
16. Who Do
17. Bellvue
18. Cash group
19. Mack
20. St. Joe
21. Ready Cash
22. Black Cloud
23. Atlanta
24. Big Horn
25. King
26. First National Bank
27. Morning Glory
28. Myrtle
29. Tammany
30. Evans
31. Dana
32. Grant
33. Goldsmith Maid
34. Victoria
35. Scotia
36. Valley Forge
37. Belle
38. Golden Eagle
39. Fairfax
40. Minneapolis
41. Richmond
42. Ingram
43. Three Brothers
44. Melvina
45. Critic and Railroad Boy
46. Baron
47. Sunshine
48. Atchison
49. Sussex
50. Snowbound
51. Belle of Memphis
52. Delaware group
53. St.Louis
54. Washington Irving
55. Cleveland
56. Tillie Butzel
57. Sun and Moon
58. Hidden Treasure
59. Nil Desperandum
60. Dolly
61. Gillaspie
62. American
63. Interocean
64. Oceola
65. White Crow
66. Grand View
67. Washburn
68. White Eagle (Archer)
69. Golden Harp
70. Richard
71. Plough Boy
72. Home Sweet Home and Little Johnny
73. Emancipation group
74. Minnie Bell
75. New York-Union
76. Pilot
77. Sakhrat
78. Gold Lode
79. Great Britain
80. Lucky Star
81. Emerson
82. Concord
83. Forest
84. Franklin
85. Gillard
86. Gray Copper
87. Wood Mountain group
88. Last Chance
89. Doss
90. Gladys
91. Temborine
92. Dime
93. Evening Star
94. Grand Republic
95. Logan
96. Yellow Pine
97. King
98. McKnight Placer
99. Poorman group
100. Bell

SKETCH MAP SHOWING RELATION OF PRODUCTIVE VEINS OF THE GOLD HILL DISTRICT TO BRECCIA REEFS

862135 O - 50 (Face p. 238)

WALL-ROCK ALTERATION

The wall-rock alteration was chiefly sericitic, but locally, especially in the wider parts of some of the veins, there was much silicification. The wall rock is commonly altered for 6 to 36 inches from the vein, and the feldspars are partly or wholly changed to sericite. Where the alteration was not severe the biotite was slightly chloritized, but where it was strong the biotite was changed to sericite. The alteration of the walls was commonly stronger near ore bodies than along weakly mineralized parts of the vein, but several exceptions to this rule have been observed.

SIZE AND STRUCTURAL CONTROL OF ORE BODIES

The ore bodies generally range from about 50 to 300 feet in breadth and 100 to 400 feet in length but are of relatively high grade. The most persistent ore shoot mined in the district was in the Slide mine; it extended from the surface down to the 1,000-foot level. Its breadth ranged from 60 to 230 feet (pl. 24). Most of the ore shoots pitch at nearly 90°.

As already pointed out, nearly all the important ore deposits of the district are in the vicinity of breccia reefs. Fully 90 percent of the district's output has come from ground within 2,000 feet of breccia reefs, but in many places the ore bodies are several hundred feet from the reefs. It therefore seems probable that the breccia reef fissures served as deep channels for the circulation of ore-forming solutions. The metalizing fluids apparently rose along these more persistent fissures, moved out into the more open but less continuous cross fissures wherever they could, and deposited ore wherever openings were present.

The distribution of ore within the veins seems to have been dependent chiefly on structural conditions that favored the formation of openings. The most important of them were vein junctions, which are conveniently classified into three types: (1) Junctions of important veins with breccia reefs, (2) junctions of two productive veins, and (3) junctions of productive veins with barren, gougy fissures. In the first type, the veins broke across breccia reefs to form relatively wide breccia zones in the easily shattered bull quartz of the reef and in the granite adjacent to it, preparing wide and relatively open zones for the deposition of the ore. The ore bodies in the Cold Spring and Red Cloud mines are of this type. In the second type, two fissures join or cross each other, and such junctions are likely to coincide with relatively wide and extensive fracture zones very suitable to the deposition of ore, but in some places the movement was less pervasive and the faulting along one fissure seemed only to pull open a cross fissure. Many of the shoots on the Slide vein are related to cross fractures of this sort. In the third type, gently dipping, tight, gouge-filled fault fissures serve as dams or baffles to the circulating solutions and tend to cause deposition of ore immediately below or above the fault. Ore bodies in the Poorman, Yellow Pine, and Logan mines are of this type. Other favorable factors in the localization of ore are the junctions of veins with pre-Cambrian pegmatite or aplite dikes and sudden changes in direction of strike or dip of the vein.

GRADE OF ORE

The grade of the gold-telluride ores from the district is high. In the early days a large amount of ore shipped in small lots assayed from \$1 to \$5 per pound in gold and silver. Large tonnages ranged from 1 to 10 ounces of gold and from 1 to 50 ounces of silver to the ton. Since 1900 considerable high-grade ore as rich as that found in the early days has been mined, but the average grade of telluride ore shipped in ton lots ranged from about a half to 2 ounces of gold and 1 to 10 ounces of silver to the ton. The average ratio of gold to silver by weight throughout the district is about 1:2, though in some of the ore it is 1:1. In some shipments the silver content of the ore is not listed. The grade of the free-gold ore is about the same as that of the telluride ore, but local pockets have assayed as high as 0.5 to 1.0 ounce to the pound. The pyritic gold ore of the district is of lower grade, ranging from about 0.25 to 1 ounce of gold to the ton but locally as much as 4 ounces. The silver is about as abundant as in the telluride veins. Silver-lead ore taken from the Yellow Pine mine contained 33 to 1,440 ounces of silver to the ton. A few shipments contained a trace to 0.4 ounce of gold to the ton. Tungsten ore taken from the Logan vein averaged between 5 and 10 percent of WO_3.

The most accurate data that has been obtained on the grade of Gold Hill ores in the early days is in the Boulder Sampler records,[68] and a few representative shipments are given in the following table:

Representative shipments of ore from the Gold Hill district to the Boulder Sampler, 1878–92

[Data taken from Boulder Sampler records]

Date	Mine	Net weight (pounds)	Gold (ounces per ton)	Silver (ounces per ton)
Aug. 5, 1878	Slide	147	162.2	1,056
Sept. 11, 1878	do	21,107	12.2	60
Dec. 1, 1878	do	5,978	3.6	11
Nov. 2, 1882	Ingram	45.5	1,139	792
Do	do	107.5	201	268
Do	do	1,575	6.25	15
Nov. 17, 1882	do	1,771	3.3	7
June 24, 1883	Yellow Pine	13,857	0	277
Do	do	3,916	0	212
Do	do	110	0	115.5
Aug. 21, 1883	Interocean	7,315	4.9	11
Do	do	94.5	126	237
Do	do	4.25	1,747	701
Nov. 5, 1884	Emancipation	5.88	713	230
Do	do	59.5	118	36
Do	do	6,433	4.7	3
Mar. 3, 1887	Poorman	3.25	1,530	302
Do	do	59.5	114.5	68
Do	do	2,685	6.5	7.5
June 17, 1890	Logan	2.5	2,169	487
Do	do	1,642	5.3	2.5
Do	do	594	2.2	3.7

[68] Four record books of the Boulder Sampler, a milling and sampling works in Boulder, are on file at the office of the Boulder County Miner and Farmer at Boulder. They cover the periods May 1, 1878, to January 20, 1889, and December 1, 1890, to May 30, 1892.

PLACERS

The placers of the Gold Hill district have been relatively unimportant. Fossett[69] stated that $100,000 in gold was taken from Gold Run in the summer of 1859, but after the first few years only occasional placer operations on Gold Run and Fourmile Creek were carried on. In 1873 Thompson[70] reported that "gulch mining" was carried on to some extent the previous year, in Fourmile Creek, which resulted in an output valued at $6,000. Smith[71] stated in 1883 "the placers have not been extensively worked during the past two years; some effort has been made on Fourmile, Lefthand, and other creeks, but with those exceptions they have been wholly idle." As a result of the depression in 1931 many people took to the hills to try their luck at placering, and there was considerable activity along Fourmile and Lefthand Creeks. Placer production, however, was very small, and few people returned a second summer. In 1935 about 400 ounces of placer gold was recovered from the Colby and Giggey placers on Fourmile Creek, just above Wallstreet, where a power shovel and portable trommel were installed. This plant was operated until 1939, when it was closed down.

Most of the gold in the stream valleys of the Gold Hill district is extremely fine, as most of the lodes from which it is derived are telluride veins, and on oxidation yield a very fine rusty gold. Only locally in such veins as the Logan has the gold been coarse enough to form good placer deposits, and most of these local areas were worked out in the early days.

SLIDE MINE, INCLUDING THE KLONDIKE AND TWIN VEINS

The Slide mine, one of the most productive in the district, is on the south side of Lefthand Creek, half a mile northeast of Gold Hill. The Slide shaft, the collar of which is at an altitude of 8,290 feet, extends to a depth of 1,080 feet below the surface and has 11 levels aggregating more than 5,000 feet in length. The Corning tunnel, a crosscut about 2,500 feet long, is at an altitude of 7,750 feet and intersects the Slide vein 950 feet, the Klondike vein 575 feet, and the Twin vein 400 feet from the portal. On the Klondike vein, a winze with 3 levels aggregating 3,200 feet extends from the Corning level to a depth of 500 feet below it (1940) and also connects with the Prussian tunnel, which is about 1,800 feet long and 300 feet below the Corning. From 1933 to 1942 the three veins were controlled by the Slide Mines, Inc., and were worked through the Corning tunnel. The tunnel extends beyond the Slide vein to the Horsefal vein, but this part has been bulkheaded for several years.

The Slide vein was discovered in 1875 and is reported to have had an output valued at more than $1,000,000 prior to 1933; this figure seems reasonable considering the size of the stopes and the richness of the ore. The Corning tunnel was driven in 1876. In 1933 the Slide Mines, Inc., opened up the Corning tunnel and constructed a 60-ton mill at its portal. During the next 3 years a large tonnage of low-grade pyritic gold ore from the Klondike and Twin veins was milled. In 1937 the Twin vein was abandoned, but large tonnages were taken from the Klondike and Slide veins and the Slide dump until August 1942, when operations ceased, owing to the war. From 1934 to 1942 the output of the Slide group amounted to 40,611 ounces of gold, 145,066 ounces of silver, 747,517 pounds of copper, 886,500 pounds of lead, and 440,056 pounds of zinc, having a value of about $1,650,000.[72]

The chief wall rock throughout the mine is Boulder Creek granite, which is strongly gneissic in places because of its position near the border of the batholith. Irregular dikes of pegmatite and aplite 10 to 100 feet wide are fairly abundant and generally trend parallel to the gneissic structure, which in most places strikes about N. 75° E. and dips steeply to the north. Locally in the Twin vein there are irregular seams of soft altered biotite latite intrusion breccia, 1 to 2½ feet wide, but no porphyry dikes have been observed.

Nearly all the output of the Slide group has come from four veins, the Slide, the Slide "footwall streak," the Klondike, and the Twin (pl. 24). The Slide vein contains high-grade telluride ore, the Slide footwall streak both telluride and pyritic gold ore, and the Klondike and Twin veins low-grade pyritic ore. A fifth vein, the Prussian, has been productive in the Prussian mine, and its junction with the Klondike vein has apparently influenced the localization of ore in the latter. Other veins, of little importance, are the Iowa and Telluride. All these veins are subparallel, striking northeast and dipping steeply to the northwest. In many places the veins follow the walls of pegmatite or aplite dikes or cut diagonally through them. The relations of the various veins are best shown on plate 24.

The Slide vein was by far the most important of the group prior to 1933. It strikes about N. 50° E. in the vicinity of the shaft, but 200 feet to the southwest it swings to S. 20° W. A hundred feet northeast of the shaft the vein breaks up into a group of irregular slips and apparently feathers out. It dips 75°–85° NW. in most places, but locally dips steeply to the southeast. The Slide vein ranges in width from a few inches to 5 feet and is made up chiefly of sericitized or silicified granite containing numerous interlacing veinlets of horn quartz a fraction of an inch to 18 inches wide. In many places, particularly in the vicinity of the shaft,

[69] Fossett, F., op. cit., p. 49.

[70] Thompson, L., Mines of Boulder County: Mining Rev., vol. 1, no. 5, p. 8, Jan. 1873.

[71] Smith, J. A., Report on the development of the mineral resources of Colorado, p. 35, Denver, Tribune Publishing Co., 1883.

[72] Data furnished by C. W. Henderson, U. S. Bureau of Mines.

small veinlets of horn quartz a quarter of an inch to 3 inches wide extend out into the wall rock on either side of the vein for distances of 10 to 40 feet. Where these veinlets join the main vein it is common to find unusually rich ore, and high-grade ore may extend out along the veinlets for many feet.

Movement along the Slide vein fissure appears to have been small. Grooves on the wall and displacements of pegmatite dikes indicate that the southeast wall moved southwest almost horizontally with a displacement of 2 to 3 feet. This movement was followed by the telluride deposition. In a few places the vein was reopened by a movement in which the northwest wall moved down to the southwest a few feet; such openings were filled with pyritic gold ore. Also in a few places there was a slight postore movement that sheared the pyritic gold ore, but the exact direction of this movement could not be determined.

The chief ore minerals in the Slide vein are the gold tellurides, which occur as irregular films and blades finely scattered through the horn quartz. Associated with them is very finely disseminated pyrite. Free gold in small grains and flakes associated with the tellurides is common in places and is locally abundant. One specimen reported to have come from level 11 (1,000 feet deep) showed abundant fine-grained free gold in horn quartz, surrounded by rosettes of fine-grained roscoelite (fig. 74, C). The chief telluride mineral in the ore is petzite, which appears to make up more than 60 percent of the tellurides present, but appreciable amounts of hessite, sylvanite, and altaite are commonly intergrown with the petzite (fig. 74, *D*). In the pyritic gold ore pyrite and chalcopyrite are the chief ore minerals, but some galena, sphalerite, and gray copper are also found.

The Slide footwall streak branches from the Slide vein about 275 feet southwest of the shaft and extends nearly parallel with it for about 150 feet to the northeast (see pl. 24). At this point it almost ends but is intersected by an eastward-trending vein of the pyritic gold type, which is commonly regarded as a part of the Slide footwall streak. This vein, dipping 70° to 82° N., extends westward to the main Slide vein and may cross it, but relations are obscured by stoping and cribbing. The pyritic gold vein is mostly 3 to 12 inches wide, but near the main Slide vein it locally widens to as much as 4 feet.

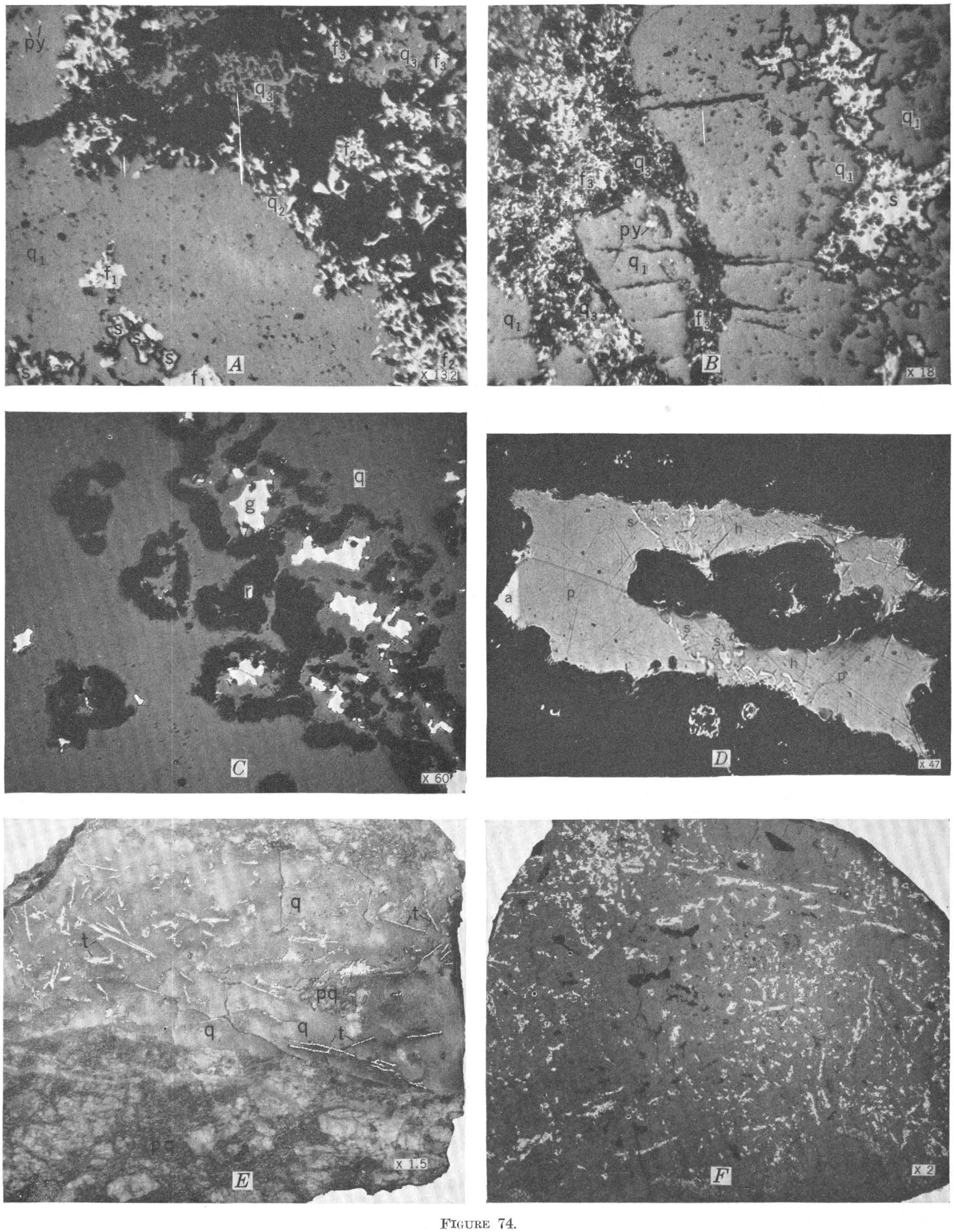
Fifty feet northeast of the Slide shaft the main vein is intersected by a system of small veins that have an average strike of N. 70° W. and a dip that is steeply northeast. They are largely filled with horn quartz and appear to have been formed at the same time as the Slide vein. They are relatively unproductive themselves but apparently form the northeast limit of the productive part of the Slide vein.

The Slide ore is for the most part of high grade. The ore shipped to the Boulder Sampling Works from 1878 to 1892 ranged from 2 ounces of gold and 7 ounces of silver to the ton to 265 ounces of gold and 1,101 ounces of silver to the ton. Relatively large tonnages of ore containing 2 to 20 ounces of gold and 7 to 60 ounces of silver to the ton were shipped, but most of the ore of higher grade was shipped in lots of a few hundred pounds. Pyritic gold ore in the footwall streak contained 0.3 to 4 ounces of gold to the ton. During 1936 and 1937 considerable stope fill was pulled from the Slide workings; it contained 0.2 to 1.5 ounces of gold to the ton. Ore taken from the Slide dump contained 0.1 to 3 ounces of gold to the ton.

Nearly all the Slide output has come from a single ore shoot extending from the surface to a depth of a thousand feet. (See pl. 24.) It has a stope length of 70 to 325 feet and an average pitch of 85° W. This is the deepest ore shoot in the district, and it is reported that there is still minable ore in the bottom. The localization of this shoot seems to be related to the junction of the Slide vein with the Footwall streak and its branches and to the N. 70° W. group of veins that limits the ore shoot on the northeast; some ore has been found at the junction of this group with the main vein. The numerous westward-trending to northwestward-trending seams in the walls of the Slide vein appear to be gash veins filling tension cracks produced by the movement along the Slide fissure. Their junctions with the main vein apparently served to localize rich pockets of ore. Another factor contributing to the localization of the shoot is the relatively sharp bend in the vein 200 feet southwest of the shaft. As its southeast wall moved southwest, the N. 50° E. part of the fissure would tend to be open and the N. 20° E. part tight, thus forming an open channel for the deposition of ore. Smaller ore bodies 50 to 200 feet long and 20 to 50 feet in breadth are found in places along the Slide footwall vein; the chief factors controlling their distribution seem to be irregularities in the vein and junctions of small feeders with the main vein.

The Telluride vein is about 100 feet north of the Slide vein on the Corning tunnel level. It strikes irregularly eastward and ranges in dip from 65° N. to 85° S. It is made up of thin horn quartz seams with some pyrite and ankerite and has apparently had a small output of telluride ore, for there are a few small stopes on the Corning tunnel level.

The Klondike vein lies 300 to 350 feet northwest of the Slide vein on the Corning tunnel level. It was little worked prior to 1934, but since then has been by far the most productive vein of the Slide group. The vein has a general strike of N. 70° E., but locally turns to N. 30°–50° E. Its dip ranges from 60° to 80° N. but in most places is about 70° N. For much of its exposed length this vein lies in or along the border of an extensive peg-


py
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q_3
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B
x 18
q
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C
x 60
s
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p
s
s
h
p
D
x 47
q
t
t
pq
q
q
t
pq
E
x 1.5
F
x 2

FIGURE 74.

matite dike. It has been explored for a length of 1,100 feet on the Corning tunnel level and to a depth of about 1,000 feet below its surface outcrop. It occupies a strong fault fissure 1 to 8 feet wide and consists of numerous veinlets of horny to sugary quartz and ore minerals scattered through strongly sheared and altered wall rock and gouge. Grooves on the wall and displacement of granite-pegmatite contacts indicate that the hanging wall moved down and to the southwest at an angle of 60° to 85°. The displacement appears to have been between 5 and 10 feet. This movement is believed to be contemporaneous with the posttelluride movement along the Slide footwall streak, which was in the same direction. If so, the Klondike vein is for the most part later than the main Slide vein. Rather strong postore movement along the Klondike vein has sheared or brecciated the ore in places, but the direction of movement could not be determined.

Between 570 and 610 feet southwest of the Klondike winze the Klondike vein is joined by the Prussian vein, which here strikes N. 30°–58° E. and dips 70°–83° NW. In the vicinity of this junction the Klondike vein widens to several feet and in the lower levels contains some of the richest pyritic gold ore in the mine.

The chief ore minerals in the Klondike vein are pyrite and chalcopyrite, but free gold is present in the lower levels, galena and sphalerite are abundant in places, and gray copper is present locally. Much of the pyrite is in coarse barren cubes, but it is fine-grained in places. This fine-grained variety probably resulted from shearing of the coarse pyrite during postore movements. The gold seems to be chiefly in close association with the chalcopyrite, though some gold is found in the fine-grained pyrite. Near the junction with the Prussian vein on the lower levels, free gold was found in vugs and small fractures, and in a few places there were rich nests of wire gold. Silver is associated with galena and gray copper. The best ore is made up of nearly solid sulfide seams 2 to 6 inches wide that interlace through the vein.

The grade of the Klondike ore commonly ranges from 0.10 to 3 ounces of gold to the ton but averages about 0.33 ounce. Ore from the vicinity of the junction with the Prussian vein in the lower levels averaged about 0.75 ounce of gold to the ton, and some samples taken across the full width of the vein contained as much as 60 ounces. The silver content is variable but averages about three or four times that of gold.

Nearly all the Klondike ore has been taken from an irregular but nearly continuous shoot having a stope length of about 1,100 feet and a maximum vertical extent of more than 700 feet (pl. 24). This shoot apparently pitches about 60°–70° W., but the bottom had not yet been reached when operations ceased in 1942, owing to the war. Ore in the lower levels was of higher grade than in the upper levels.

The ore in the Klondike vein is localized both by its junction with the Prussian vein and by a large pegmatite dike that the vein follows. The vein cuts alternately through granite and pegmatite, and such alterations apparently served to produce frequent and extensive open spaces favorable for the deposition of ore. Irregularities in the fissure also had some influence, for the best ore occurs where the vein is steep, whereas the gently dipping parts are relatively barren. Changes in strike of the vein appear to have had little effect, as would be expected where the movement has been steep.

The Twin vein is another pyritic gold vein, 100 to 175 feet north of the Klondike vein. It strikes about N. 80° E. and dips about 75° N. This vein occupies a very strong fault fissure 1½ to 5 feet wide and is made up of sheared wall rock and gouge containing thin irregular stringers of sulfide ore. Grooves on the wall and displacement of pegmatite dikes indicate that the hanging wall moved down and to the west at an angle of about 45° for 10 feet or more. Strong postore movement, in which the hanging wall moved up and to the east, has sheared and brecciated the ore. This vein was worked in 1934 and 1935 but was abandoned in 1936 because it was too soft and gougy. The chief ore mineral is pyrite, both fine and coarse-grained, accompanied by small amounts of chalcopyrite, galena, and sphalerite. The grade of the ore from the Twin vein ranged from 0.12 to 0.42 ounce of gold to the ton. In this vein, as in the Klondike, the chief factor controlling localization of ore was the alternation of granite and pegmatite in the wall rock.

The Iowa vein is a small vein 200 feet north of the Twin. It strikes N. 88° E. and is nearly vertical. It is

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EXPLANATION OF FIGURE 74

A, Photomicrograph of gold-tungsten ore from west end of 280-foot level of Kekionga mine, Magnolia district. Sylvanite (*s*) in crustified quartz (q_1 and q_2) associated with early coarse-grained ferberite. Fine-grained ferberite with a little quartz lies on the earlier quartz and is in turn incrusted and veined by late quartz (q_3) containing some ferberite of three generations (f_1, f_2, and f_3). *py*, Pyrite.

B, Photomicrograph of gold-tungsten ore from Kekionga mine, Magnolia district. Sylvanite (*s*) in vuggy quartz (q_1), which contains a little pyrite (*py*). Quartz (q_3) and ferberite (f_3) cut the early quartz.

C, Photomicrograph of high-grade gold ore from shaft ore shoot, 1,100-foot level, Slide mine, showing native gold (*g*) associated with roscoelite (*r*) and quartz (*q*).

D, Photomicrograph of telluride ore from shaft ore shoot, 900-foot level, Slide mine. Altaite (*a*) is later than petzite (*p*), which is contemporaneous with hessite (*h*). Veinlets of sylvanite (*s*) cut both petzite and hessite. Black area is horn quartz.

E, Seam of high-grade telluride ore bordering main vein of fine-grained pyrite and horn quartz, 800-foot level near shaft, Ingram mine. The blades of telluride (*t*) although chiefly sylvanite are in part intergrown with petzite and lie in a milky-colored horn quartz (*q*). *pq*, Fine-grained pyrite and horn quartz.

F, High-grade gold-telluride ore from Smuggler mine. Light-colored blades and blebs are chiefly mixtures of petzite and altaite, with minor amounts of native gold and sylvanite. Pyrite is sparingly disseminated in the quartz.

made up of thin horn quartz and pyrite-ankerite seams. It apparently has had no output but was an important factor in the localization of ore in the Prussian vein farther west.

POORMAN GROUP

The Poorman mine, on Poorman Hill about 3.2 mile N. 75° W. of Boulder, is the easternmost mine in the district and is nearly 2 miles from the main part of the Gold Hill district. It is developed on a rather complex group of veins, which includes the Poorman, Gladstone, Gold Medal, Grand Central, and Pride of the Mountain. The output from this group has probably amounted to at least several hundred thousand dollars. The workings consist of the Poorman shaft, which is approximately 450 feet deep, numerous other shallow shafts, and the Poorman tunnel, which is 171 feet below the collar of the Poorman shaft and comprises about 2,000 feet of workings, including a 550-foot crosscut. The shaft collar is at an altitude of 6,345 feet.

The chief wall rock throughout the workings is Boulder Creek granite, which is cut in places by small pegmatite dikes and by dikes of monzonite and alaskite porphyry. The veins all lie on the southwest side of the junction of the Poorman and Maxwell reefs or "dikes." (See pl. 25.) Some of the veins apparently cut spurs of the Maxwell reef but do not extend for any appreciable distance to the east of the main reef. The Poorman "dike" is a strong breccia reef of silicified granite 30 to 50 feet wide, which crosses the top of the hill near the Poorman mine at an altitude of about 6,400 feet. In the vicinity of the mine it strikes from N. 80° W. to N. 85° E. and dips steeply to the north. The Maxwell reef has a general strike of N. 28° W., dips steeply to the east, and intersects the Poorman reef just north of the crest of Poorman hill. On the south side of the Poorman reef the Maxwell reef breaks up into numerous small shear zones, which are more or less silicified and form the top of Poorman Hill. The Maxwell reef picks up again about 600 feet east of the top of the hill and extends far to the south. North of the Poorman reef and also 400 feet farther south, the Maxwell reef is marked only by strong shearing and gouge containing some red iron stain. Near the place where the Maxwell reef breaks up on Poorman Hill, the Gold Medal reef, a silicified breccia reef about 5 to 8 feet wide, branches off and trends nearly due west.

The most productive vein in the group is the Poorman, which crops out on the surface about 225 feet south of the Poorman reef. It trends about N. 80° E., and dips about 70° N. The relationship of the other veins to the Poorman is best shown on the tunnel level, called the 200-foot level by the miners (fig. 75). The Poorman vein on this level ranges in strike from N. 60° E. to N. 80° W. and dips 58°–78° N. Twelve feet south of the Poorman vein, at the crosscut, there is a barren shear zone striking about N. 72° E. and dipping 75°–80° N., which lies on the footwall of the Poorman vein for a short distance but diverges toward the southwest. This shear zone shows hematite in places and is apparently related to the breccia reefs. Thirty feet west of the Poorman shaft the Poorman vein cuts through the Gladstone vein, which ranges in strike from N. 80° E. to N. 85° W. and dips 65°–68° N. West of this junction the two veins are approximately parallel and about 10 to 15 feet apart, the Gladstone being north of the Poorman. East of the junction the two veins diverge rapidly, the Poorman striking about N. 65° E. and the Gladstone striking about S. 85° E. Thirty feet above the tunnel level the Gladstone vein flattens and intersects the Poorman again, and the two apparently continue as one vein to the surface.

One hundred feet south of the Poorman vein the crosscut tunnel intersects the Gold Medal vein, which strikes about N. 65° W. and dips 75° N. The footwall of this vein is the Gold Medal reef, which also forms the hanging wall of a pegmatite dike 20 to 25 feet wide. The junction of the Gladstone and Poorman veins with the Gold Medal vein does not show on the tunnel level, but it is reported that the Poorman-Gold Medal junction has been explored on the 275-foot level.

Twenty feet west of the crosscut, the Poorman and Gladstone veins are cut by a strong northwesterly fault called the Flat "vein." This fault strikes N. 30°–55° W. and dips 30°–50° SW. It is unmineralized throughout most of its extent, but has apparently been effective in the localization of ore bodies at its junction with the other veins.

About 180 feet north of the Poorman vein, the crosscut tunnel intersects the Grand Central vein, which ranges in strike from N. 88° E. to N. 70° W. and dips 60°–72° N. Thirty feet north of this vein is the Pride of the Mountain vein, which strikes N. 88° E. and dips 71° N. On the surface the Pride of the Mountain vein is on the south wall of the Poorman reef and in places cuts into the reef, but on the tunnel level the Poorman reef is not exposed.

Movement along the vein fissures has ranged from a few feet to as much as 25 feet. On the east-west veins the movement has been nearly horizontal, and the north walls have moved west 8 inches to 12 feet. Of these veins, the Gladstone is apparently the earliest. It is cut by the Poorman vein, along which its western segment has been displaced about 10 feet southwestward. The Poorman vein fissure was apparently formed shortly after the Gladstone, for both are cut by the Flat vein fault, along which their western segments have moved about 30 inches northwestward. The Flat vein zone, however, is so strong a fault, with so much gouge, that the movement along it was probably considerably more than is indicated on this displacement. Furthermore,

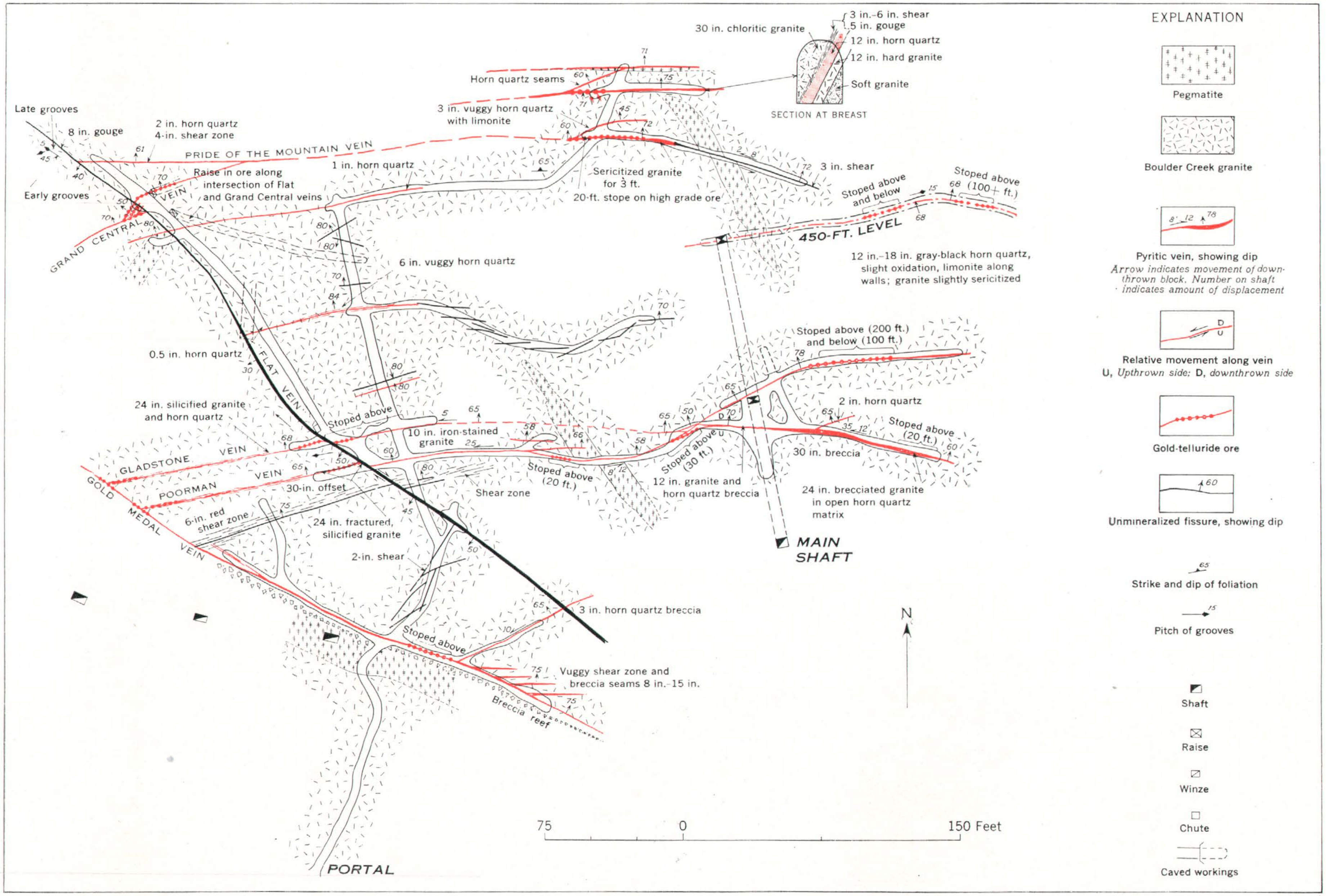

FIGURE 75.—Plan of the Poormans Relief mine, Gold Hill district.

the Flat vein fault displaces the Grand Central vein in the opposite direction, the segment on the west side of the fault having moved southeast about 9 feet. Slickensides on the walls of the Flat vein indicate two directions of movement; one set of grooves pitches 5° N. and another 45° N. It therefore seems probable that the Flat vein fault has undergone two periods of movement, both of them fairly large. It apparently cut through the Gladstone and Poorman faults shortly after their formation and displaced them about 10 feet north on the west side, the movement being about horizontal. Subsequently the Grand Central vein was formed, cutting through the Flat vein with little or no displacement. Later the Flat vein fault underwent a reversal of movement, its hanging wall moving up and to the east at an angle of about 45° for a distance of about 25 feet. Thus the west segment of the Grand Central vein was offset to the south, and the Gladstone and Poorman veins were restored to within a few feet of their original position.

The veins of the Poorman group range in width from a few inches to 2½ feet and are made up chiefly of sheared, sericitized, or silicified granite containing numerous seams of horn quartz.

The chief ore minerals are gold tellurides, of which sylvanite, petzite, and altaite appear to be the most abundant. Rusty gold is abundant in places in the upper levels of the mine and has been found as deep as the 250-foot level. Free mercury in the ore was found at a depth of 200 feet beneath the surface and apparently indicates the presence of coloradoite. Finely disseminated pyrite is common throughout the veins and is nearly everywhere associated with the ore. The wall rock is sericitized for a few inches to 3 feet on each side of each vein and in most places is more intensely sericitized along the ore bodies than elsewhere. Silicification is not common except within the veins.

Like most telluride ores, the ore from the Poorman mine shows a great range in grade. Ore shipped to the Boulder Sampler in the early days ranged from 1.8 ounces of gold and 3 ounces of silver to the ton to as much as 1,530 ounces of gold and 302 ounces of silver to the ton. Most of the shipments in ton lots or more assayed between 1.8 and 9.2 ounces of gold and between 3 and 12 ounces of silver to the ton. Most of the shipments of higher-grade ore were in lots of a few to a few hundred pounds, and few shipments contained more than 400 ounces of gold to the ton. The ratio of gold to silver ranged from about 10 : 1 to 1 : 2 but averaged about 2 : 1. The relatively high gold content is probably due to large amounts of rusty gold mined at shallow depths in the early days. Ore shipped in 1935 commonly ranged from 0.5 to 3 ounces of gold to the ton, and its silver content had a similar range. A few shipments, however, contained as much as 50 or 60 ounces of gold to the ton.

The occurrence of productive gold-telluride veins so far southeast of the main part of the Gold Hill district is probably due to the formation of structurally favorable fault fissures close to the junction of the Poorman and Maxwell reefs. This junction apparently served as a trunk channel for the circulation of ore-forming solutions. The chief factor governing the localization of ore in the mine appears to be junctions of veins. According to the miners, the principal junctions are those of the east-west veins with the Flat vein. Extensive stopes occur on both the Gladstone and Poorman veins, just above and just below their junctions with the Flat vein. A long narrow stope followed good ore up the junction of the Grand Central and Flat veins, the best ore coming from above the Flat. Good ore was also taken from the junctions of the Gladstone and Poorman veins. It is reported that high-grade ore was also mined from the junction of the Poorman and Gold Medal veins below the tunnel level. Abrupt changes in strike of the veins seems also to have had an influence in the localization of ore. As the south sides of the veins moved eastward in a nearly horizontal direction, openings were produced wherever a vein took a pronounced bend to the northeast. Thus on the Poorman vein in the vicinity of the shaft there are extensive stopes about 200 feet long and more than 100 feet high where the vein turns abruptly to a N. 60° E. direction.

INTEROCEAN MINE

The Interocean mine is located at Sunshine, in the eastern part of the district, 2¼ miles east of Gold Hill. The chief vein is covered by the Interocean, the Oceola, and the White Crow claims, which were formerly operated as separate mines but in 1934 were consolidated under the United Empire Gold Mines Co. The Interocean vein was discovered in 1876 and has been one of the most productive of telluride ore in the district. The value of output up to 1885 is reported to have been $50,000.[72a] The value of the total output to date has probably been at least several hundred thousand dollars.

The workings consist of the Interocean shaft, 600 feet deep with nine levels; the Oceola shaft, 150 feet deep with two levels; the White Crow shaft, 350 feet deep with seven levels; and the Interocean tunnel. The tunnel, at an altitude of about 7,100 feet, follows the vein for about 2,100 feet and lies beneath the shaft collars at depths of 130, 350, and 350 feet, respectively.

The chief wall rock throughout the mine is Boulder Creek granite, which is cut in places by small dikes of pegmatite 5 to 10 feet wide and mostly of northerly trend. The Interocean vein strikes about N. 20° E. in the southwestern part but swings to a N. 50° E. course

[72a] Corregan, R. D., and Lingane, D. F., Colorado Mining Directory for 1883, Denver, Colorado Mining Directory Co.

in the northeastern part. At this bend on the surface the vein appears to be joined on the north by the American vein, which strikes N. 30°–45° E. and dips about 84° SE., but this junction does not show in the Interocean tunnel. Near the portal of the tunnel the Interocean vein is joined on the east by the Monongahela vein, which strikes about N. 85° E. and dips about 80° N. Another vein, striking N. 40° E. and dipping 83° W., joins the Interocean vein on the north about 650 feet from the portal. Two hundred and fifty feet from the breast of the tunnel and 200 feet southeast of the Interocean vein a crosscut intersects a vein striking N. 45° E. and dipping 42°–55° SE. To the southwest this vein breaks up into a number of veinlets, which join the main vein in different places. Grooves on the walls of the Interocean vein indicate that the movement was nearly horizontal, and displacements of pegmatite dikes indicate that the southeast wall moved southwestward about 14 feet.

The Interocean vein ranges in width from 1 to 4 feet and is made up of sheared, sericitized, and in places silicified wall rock containing numerous interlacing seams of horn quartz. Locally it is a solid vein of horn quartz. Pyrite is finely disseminated throughout. The chief ore minerals are the gold tellurides, but in places free gold is abundant. According to M. S. Brandt, manager of the mine, most of the free gold came from the 100-foot and 150-foot levels, but some was found as deep as the 400-foot level. The tellurides are commonly associated with marcasite. A high-grade specimen donated by Mr. Brandt showed petzite, hessite, and free gold associated with marcasite. Calaverite and sylvanite have also been reported as common in places. The quartz gangue grades from gray to white in color and from horn to sugary in texture. In places small ankerite seams cut the horn quartz and are apparently later than the ore; locally minute galena and sphalerite crystals are found in vugs.

The ore taken from the Interocean vein system has been of moderately high grade. Ore shipped during the period 1878 to 1892, as indicated by the Boulder Sampler records, ranged from 0.86 to 2,169 ounces of gold to the ton and from 0.7 to 1,411 ounces of silver to the ton. Ore in shipments of several hundred pounds each commonly ranged from 23 ounces of gold and 17 ounces of silver to 198 ounces of gold and 392 ounces of silver to the ton, and ore in a few shipments ranging from a few pounds to 200 pounds each were of much higher grade.

Ore shipped in recent years has commonly ranged in grade from 0.43 to about 3 ounces of gold and from 1.5 to 25 ounces of silver to the ton. Ore taken from the stope at the junction of the Monongahela and Interocean veins averaged 2.927 ounces of gold and 24.84 ounces of silver to the ton. Ninety tons of ore shipped in 1927 and 1928 from the tunnel level near the Interocean shaft contained 0.43 to 0.71 ounce of gold to the ton. One hundred and fifty-three tons shipped in 1930 and 1931 from a stope on the Oceola part of the vein contained 0.41 to 0.51 ounce of gold and 1.4 to 1.5 ounces of silver to the ton.

Only scant data on the size and shape of the ore bodies are available, for the shaft workings were inaccessible in 1934. M. S. Brandt reports that there are extensive stopes in both the Interocean and the White Crow shaft workings. On the tunnel level, at the junction of the Interocean and Monongahela veins, there is a stope about 300 feet in length, which is reported to connect with large stopes in the shaft workings. Another stope extending about 100 feet along the drift and more than 40 feet above it lies at the junction of the main vein with a vein branching to the southwest 1,400 feet from the tunnel portal. A third stope lies near the breast of the tunnel, where a branch vein joins the main vein from the east. It therefore appears that junctions of the main vein with branch veins are the most influential factors in the localization of ore in the Interocean vein. Irregularities in the vein have probably also had an influence. As the southeast wall of the vein fissure moved southwest, openings favorable for ore deposition tended to form in the more eastward-trending parts of the vein. Changes in character of wall rock seem to have had little effect on ore distribution.

YELLOW PINE MINE

The Yellow Pine mine is on the northeast slope of Logan Hill, near the head of Sunbeam Gulch, about 3 miles southeast of Gold Hill. It is accessible over 7 miles of good automobile road from Boulder, the nearest shipping point. The mine is developed by six levels, opened by a number of adits, an underground shaft, and several winzes. The mine is the outstanding source of silver ore in the district but is also credited with an output of very high-grade free-gold ore from the upper levels. More than $125,000 worth of silver ore was shipped to the Boulder Sampler between 1878 and 1892, and the total value of output amounted to at least several hundred thousand dollars.

The predominant country rock of the mine is the Boulder Creek granite, but there is some pegmatite and aplite. In a few places it is cut by dikes of biotite monzonite porphyry and associated dikes of biotite latite intrusion breccia. The most conspicuous structural feature of the area is the Hoosier "dike" or breccia reef, which strikes northwest and is nearly vertical. It is not a simple fissure filling, as in many other places, but has a braided structure, and near the top of Arkansas Mountain it splits into two prominent subparallel branches connected by a westward-trending cross reef. (See pl. 2.) The southwest branch is the one known locally as the Hoosier dike and is the only part well shown in the mine workings.

The veins exploited include the northwesterly Yellow Pine vein and Hoosier breccia reef, the west-northwesterly Mud vein, and the northeasterly Gray Copper, Vaucleuse, South Vaucleuse, and Michner veins. The nearly vertical Hoosier reef, striking N. 40° W., is cut by the No. 6 adit about 240 feet from the portal and is here 50 feet wide. The Yellow Pine vein, to which most of the output of the mine is credited, follows the southwestern edge of the Hoosier reef for several hundred feet, and the drifts along it offer a good opportunity to observe the character of the breccia reef. Boulder Creek granite, pegmatite, and aplite are present, and all are brecciated and silicified in most places. Many seams of gouge cut the reef parallel or diagonal to its strike. Grooves, striations, and displacement along the northeast side show that the rock to the northeast moved down to the southeast at an angle of 70°. Northwest of the place where the Yellow Pine vein diverges from the breccia reef, striations and displacement indicate that the wall rock on the southwest side of the reef also dropped, the wall moving down to the south at 80°. Thus the movements along the two walls indicate that the middle part of the reef rose and became essentially a long narrow horst. Late movement along the Yellow Pine vein was nearly horizontal and obscured this relationship where the vein follows the wall of the breccia reef. Biotite monzonite porphyry and associated intrusion breccia (fig. 17, *A*) extend out from the Hoosier reef along late fractures and occur within the reef itself in late irregular fractures. The porphyry is strongly altered in most places, as is the adjacent country rock, but both it and the intrusion breccia are later than the silicification and most of the movement within the breccia reef. The horstlike attitude of the breccia reef itself suggests that some of the brecciation between the two walls is due to the upward push of an underlying magma that followed the general course of the reef, which can thus be properly classed as an intrusive breccia—the advance guard of an underlying intrusion. The biotite monzonite porphyry, however, is distinctly later than the magma responsible for the brecciation and silicification of the Hoosier reef.

The Yellow Pine vein follows the southwest wall of the breccia reef for more than 1,000 feet, but just west of the portal of the No. 5 adit it breaks from the reef, swings northwestward, and evidently feathers out within a short distance, as it has not been seen in the Logan property, which is on its line of strike. Along the Yellow Pine vein the right-hand wall moved forward at a very low angle, but the displacement is small and does not exceed 6 feet. Argentiferous gray copper-galena ore occurred in nearly vertical chimneys 50 to 100 feet in stope length but several hundred feet in pitch length. The stope seen by the writers followed a nearly vertical pegmatite dike, along which the vein dipped steeply northeast. Throughout the barren section of the vein on the No. 6 level the dip is steeply southwest.

The Mud vein strikes west-northwest, dips approximately 35° N., and intersects the Hoosier reef 700 feet from the portal. The Mud vein itself has been productive only locally, but most of the ore in the South Vaucleuse and Michner veins was found just below their intersections with the Mud vein. Throughout the productive part of the Mud vein on the sixth level it is a gougy sheeted zone 1 to 10 feet wide containing one or two intrusion breccias. Several periods of movement have affected it. The net movement has been that of a reverse fault, the footwall moving down and to the northeast; the direction of striations ranges from N. 65° E. to N. 30° E. The northeasterly veins, such as the Vaucleuse and Michner, are much stronger below the Mud vein than are their continuations above it. The displacement of these veins by the Mud vein fissure shows that much of its movement took place after the northeasterly veins had been formed, but the weakness of the displaced segments in the hanging wall shows that the Mud vein fissure was already in existence when the fractures occupied by the northeasterly veins were formed, the northeasterly veins tending to end at the Mud vein fracture or to extend only slightly beyond it. This history of recurrent movement alternating on the Mud vein and the northeasterly veins is similar to that found in the Logan mine.

Between the intersections of the Michner and South Vaucleuse veins with the Mud vein a light-gray felsite lies close to the hanging wall. To the east the felsite grades into an intrusion breccia, which soon becomes indistinguishable from the gray gouge that makes up most of the Mud vein in this vicinity. At least part of this gouge resulted from attrition of the intrusion breccia during subsequent movements along the fault. The felsitic intrusion breccia is distinguishable again about 250 feet to the east and can be traced approximately 100 feet along the drift. It is cut sharply by the later biotite latite intrusion breccia and has been much more affected by the repeated movement along the vein than has the later breccia. That part of the Mud vein in which the felsitic intrusion breccia is recognized coincides with the zone of most intense lead-silver deposition, and it is possible that the magma from which the lead-silver minerals were derived is closely connected with the felsite porphyry. The biotite latite intrusion breccia is in the hanging wall of the Mud vein, and its relation to the lead-silver ores could not be ascertained. The occurrence of biotite latite intrusion breccia in the Mud vein on the third level of the Logan mine has been interpreted as indicating intrusion along the Logan vein, but it is also possible that it is more directly connected with the biotite latite intrusion breccia of the Mud vein in the Yellow Pine mine.

The South Vaucleuse vein follows a sinuous course and dips 25°–40° SE. It occupies a fault, the hanging wall of which moved upward to the west, favoring the creation of open spaces where the dip decreases or the vein swings to the right. Close to its intersection with the Mud vein both the course and the dip favor the enlargment of the vein, and the greatest output came from this place. The localization of the ore was apparently related to the intersection of the Mud vein as well as to the spaces created by the movement of the walls; the tenor of the ore decreased with distance from the intersection. So far as is known the vein is barren beyond a point 300 feet southwest of the Mud vein.

The Michner vein occupies a steep fault, the southeast side of which moved downward to the northeast at an angle of 70° for approximately 20 feet. The vein dips both northwest and southeast, but it is apparent that the most open space along it occurred where the vein dips southeast, a position in harmony with the occurrence of the ore shoots. The ore is further localized close to the intersection of the overlying Mud vein, a relation already noted in the South Vaucleuse.

On the sixth level the northern Vaucleuse vein is a seam of gouge 12 to 16 inches thick dipping east at 30°–50°. The vein is apparently not productive even in its upper levels except close to its intersection with the Gray Copper vein. The Gray Copper vein on the 60 level is a small tight fracture, which evidently does not persist far beyond the breast of the southwesterly drift that exposes it, as its intersection with the Mud vein 150 feet to the southwest has not been recognized. Where seen, the Gray Copper vein consisted of 1 to 6 inches of sheared rock containing a maximum of 3 inches of gray copper ore frozen tightly to the walls.

In both the South Vaucleuse and the Michner veins the ore was found through a width ranging from 6 inches to 3 feet. In many places in the South Vaucleuse, the ore is "frozen" to slightly altered pegmatite, but the country rock adjacent to the Michner vein is strongly sericitized.

The chief minerals of the Yellow Pine ore are argentiferous galena and argentiferous gray copper. Some sphalerite and pyrite are associated with the ore, and the chief gangue is glassy quartz and silicified wall rock. Headden [73] reports the presence of stromeyerite in the ore, and its presence in the Vaucleuse vein has been verified by the writers. Here it is associated with stephanite, galena, and bornite as a late hypogene mineral. More than 200 shipments of Yellow Pine ore were made to the Boulder Sampler from 1878 to 1892, most of them ranging in weight from 1 to 10 tons. The majority of these shipments contained 100 to 250 ounces of silver to the ton, but the grade of some ranged between 28 and 100 ounces, and a few contained much more than 250 ounces. One shipment of 222 pounds made on December 30, 1882, had a grade of 2,278 ounces of silver and another of 1,802 pounds shipped on June 3, 1890, a grade of 1,440 ounces of silver to the ton. Most of the shipments contained no gold, but a few contained a trace to 0.8 ounce of gold, and one shipment from the Gray Copper vein contained 5.3 ounces of gold and 197 ounces of silver to the ton.

[73] Headden, W. P., Stromeyerite—Yellow Pine mine, Boulder County, [Colo.]: Am. Mineralogist, vol. 10, pp. 41–42, 1925.

INGRAM MINE

The Ingram mine is on the east side of Mineral Point Gulch, half a mile northwest of Salina, in the central part of the Gold Hill district. The workings consist of a main inclined shaft, 1,000 feet deep along the vein and about 900 feet vertically with 10 levels aggregating about 6,000 feet of workings. A tunnel connects with the 120-foot level of the shaft, and in recent years the shaft was operated from this level. The collar of the shaft is at an altitude of 7,060 feet, and the portal of the tunnel is at an altitude of 6,950 feet.

The Ingram mine was discovered prior to 1882 and has supplied several hundred thousand dollars worth of gold-telluride ore. After being idle for many years, it was reopened in 1935 by the Mines Development Corp. In 1936 this company sank the shaft from the 7th to the 8th level and from October 19, 1936, to November 31, 1937, produced 2,022 ounces of gold and about an equal amount of silver from the ore mined between the two levels.[74] The ratio of gold to silver in this ore was about 10:9. In 1938 the company extended the shaft to the 10th level, but operations were abandoned the following year.

The country rock in the Ingram mine is chiefly gneissic Boulder Creek granite, the foliation of which has a general northeasterly strike and moderately steep northwesterly dip. Dikes of pegmatite and aplite trending northeastward and northwestward are common in the workings. A northeasterly dike of fine-grained granite gneiss is exposed on the 610-foot level. On the lower levels, 100 to 275 feet west of the shaft, there are several narrow dikes of quartz diorite gneiss a few inches to 5 feet wide. They range in strike from N. 10° E. to N. 55° W. and in dip from 62° W. to 80° E. These dikes, which are nearly at right angles to the vein, have apparently had a strong influence on the localization of the ore.

The Ingram vein occupies a rather irregular fissure, which strikes from N. 10° E. to N. 75° E. and dips 52°–70° NW. In the upper levels the average strike is about N. 45° E. On the 120-foot level there are two

[74] Data furnished by H. C. Shotwell of the Mines Development Co.

nearly parallel veins 20 to 40 feet apart and numerous veinlets extending diagonally across from one to the other (pl. 26). These veins converge upward and on the 80-foot level form a strongly mineralized fissure zone 20 feet wide. They apparently also converge downward and join somewhere between the 120-foot and 245-foot levels. In the lower levels the Ingram is mostly a single vein, but it splits to the east on the 610-foot level, 210 feet east of the shaft. In general, the dip of the vein is relatively steep in the upper workings and tends to decrease with depth.

Movement along the Ingram vein fissure has apparently been rather complex. Cross faults and dikes have been displaced eastward on the south side of the vein in some places and westward in others, but the horizontal displacement is nowhere more than 5 feet. Some grooves on the walls pitch 60°–65° NE. and others pitch 58°–60° SW. It therefore seems probable that the movement of the vein walls has been somewhat different in different blocks bounded by cross faults and dikes. Taken as a whole, the displacements seem to indicate that the hanging wall moved up at a steep angle, but the total displacement was probably not more than 10 feet. Some of the grooves pitching northeast are on late carbonate seams and seem to indicate that the hanging wall moved down. If so, there was a slight readjustment after the deposition of the telluride ore, the hanging wall moving a few feet downward.

There are several barren faults in the mine that have had a marked influence on the localization of ore. The most extensive of them is the Fortune breccia reef, which strikes N. 80°–85° W. and dips 30°–45° N. It can be traced for more than 2 miles across the central part of the Gold Hill district. This reef crops out at the surface only 50 feet northeast of the main shaft, but on the 6th level it is 725 feet northeast of the shaft. It is commonly made up of 3 to 5 feet of strongly sheared and gougy wall rock but locally widens to a weak shear zone 15 feet wide. It contains a small amount of hematite in places and is silicified in the vicinity of the Ingram vein.

On the lower levels of the mine, in a zone extending from 25 feet east to 250 feet west of the shaft, there are several faults of moderate to small size, which also were formed during the breccia-reef period of faulting. They range in strike from north to N. 30° W. and in dip from 80° E. to 82° W.; without exception they follow dikes of quartz diorite gneiss. These faults range from 2 inches to 5 feet in width and are marked by strongly sheared, chloritized quartz diorite gneiss and some granite. The larger ones are partly silicified and contain some fine-grained hematite.

The Ingram vein ranges in width from a few inches to 8 feet and is commonly made up of interlacing horn-quartz veinlets in a zone of silicified or sericitized wall rock. Small quartz veinlets and slips commonly branch out into the walls. The chief ore minerals are gold tellurides, but galena, gray copper, and sphalerite have been found in places and are locally abundant enough to form lead-silver ore. Pyrite is very finely and sparingly disseminated throughout the horn quartz and silicified wall rock. Ankerite and rhodochrosite are moderately abundant in places, either separately or together, and occur in veinlets cutting the horn quartz or cementing horn-quartz breccia.

The chief telluride mineral in the ore is sylvanite, but small amounts of petzite are intergrown with it. In the high-grade ore the sylvanite is commonly in bunches of roughly parallel, broad, thin tabular blades (fig. 74, *E*). This ore usually breaks parallel to the broad faces and exposes a spectacular sheen of sylvanite crystals.

The lead-silver ore is definitely later than the telluride ore. Galena, sphalerite, and gray copper with small amounts of pyrite and chalcopyrite are associated with ankerite and rhodochrosite in veins that cut or border the horn quartz. In places these ore minerals are disseminated in the ankerite, but in other places the sulfides form solid seams 2 to 4 inches wide with thin borders of ankerite.

Nearly all the ore shipped from the Ingram mine has been telluride ore, and some has been of very high grade. Shipments to the Boulder Sampler during the period 1882–87 seem to be fairly representative of the early production. Relatively low-grade ore in lots of one to several tons contained 1.5 to 13 ounces of gold and 4 to 25 ounces of silver to the ton. High-grade ore shipped in lots of 10 to several hundred pounds contained 40.6 to 1,139 ounces of gold and 60 to 1,036 ounces of silver to the ton. Much of the ore shipped from 1935 to 1938 contained 0.78 to 7 ounces of gold to the ton, and its silver content was about that of the gold. The best shipment of high-grade ore taken out between levels 7 and 8 in 1937 weighed 850 pounds and brought a net return of $3,600 after treatment and freight charges had been paid.

Lead-silver ore from the east drift of the 900-foot level contained 1.5 ounces of gold and 18 to 20 ounces of silver to the ton.

In most of the mine, the chief wall-rock alteration has been sericitization. In most places bordering ore bodies the wall rock is sericitized for distances of 2 to 3 feet from the vein, but along barren parts of the vein this alteration effect commonly extends for only a few inches to 1 foot from the vein. In the upper levels, on the underside of the Fortune dike, silicification of the wall rock is common. It extends for a distance of 1 to 6 feet from the vein and in most places borders ore. In other parts of the mine there is little silicification of the wall rock except within the vein itself. Pyrite is for the most part finely disseminated in silicified wall rock.

Most of the ore shoots in the Ingram mine have been small but of high grade, as shown on plates 26 and 27. They seem to be limited to a zone of mineralization about 600 feet in breadth, which pitches about 65° to the southwest in the plane of the vein but seems to steepen in the bottom levels. Two or more ore bodies have been found on every level from the surface to the bottom of the shaft. The largest ore body was between the surface and the 245-foot level on the underside of the Fortune dike and measured about 300 feet in pitch length, 175 feet in breadth, and in most places had a thickness of 2 to 8 feet. On the 80-foot level, where two parallel veins converge, a body 20 feet wide was mined. Smaller ore bodies also extended across to the upper side of the Fortune dike. Most of the ore bodies in the mine range from 30 to 150 feet in length, 25 to 100 feet in breadth, and 1½ to 6 feet in thickness. On the 315-foot level, however, west of the shaft, there is a continuous stope 425 feet long and 20 to 60 feet high, and just west of the shaft there was a nearly continuous ore shoot extending from above the 510-foot level to the 710-foot level, having a length of about 250 feet and a breadth of 50 to 100 feet. In these moderately high grade ore shoots there are scattered small pockets of very rich ore.

The chief factors localizing ore in the Ingram mine seem to be junctions of the vein with earlier faults. The largest ore body in the mine was found in the upper part at the junction of the Ingram vein with the Fortune reef where the vein split into two parallel branches (pls. 26 and 27). Most of the ore was deposited on the under side of the reef. Apparently the reef served as a dam or baffle to the ore-forming solutions rising from depth and caused deposition on the under side, but in places small amounts of the solutions broke through and deposited ore above the reef. The branching and uniting of the two parallel splits of the Ingram vein in the upper workings were apparently also effective in the localization of the ore, for on the lower levels the intersection of the vein and the reef is barren.

On the lower levels the steep northwestward-trending breccia reefs and the dikes of quartz diorite gneiss seem to have been the chief factors in localizing the ore. Most of the ore shoots in the lower workings are bounded either on the west or on the east by one of these reefs or by a gneissic quartz diorite dike, and some shoots are bounded at both ends by faults or dikes. It therefore seems probable that these cross structures caused differential movement in different blocks of the walls of the Ingram vein, the walls along some blocks being opened and those along others being closed. The cross structures also caused irregularities and resulting openings favorable to ore deposition to form in the vein. In addition, the early reverse movement tended to open the more gently dipping parts of the vein, and these parts are therefore favorable for the occurrence of ore. Alternations of granite and pegmatite in the wall rock also seem to have influenced the formation of openings by causing irregularities in the vein and differential movement along the wall, and we find that many of the ore bodies are bounded by pegmatite along one wall or at one end.

GRAND REPUBLIC MINE

The Grand Republic vein was one of the most productive in Boulder County from 1934–37, when it was operated by the St. Joe Mining and Milling Co. In 1935 its output amounted to 28,515 tons of ore having an average gold content of about 0.28 ounce to the ton. The mine is in Sunbeam Gulch, on the east side of Logan Gulch 5 miles west of Boulder, at an altitude of about 7,000 feet. It is easily accessible by truck and automobile. In 1935 the ore was moved by truck to the flotation mill on Lefthand Creek, north of Gold Hill, at a cost of about 88 cents a ton.[75]

The mine is developed by a short shallow adit with about 800 feet of workings (fig. 76) and an inclined shaft, from which levels were turned at slope distances of 100, 160, and 220 feet, aggregating about 1,100 feet of drifts.

The country rock of the mine is Boulder Creek granite cut by related pegmatite and aplite dikes. The strongly silicified Hoosier breccia reef lies 100 feet east of the shaft and locally follows a northwest dike of pre-Cambrian pegmatite. The reef is cut and offset about 100 feet by the Grand Republic vein, the south side moving east.

As shown in figure 76, the Grand Republic vein is more properly termed a lode; it consists of a mineralized fracture zone, which strikes from N. 80° W. to N. 55° E. and averages about N. 80° E. The lode dips about 62° N., but the strongly mineralized fractures within it range in dip from vertical to 35° N. The hanging wall of the lode is a nearly continuous fracture that dips northward at 55°–65° near the surface but steepens to 80° at the 100-foot level and below. Grooves on the walls of this fracture pitch about 15° W., indicating nearly horizontal movement. The displacement of the Hoosier breccia reef totals about 115 feet, but it is distributed through the lode and is probably the result of movements that took place over a long period of time and may have alternated with movements along the Hoosier reef itself—a process similar to the one that took place in the Yellow Pine mine nearby. (See p. 248.) The lode is not well exposed east of the reef but seems much narrower than to the west. For a distance of 400 feet to the west it ranges from 30 to 100 feet in width, but farther west it is limited to a strong gougy zone only a few feet in width along the hanging wall. In the wider part of the lode most of the fractures

[75] Guiteras, J. R., Operations and costs at the St. Joe Mining and Milling Company, Boulder County, Colo.: U. S. Bur. Mines Inf. Circ. 6976, p. 31, 1937.

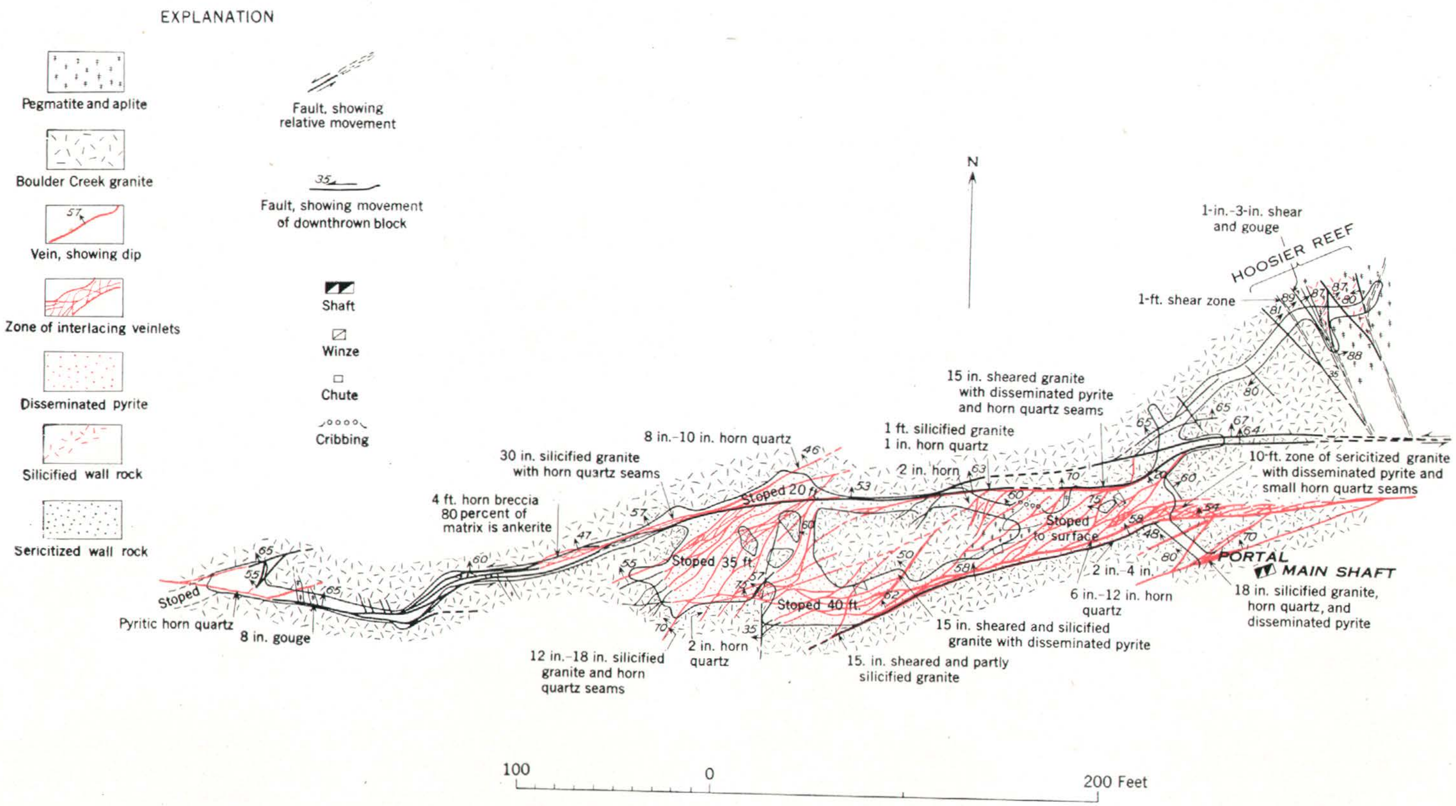

FIGURE 76.—Plan of the 50-foot, or tunnel level, of the Grand Republic mine.

strike either subparallel to the hanging wall or northeastward in an echelon pattern. Although the footwall of the lode is not a single continuous fracture, the bulk of the fractures in the widest part lie between the hanging wall and a nearly parallel moderately persistent, slightly mineralized fault that dips about 50° N.

The rock between the footwall and hanging-wall fractures is strongly altered, as shown in figure 76. The intensity of alteration is indicated by the abundance of quartz, pyrite, chlorite, and sericite. The granite is somewhat sericitized throughout the lode, and along many of the fissures the sericitization has been intense. The biotite of the granite is strongly chloritized in many places, especially where pyrite is abundant, but sericitized rock may be evident where no chlorite is evident megascopically. Pyrite is widely disseminated but is much more abundant in certain zones than others. Silicification accompanied by the introduction of pyrite was more localized than the other types of alteration. Some of the silica was introduced as veins and veinlets of horn quartz, and some effected a mass replacement of the granite near channels of mineralization.

The character of the altered rock is used by the miners as a guide in discriminating between commercial ore and waste. Rock in which the biotite is apparently unchloritized is below commercial grade. Abundant fine-grained disseminated pyrite or the presence of many seams of pyritic horn quartz in altered granite are the most reliable indications of commercial ore. Near the surface Lovering observed some free gold associated with a late dark horn quartz, but the gold in most of the ore mined was not discernible. According to Guiteras,[76] the gold appeared to be in the form of tellurides associated with pyrite, but so far as the writers have been able to learn no telluride minerals have actually been observed. Small amounts of marcasite and arsenopyrite were noted in the ore by Guiteras, and both were found by the writers in specimens of ore from the east end of the 220-foot level, where they were associated with ferberite. Pyrite, arsenopyrite, and quartz were earlier than the ferberite, which was contemporaneous with or slightly earlier than marcasite. Arsenopyrite has not been reported in telluride ore elsewhere in the Front Range, and its presence suggests that the ore may belong to the pyritic gold group. Both pyritic gold ore and telluride ore have been mined in the Logan mine, a quarter of a mile to the southeast. The ore was slightly oxidized in the tunnel level, but on the 100-foot level little limonite was observed. Enrichment by supergene solutions was probably of little influence in raising the tenor of the bulk of the ore mined.

The ore mined in 1935 contained $7.291 worth of gold and $0.057 worth of silver per ton.[77] The cost of mining was $2.434 per ton, the cost of milling $1.677 per ton, and the net profit from the operation before allowing for depletion $1.763 per ton. According to Mr. Orville Kelly, the mine foreman, a gold content of 0.18 ounce to the ton was regarded as the lower limit of commercial ore. A 660-pound sample of ore assayed for testing purposes in 1936 had the following composition:[78] 0.26 ounce of gold and 0.30 ounce of silver to the ton, 5.84 percent of iron, 1.77 percent of sulfur, 0.07 percent of arsenic, and 81.20 percent of insolubles.

The intersection of the northwesterly Hoosier breccia reef and the westerly Poorman reef lies only a few hundred feet north of the mine and suggests an area where mineralization would be expected. The ore shoot lies just west of the Hoosier breccia reef in a vein occupying a strong cross fault and pitches north-northeastward toward the reef. The movement of the walls of the Grand Republic lode was such that northeasterly fissures tended to open and afford places for mineralization. Boulder Creek granite is a better host rock than the pegmatite in this mine.

The vein material on the 220-foot level was visibly poorer than that on the 160-foot level and was of too low grade to be mined. The workings on this level, however, have apparently not penetrated the hanging-wall fissure, and it is possible that further exploration will reveal ore of commercial grade. The presence of ferberite in only the east end of the bottom drift is of interest. In the nearby Logan mine a body of auriferous tungsten ore stoped on the lowest levels yielded $80,000 in ferberite. It seems possible that the ferberite in the Grand Republic mine may be the top of a shoot of tungsten ore. The strength of the premineral fault zone and the proximity to the Hoosier reef should encourage deeper development.

OTHER MINES

Data on other representative mines are given briefly below.

CASH

Development.—Shaft 600 feet deep with several thousand feet of levels. Tunnel more than 500 feet long connects with upper workings.

Production.—Several hundred thousand dollars.

Veins.—Cash: Strike N. 52°–58° E.; dip, 68°–80° NW.; cuts Hoosier reef 650 feet southwest of shaft. Freiberg: Strike, N. 30°–40° E.; dip, nearly vertical; joins Cash vein 50 feet east of shaft. Parallel: Strike N. 15°–40° E.; dip, 75°–85° northwest; joins Cash vein 100 feet southwest of shaft. Stirling: Strike, N. 38° E.; dip, 80°–85° SE.; northeastward continuation of Cash vein. Veins 10 inches to 12 feet wide, average 2 or 3 feet; made up of interlacing horn quartz seams in sericitized granite.

Wall rock.—Boulder Creek granite and small pegmatite dikes.

Ore and sulfide minerals.—Petzite, sylvanite, and other telluride minerals, pyrite, a little galena, and sphalerite.

Gangue minerals.—Horn quartz and silicified granite.

Ore shoots.—Chiefly a single ore shoot from surface to 600-foot level; stope length at surface 300 to 400 feet.

[76] Guiteras, J. R., op. cit., p. 6.

[77] Idem., p. 31.

[78] Idem, p. 6.

Tenor.—Medium to high grade ore. Large lots shipped to Boulder Sampler, 1887 to 1888, contained 0.65 to 5.85 ounces of gold and 4.5 to 26 ounces of silver per ton; small lots contained 11.2 to 312 ounces of gold and 30 to 754 ounces of silver per ton. Ore shipped from dumps contained 0.18 to 0.36 ounce of gold per ton.

COLD SPRING AND RED CLOUD

Development.—Discovered May 1872. Shaft 871 feet deep (caved for many years). Long crosscut intersects vein at depth of 675 feet.

Production.—Several hundred thousand dollars. $100,000 in 1872.

Veins.—Cold Spring and Red Cloud, nearly parallel, 35–50 feet apart near surface, separated by porphyry dike, Cold Spring on northwest side. Both strike N. 40°–45° E., dip 78° NW. to vertical, and are 2 to 12 feet wide; southeast walls moved southwest. Veins converge downward and join at depth of 470 feet, where dike thins out; they form a single gouge seam in lower levels. Veins cut Hoosier reef about 50 feet southwest of shaft.

Wall rock.—Boulder Creek granite and biotite monzonite porphyry dike.

Ore and sulfide minerals.—Petzite, sylvanite, and other tellurides, pyrite, and a little galena.

Gangue minerals.—Horn quartz and altered wall rocks.

Ore shoots.—Mostly confined to upper 400 feet. Little ore below 470-foot level.

Tenor.—Mostly high-grade ore. Shipments to Boulder Sampler, 1879–80, contained 4 to 58.8 ounces of gold and 10 to 244 ounces of silver per ton. Small lots contained 124 to 490.5 ounces of gold and 386 to 1,800 ounces of silver per ton.

EMANCIPATION

Development.—Shaft 575 feet deep, with 8 levels 275 to 575 feet long; Gardner tunnel, intersecting shaft 175 feet below collar, has 1,500 feet of workings, mostly on vein.

Veins.—Emancipation: Strike, N. 45° E.; dip, 75° NW. Gardner: Strike, N. 45° E., dip, 75° NW. Western Slope: Strike, N. 75° E.; dip, 70° N.; veins few inches to 12 feet wide. Emancipation and Gardner veins 150 feet apart. Western Slope vein extends diagonally between these. North of Western Slope vein, system of discontinuous N. 80° E. veinlets run diagonally across from Gardner to Emancipation. Movement on all veins nearly horizontal. On Emancipation, southeast wall moved southwest 10 feet. On Gardner southeast wall moved southwest and down 10° for 15 to 20 feet. On Western Slope, southeast wall moved northeast and down 15° for 1 foot. Thus movement on vein system was as 2 wedges moving in opposite directions. Veins lie on south side of Fortune dike, which strikes N. 70° W. and dips 45° N.

Wall rock.—Boulder Creek granite: foliation trends N. 75° E. and dips 80° N. Dikes of Silver Plume granite and of pegmatite. Granite sericitized 6 inches to 2 feet beyond veins and partly sericitized several feet farther.

Ore and sulfide minerals.—Gold tellurides, free gold, and some pyrite.

Gangue minerals.—Horn quartz, silicified granite, and some calcite.

Ore shoots.—Largest ore bodies on Emancipation vein. One at junction with Western Slope vein has stope length of 250 feet, height of 600 feet, and thickness of 1 to 6 feet. Another, where vein of N. 80° E. system joins Emancipation, has stope length of 125 feet and vertical length of 400 feet. Small stopes on Gardner and Western Slope veins near junctions.

Tenor.—Medium-grade to high-grade ore. Shipments to Boulder Sampler, 1879 to 1885, contained 1.7 to 15.8 ounces of gold and 1 to 35 ounces of silver per ton. Small lots contained 16 to 581.4 ounces of gold and 11 to 430 ounces of silver per ton.

LOGAN

Development.—Seven tunnels.

Veins.—Logan: Strike, northeast north of Mud vein and north to northeast south of Mud vein; dip, 60°–75° N., north of Mud vein and 40°–70° W. south of Mud vein; 6 inches to 3 feet wide. North of Mud vein, hanging wall of Logan vein moved down and southwest at 65° for 3 feet. Between Mud and Flat veins, hanging wall moved up and southeast. Teller: Nearly parallel with Logan; 3 feet wide. In early movement hanging wall moved down and southwest at 20°; in later movement hanging wall moved up and southwest at 50°; in both cases right-hand wall moved ahead. Mud vein: Strike, northwest; dip, 20°–45° N. Gougy zone below 3d level; horsetails above and represented by number of northward-dipping faults. Reverse fault and right-hand wall moved ahead. Successive movements along both Logan and Mud veins, followed by introduction of intrusion breccia and further movement on both veins. Flat "vein": Strike, northwest; dip, 20°–45° N.; 600–700 feet S. of Mud vein.

Wall rocks.—Boulder Creek granite, sericitized along veins. Dike of monzonite porphyry in Logan vein at intersection with Hoosier breccia reef. On Mud vein silicified breccia on hanging wall. Biotite latite intrusion breccia follows intersection of Mud and Logan veins up to 3d level.

Ore and sulfide minerals.—In Logan vein, gold, gold telluride, pyrite and ferberite, some argentiferous tetrahedrite, sphalerite, and galena. In Teller vein, gold telluride. In Mud vein, pyrite and gold.

Gangue minerals.—Wall rock and chalcedonic quartz.

Changes with depth.—On Mud vein mineralization is very meager in upper levels.

Ore shoots.—In Logan vein most of gold ore is between intersections with Flat and Mud veins. Tungsten ore shoot 60 feet long and 80 feet deep north of Mud vein near intersection with Hoosier reef. Most stopes are where openings were formed by vein swinging left or by dip flattening. Branch veins yielded much ore. On Teller vein several large stopes; rich ore body beneath intersection with minor Albany vein; other ore bodies between Mud and Flat veins.

Tenor.—Medium-grade to high-grade ore. Shipments to Boulder Sampler 1879 to 1885 contained 0.5 to 12.8 ounces of gold and 1 to 51 ounces of silver per ton. Small lots contained 14.9 to 550.8 ounces of gold and 13 to 738 ounces of silver per ton. Silver ore from fifth level assayed 50 to 150 ounces of silver per ton.

MELVINA

Development.—Discovered July 1875. Shaft 550 feet deep (700 feet on the incline) with 9 levels; two tunnels connect with shaft workings about 100 and 200 feet below surface; total workings more than 5,000 feet.

Production.—$300,000 up to 1883.

Vein.—Melvina: Strike, N. 15°–40° E.; dip, 55°–78° NW.; 1 inch to 2½ feet wide, ore seams commonly 2 to 12 inches wide. Occupies breccia reef fissure northeast of shaft, branches from it to southwest.

Wall rock.—Boulder Creek granite and pegmatite.

Ore and sulfide minerals.—Gold tellurides and free gold, a little pyrite and galena.

Gangue minerals.—Horn quartz and fluorite.

Ore shoots.—In upper 6 levels, ore shoot 550 feet in pitch length and 400 feet in stope length; in lower levels, a second ore shoot 230 feet in pitch length and 120 feet in stope length; both pitch about 45° NE. Upper ore shoot apparently controlled by junction of vein with breccia reef fissure.

Tenor.—Ore mostly high grade, commonly contains a few ounces to 30 ounces of gold per ton; some small shipments contained 66 to 2,115 ounces of gold per ton. Silver content averages about same as gold. Shipments from dump contained 0.11 to 0.46 ounce of gold per ton. Stope fill in places contained 0.75 to 1.10 ounces of gold per ton.

WOOD MOUNTAIN MINE GROUP

Development.—Wood Mountain crosscut tunnel, 1,750 feet long, connects with 2,750 feet of drifting; many stopes.

Production.—Total, about $1,000,000: 1928, $6,999.57; 1929, $8,008.20; 1930, $2,777.67.

Veins.—Eight veins range in strike from N. 5° E. to east. Zopher: Cut by tunnel 950 feet from portal; strike, N. 70° E. to N. 83° W., average N. 88° E.; dip, 50°–78° N.; 1 to 15 feet wide. Earliest of group. Cut by Franklin vein. Several veins run into Zopher but do not cross it. South wall moved east, probably 20 feet or more. Summit: In tunnel 120 feet south of Zopher vein; strike, N. 55°–70° E.; dip, 45°–56° NW.; 1½ to 3 feet wide. Joins Zopher vein 250 feet east of crosscut. New Era: Strike, N. 40° E.; dip, 80° NW.; ½ to 6 inches wide. Cuts diagonally between Summit and Zopher veins. Movement very small. Gray Copper: Strike, N. 20°–38° E.; dip, 68°–74° NW.; 1 to 2 feet wide. Movement horizontal; east side moved south 35 feet. Joins Zopher vein at crosscut. Henry: Strike, N. 13° E.; dip, 68° W.; joins Zopher on south 130 feet west of crosscut. Franklin: Cut by crosscut 1,320 feet from portal; exposed for 1,000 feet in tunnel; strike, N. 5°–30° E.; dip, 80° NW. to vertical; 8 inches to 2½ feet wide, locally as much as 4 feet. 370 feet south of crosscut, vein cuts branch of Zopher and displaces it 12 feet south on east side. Here Zopher is a barren shear zone 3 inches wide. Franklin-Gillard: Strike, N. 35° E.; dip, 80° W.; 8 inches wide, 4 feet at junction; splits from Franklin at crosscut junction. Star: Cut by crosscut 1,730 feet from portal, explored 180 feet; strike, N. 22°–35° W.; dip, 73°–82° W.; 4 to 18 inches wide. East wall moved south horizontally. Vein is 420 feet west of Franklin and does not intersect any other vein of group.

Wall rock.—Boulder Creek granite. Foliation trends N. 60° E., and dips 55° NW. Pegmatite and aplite dikes in places. Walls sericitized 1 to 3 feet from vein, and locally silicified. Some kaolinic alteration on Franklin vein.

Ore and sulfide minerals.—Gold tellurides and free gold, some marcasite and pyrite. A little galena and sphalerite in Summit vein. Free gold in New Era and Star veins.

Gangue minerals.—Horn quartz, altered or silicified wall rock; a little calcite in Summit and New Era veins.

Ore shoots.—Chiefly localized by junction of veins. Locally character of wall rock had effect. Irregularity of veins, plus movement, had little effect. Extensive stopes on Zopher vein due to junction with Gray Copper, New Era, and Summit veins. Stope 420 feet long and 30 to 120 feet high between junctions with Summit and Henry veins. New Era vein stoped 80 feet high between Summit and Zopher veins. On Gray Copper vein, few small stopes on tunnel level, larger stopes near surface. Stope 100 feet long and 25 to 30 feet high where vein cuts diagonally across aplite dike. Ore in Henry vein only where it joins other veins. Franklin vein mostly barren on tunnel level, several ore shoots in tunnels farther west.

Tenor.—Average value of ore milled in 1928–30 under $5 per ton; average value of smelting ore, 1928–30, $25 per ton. Concentrates shipped averaged $50 per ton. In Summit vein principal values were in silver.

JAMESTOWN DISTRICT

LOCATION, HISTORY, AND OUTPUT

The Jamestown mining district lies in the central part of Boulder County, 9 miles northwest of Boulder, and is easily accessible over a good automobile road with a gentle grade. Jamestown, the only town in the district, has a population of about 100. The district includes approximately 36 square miles and ranges in altitude from 6,300 to 8,600 feet. It is well watered and has a good supply of native timber.

In the early summer of 1865 Captain Buchanon, Johnny Noop, Hutchinson, and James, after whom the camp was named, left Blackhawk and prospected along the valley of Little James Creek to the west of Jamestown. They returned to Blackhawk in the fall and displayed such rich specimens of gold ore that about 500 people flocked into the new district the following spring. The Buckhorn was one of the first claims located and became one of the chief sources of lead-silver ore in the district. The first mill was erected in 1867 by Willard at the junction of Big and Little James Creeks.

In October 1875 the first telluride ore was discovered on the John Jay property, which was staked by A. J. Vanderen and Edward Fuller. The total value of output during the first year was between $40,000 and $50,000. The Golden Age vein was discovered in the same year, the Smuggler was located the following spring, and the Buena vein was found in 1879.

Jamestown's biggest "boom" came at the beginning of 1883. In January Colonel Straight shipped some rich lead carbonate ore from the Buckhorn and Argo mines, and the rumor soon spread that large blanket deposits of lead-silver ore, similar to those of Leadville, had been discovered at Jamestown. This caused an immediate influx of approximately 3,000 people. The town became a tent city with more than 30 saloons and extended for more than a mile up the gulch. The rumor was soon proved false, and before the summer was over the population had dwindled to about 200.

The presence of commercial deposits of fluorspar was not known until 1903, when a man named Emerson arrived to prospect for it. He found large quantities of fluorspar float on Blue Jay Hill and shipped about 400 tons during the first summer. In June 1916, Ed Lehman built a small mill to treat lead-fluorspar ore from the Alice and Argo mines. A high point in fluorspar output was reached in 1918, when 22,810 tons were shipped, but production fell off sharply in the following years, and from 1930 to 1940 the fluorspar mines were largely idle.

A great impetus was given to gold mining in the district by the rise in the price of gold in the latter part of 1933, and many of the larger mines that had been closed for some time were reopened. New ore bodies were found in most of these mines, and the annual gold output of the district jumped from 655.38 ounces in 1933 to 3,149.73 ounces in 1934. Most of this increased output came from the Buena mine, but good ore bodies were also found in the Smuggler, John Jay, and Mount Pleasant mines. The Buena output steadily increased until May 1942, when nearly all gold mining in the district ended owing to World War II, and interest turned to the fluorspar deposits.

By 1942 the General Chemical Co. and Harry M. Williamson & Son had reopened most of the larger fluorspar mines in the district and were actively mining and milling fluorspar ore. The former produced only fluorspar of acid grade from their flotation mill at Valmont, but the latter produced both acid and metallurgical spar from the remodeled Wano mill. In 1943 the fluorspar output reached a new peak of more than 36,000 tons of crude ore, which ranged in grade from about 45 to 75 percent of CaF_2.

The total output of the Jamestown district is estimated by Goddard to have amounted to about $7,000,000, of which approximately $3,500,000 has come from telluride ores, about $1,200,000 from pyritic gold ores, about $1,000,000 from lead-silver ores, and about $1,300,000 from fluorspar. The reports of the Director of the Mint, which do not list many of the mines then active, record the output for certain years as follows:

	Gold	*Silver*	*Total*
1882	$80, 705	$12, 903	$93, 608
1887	39, 083	13, 380	52, 463
1888	9, 333	1, 420	10, 753
1889	77, 914	20, 910	98, 824
1890	53, 414	13, 526	66, 940

The output of the district from 1901 to 1943, inclusive, as furnished by C. W. Henderson of the United States Bureau of Mines, has amounted to 57,614.80 ounces of gold, 200,925 ounces of silver, 963,951 pounds of lead, 144,611 pounds of copper, and 7,000 pounds of zinc, having a total value of about $1,880,000.

The total output of fluorspar from the district from 1903 to 1943, as furnished by H. W. Davis of the United States Bureau of Mines, has amounted to 61,116 short tons of metallurgical spar averaging between 80 and 85 percent of CaF_2 and 19,138 short tons of acid spar containing about 98 percent of CaF_2.

GEOLOGY

The Jamestown district lies entirely within the pre-Cambrian complex of the Front Range. The nearest sedimentary rocks are the Pennsylvanian red beds of the Fountain formation, which lie unconformably on the pre-Cambrian granite and schist about 2 miles east of the mineralized area (pl. 2).

The rocks of the Jamestown district can be divided into three classes: Pre-Cambrian metamorphic rocks, including the Idaho Springs formation and the Swandyke hornblende gneiss; pre-Cambrian granites, including the Boulder Creek granite, the Overland Mountain stock of similar granite, and the Silver Plume granite; and intrusives of the Laramide revolution, including a variety of porphyry stocks and dikes.

Pre-Cambrian rocks.—The schists of the Idaho Springs formation occupy about 15 percent of the district, but small bodies are widely scattered through the other pre-Cambrian rocks. As shown on plate 2, the chief areas of schist are in the northeastern, southeastern, and southwestern parts of the district. Biotite schist is the chief type found, but there are local areas of biotite-sillimanite schist, quartz-biotite schist, injection gneiss, and lime-silicate rock. The biotite-sillimanite schist contains 5 to 30 percent of sillimanite and is worthy of consideration as a future commercial source of that mineral for the porcelain industry.

The Swandyke hornblende gneiss was apparently derived from gabbro and diorite sheets that were intruded into the schists before they had reached their present state of metamorphism; both seem to have been metamorphosed at the same time. The gneiss occupies only about 3 percent of the district and is almost entirely limited to a small area in the north-central part.

The earliest granitic intrusion in the district was that of the Boulder Creek granite. The northern edge of the Boulder Creek batholith and apophyses from it occupy 5 percent of the district and are present in the southeastern part and along the southern border. The Boulder Creek granite in these localities has the composition of a quartz monzonite. The gneissic structure is chiefly primary but is due in part to movements after consolidation. Except in the small lenticular bodies in the schist adjacent to the main batholith, it parallels the walls of the intrusive, but as the gneiss was intruded into the schist parallel to the existing structure, this gneissic structure is essentially parallel to the foliation of the schist.

The Overland Mountain stock is a mass of roughly lenticular outline about 2 miles northwest of Jamestown; it covers about 14 percent of the district. The central part of the stock consists of coarse-grained pink porphyritic granite, closely resembling the Pikes Peak granite, but much of the stock is a less coarse light-gray granite, similar to the coarser phases of the Boulder Creek granite. A chemical analysis shows this granite to be more closely related to the Boulder Creek than the Pikes Peak granite in composition. It does not show the intimate injection of the schist that the gneissic Boulder Creek granite does but seems to have pushed the schist aside as it ascended.

The Silver Plume granite is intrusive into all the rocks previously described. It makes up about 50 percent of the bedrock of the district and occupies a large area in the east-central, central, and northern parts. The most characteristic feature of the Silver Plume granite, as exposed in the Jamestown district, is the flow structure, which is due to the parallel orientation of the abundant lath-shaped feldspar crystals. Both the coarse-grained porphyritic facies and the fine-grained facies are exposed in the district, but the common type is medium-grained and only slightly porphyritic. The Silver Plume granite cuts both across and along the foliation of the schist. Dikes penetrate both the Boulder Creek granite and the Overland Mountain stock.

Pegmatites are associated with each of the pre-Cambrian granites but are difficult to distinguish. The pegmatite of the Boulder Creek granite occurs chiefly in well-defined dikes that are parallel with the gneissic structure. These dikes are very coarse grained, and some have been exploited on a small scale for feldspar and muscovite. In one of them numerous black tourmaline crystals and one large beryl crystal have been found. There are few well-defined pegmatite dikes in the Overland Mountain stock. Most of the pegmatite associated with this granite forms irregular segregations along the border and locally within the granite mass itself. It differs from the granite chiefly in its deficiency in ferromagnesian minerals and its coarser texture. Apparently, when the granite was partly solidified, the residual magmatic juice oozed out along the border and around schist bodies within the granite area and solidified as pegmatite. The pegmatites of the Silver Plume granite occur both in irregular masses gradational into granite and as very coarse-grained well-defined dikes cutting granite, schist, and gneiss. In the northeastern part of the district several small pegmatite dikes along the contacts between the Silver Plume granite and large schist inclusions contain appreciable quantities of radioactive cerite and other rare earth minerals. An analysis of some of this material by J. J. Fairchild of the Geological Survey shows a lead-uranium ratio indicating an age of 940 million years.[79]

Laramide intrusives.—The rocks of the Jamestown district intruded during the Laramide revolution occur in two large stocks and a variety of dikes ranging from diabase to alaskite in composition. These rocks are typical of the various groups discussed on pages 44–47 and accordingly will be discussed in reference to that classification.

The earliest intrusive rock in the region is a diabase of group 2 (pl. 7 and fig. 12). It forms a long northwesterly dike that extends brokenly for 40 miles from Magnolia, through Allen's Park to the west side of Mount Chapin, 10 miles west-northwest of Estes Park; it crosses the southwest corner of the Jamestown district.

Hornblende granodiorite of group 4 occupies about 4 square miles in the south-central part of the district. It is not porphyritic and differs from the typical rock of group 4 in containing considerable titanite in rather large grains. Its texture is fine-grained at the border but toward its central part becomes moderately coarse-grained. As shown on plate 2, its border is very irregular, and there are a few inclusions of granite and schist. The schist and granite along parts of the border of the stock are slightly altered.

Dikes of intermediate quartz monzonite belonging to group 5 are fairly numerous in the east-central and southwestern parts of the district. Most of them have a northeasterly trend, parallel in part to the structure of the enclosing schist. Three small areas of this porphyry are found in Jenks Gulch, 1 mile east of Jamestown, and appear to represent the roof of a buried stock. The rock is distinguished by abundant small hexagonal biotite flakes and scattered rounded glassy quartz phenocrysts.

Alaskite porphyry, which seems to belong to group 7 but for which no age relationships have been found, occurs in two prominent northeastward-trending dikes in the southeastern part of the district. They are characterized by a dense milk-white felsitic groundmass, enclosing small, widely scattered phenocrysts of orthoclase, quartz, and biotite.

A sodic granite-quartz monzonite porphyry of group 8 covers about 1 square mile, just north of Jamestown, on the northeastern border of the large granodiorite stock. In places the contact between the two is marked by a breccia of granodiorite, Silver Plume granite, and schist cemented by the sodic granite porphyry. In this porphyry, quartz phenocrysts are almost entirely lacking, but quartz is abundant in the groundmass. Dikes of sodic granite porphyry radiate from the stock in several places. The southwestern part of the stock is much silicified, and pyrite is finely disseminated throughout much of the mass. Local miners claim that the whole stock contains 0.05 to 0.10 ounce of gold to the ton, but the gold content seems largely limited to a superficial zone closely related to the ancient erosion surface that bevels the top of Porphyry Mountain. There is very little evidence of contact metamorphism in the rocks bordering the stock, although hydrothermal solutions have formed a zone of alteration around it.

Several dikes of bostonite porphyry belonging to group 9 occur in the east-central part of the Jamestown district. They are distinguished by a dense purple to reddish brown felsitic groundmass enclosing numerous white to pink anorthoclase phenocrysts. The sodic granite porphyry and bostonite dikes appear to be more closely associated with the ore deposits than any of the

[79] Goddard, E. N., and Glass, J. J., Deposits of radioactive cerite near Jamestown, Colo.: Am. Mineralogist, vol. 21, p. 199, 1936.

earlier groups. In several of the mines the veins occur in or along the walls of porphyry dikes.

Small discontinuous dikes of biotite monzonite and latite of group 10 are sparingly scattered through the eastern and southeastern parts of the district. On the east slope of Bald Mountain, 1½ miles northwest of Jamestown, there are three very small dikes of biotite latite intrusion breccia of group 11; the roof is exposed on one. The telluride ores of the district are thought to be closely related to these rocks of groups 10 and 11.

STRUCTURE

The structure in the Jamestown district has had an important bearing on the occurrence and distribution of the ores. Five types of structure have played a part in determining the course of the veins and the localization of the ore shoots: Structure of the schist and gneiss; structure of the pre-Cambrian granites; primary structure of the intrusives of the Laramide revolution; faulting during the Laramide revolution; and postintrusion faulting.

Structure of the schist and gneiss.—Throughout the Jamestown district the foliation of the Idaho Springs formation has a general northeasterly trend, which ranges from N. 10° E. to N. 75° E. The dip is moderately steep and generally to the east or southeast, but locally it is west or northwest.

In the southeastern schist area the prevailing strike is N. 50°–70° E. and the dip 70°–80° E. In the northeastern schist area the strike is N. 55°–85° SE. At the southeastern edge of this schist area the foliation swings rather sharply to the south but keeps the easterly dip, except locally. This swing suggests the nose of a pitching syncline that may reflect the push of granite intruded from the south.

The foliation in the southwestern schist area is more variable in strike. Along the southern border, in the area west and northwest of Gold Hill, it strikes about N. 30° E., but to the north it gradually swings to N. 10° W. and then back to N. 10° E. Between Walker Mountain and Rowena, where the schist is split by branches of the granodiorite stock of the Laramide, the foliation swings to N. 70° E., but this change in strike is no doubt attributable to the intrusion of the pre-Cambrian Boulder Creek granite rather than to the crosscutting granodiorite.

In the north-central part of the district the Swandyke hornblende gneiss forms part of a well-defined, shallow structural basin or trough. Along its southwest, west, and north borders, the gneiss dips 25° to 70° toward the center of this trough, the dip increasing from the center outward. Near the center the gneissic structure is almost horizontal and is modified by numerous small domes 100 to 200 feet across. The trough is broken on the south and southeast sides by the intrusion of the Silver Plume granite. On the north limb the gneiss tapers eastward into a large schist area.

Structure of the pre-Cambrian granites.—The structure of the pre-Cambrian granites of the Jamestown district has been worked out by the Cloos and Balk method.[80] In the areas of Boulder Creek granite in the southern part of the district the strike and dip of the foliation or platy structure conform in a general way with the strike and dip of the surrounding schist, and the linear structures or flow lines pitch 48° to 78° nearly due south. This seems to indicate that the granite was intruded at a moderately steep angle from the south and is therefore a part of the large batholithic mass of the Gold Hill-Boulder Canyon region.

In the Overland Mountain stock the foliation or platy structure dips in toward the center of the mass at angles of 60° to 80°. The linear structure pitches at about the same angle toward a point near the north end of the mass. It is inferred that this body of Boulder Creek granite magma came up steeply from a point near its north end and spread out to the south in a steeply inclined, somewhat funnel-shaped mass. The inference that the walls of the mass slope inward is corroborated by the fact that the foliation in the small scattered schist areas along the borders dips in toward the granite at angles of 60° to 80°. The presence of many dikes of Silver Plume granite scattered through the Boulder Creek granite area also suggests that the mass grows smaller with depth.

The structure of the Silver Plume granite is somewhat more complicated than that of the Boulder Creek granite. The linear structures point to several widely separated centers of intrusion and strongly suggest that there are four coalescing stocks of Silver Plume granite in the district. The granite west and northwest of Jamestown probably came from a center in the northwestern corner of the district. The granite body east and northeast of Jamestown apparently rose from a center 1¼ miles southeast of Jamestown and spread out fanwise to the north. Another small stock rose from a point just north of Fairview Peak, and the granite in the extreme northern part of the district, east of Balarat, seems to have come up from under the hornblende gneiss area 3 miles north of Jamestown. The platy structures in the stocks dip toward these centers and suggest that small schist areas between the stocks may widen with depth.

Primary structure of the Laramide intrusives.—The Cloos and Balk method was also used in studying the Laramide stocks of the district. In the granodiorite stock the platy structure indicates that the whole mass has a general, rather steep pitch to the southwest and

[80] Balk, Robert, Primary structure of massive granites: Geol. Soc. America Bull., vol. 36, pp. 379–696, 1925. Stuctural behavior of igneous rocks; Geol. Soc. America, Mem. 5, 1937.

approximates the shape of an inclined cylinder. The linear structure pitches uniformly to the southwest at angles of 35° to 70° and indicates that the granodiorite magma was intruded at a moderate angle from the southwest.

The structure of the small sodic granite-quartz monzonite stock is rather obscure, as the rock is altered in many places. Such observations as could be made indicated that this mass came up under the granodiorite stock from a direction of about S. 70° W. and at an angle of 45° to 60°. This direction of movement seems to have had an important bearing on the distribution of the ores, as will be shown later.

Laramide faulting.—Faulting on a large scale took place before the intrusion of the porphyries in the Jamestown district, and as in many other districts these early faults are marked by persistent silicified brecciated zones that trend northwestward. These breccia reefs are composed of strongly silicified, sheared or brecciated granite (rarely schist) and in places contain large amounts of bull quartz. Hematite is generally present in seams or is finely disseminated throughout the reef and commonly gives the entire reef a pink or red color. These breccia reefs seem to end abruptly against large bodies of schist, in which the fault movement was probably taken up by crumpling of the schist without the formation of clear-cut openings or fault zones.

As shown in plate 2, three persistent breccia reefs cut through the Jamestown district. The strongest and most persistent is the Maxwell, which trends N. 40° W. across the central part of the district and can be traced for more than 20 miles from the foothills south of Boulder to the valley of St. Vrain Creek north of Allen's Park. The dip is steep, ranging from 75° SW. to 85° NE. In the south-central part of the district it is cut out by the large granodiorite stock. In most places in the district this breccia reef is a wide, partly silicified shear zone, colored light pink to red by finely disseminated hematite. On Buena Mountain, it forms a zone of slightly sheared, slightly chloritized granite about 500 feet wide, but in the northwestern part of the district it narrows to as little as 10 feet and is marked by strongly sheared and silicified granite containing bull quartz. On Cannon Mountain the reef forks, and the east branch "horsetails" and disappears within a mile and a half, but the west branch continues beyond Allen's Park. The west branch cuts several dikes of Silver Plume granite, and the displacement of these dikes shows that the northeast side moved downward to the northwest at an angle of about 80° through a distance of 650 feet. As the breccia reef dips 80° SW. here, the fault in this part of the district is a steep thrust.

In the southwestern part of the district, near the John Jay mine, there is another strong breccia reef, which appears to be a direct continuation of the Hoosier reef of the Gold Hill district, but it is separated from it by a broad area of schist, through which the writers have been unable to trace it. This reef strikes N. 25° W. for about a mile from the vicinity of the John Jay mine to the top of Overland Mountain, where it swings to a N. 60° W. trend. It dips 66°–84° SW. Along its N. 25° W. course the reef is 4 to 20 feet wide and consists of bull quartz containing sparse granite fragments, considerable hematite, and a small amount of white flurospar; it is bordered in places by strongly silicified granite. Along its N. 60° W. course the reef is mostly covered and can be traced only by float of sheared granite.

The Standard breccia reef, in the eastern part of the district, is much less extensive than the other two. It can be traced for about a mile in a northerly direction in the vicinity of the Standard mine, 0.8 mile northeast of Springdale, but is lost on float-covered slopes farther to the southeast. Its strike is about N. 24° W., but the dip is only 15° to 20° W., and the course of its outcrop is rather irregular, owing to topographic relief. This reef is 3 to 10 feet wide and is composed of silicified red-granite breccia. The Standard vein and a porphyry dike follow the course of the breccia reef. The Standard vein occupies a normal-fault fissure, but there is no clue as to the displacement along the earlier breccia reef fault.

There are several other less extensive preore faults in the district, which appear to belong to the breccia-reef period. In the extreme southwest corner of the district at Gold Lake is a reef of strongly silicified granite and bull quartz, which strikes N. 50° W. and appears to be related to the Livingston "dike" of the Gold Hill district. The Careless Boy "vein" exposed in the Smuggler mine workings in the northern part of the district shows strong silicification and some hematite and is thought to be a breccia reef. It strikes N. 65° W. and dips 76° SW. It is cut by the Smuggler vein. Southwest of the Smuggler mine there are several short, steep-angle, northwesterly faults, which also appear to be of the breccia-reef type.

Several of the productive veins of the district are located close to the breccia reefs, which apparently served as channels at depth for some of the ore-bearing solutions. The John Jay, Last Chance, and other veins are located on the northeast side of the Hoosier reef; the Buena, Grant, Niagara, and other veins are situated on the northeast side of the Maxwell reef; and the Standard vein lies along the wall of the Standard reef.

In the Smuggler mine the Careless Boy vein has apparently been the most important factor in the localization of ore in the Smuggler vein.

Post-intrusion faulting.—The fault fissures occupied by the ore-bearing veins were formed after the intrusion of the porphyry stocks and dikes. Some veins cut the porphyry stocks, and others follow along the walls of porphyry dikes. There are two systems of mineralized fault fissures in the Jamestown district, an earlier set of northwesterly trend and a younger set of northeasterly trend.

The northwestward-trending fault fissures were filled during the earlier stages of mineralization by the lead-silver and fluorspar deposits. Most of the veins strike from N. 50° W. to due west, but some trend N. 10°–20° W. In most places the dip is to the southwest. The faults are nearly all normal faults, with the southwest side downthrown and displaced to the west. The amount of displacement is not large, rarely as much as 40 feet, but in some places the fractured or brecciated zone is several yards wide. The northeastward-trending fissures are filled with the pyritic gold and telluride ores and are normal faults. They strike from N. 10° E. to N. 80° E. and commonly dip to the southeast. In most places the southeast side of the fault moved down and toward the southwest. These veins are, on the whole, narrower than the northwestward-trending veins, and the displacement along them is small. Both sets of fissures show considerable shearing; brecciation and slickensided walls are common.

ORE DEPOSITS

The Jamestown district has been primarily a gold-mining district but has also supplied considerable amounts of fluorspar, lead, and silver and a small amount of copper. The deposits may be divided into four main classes on the basis of age and characteristic minerals. In the order of decreasing age they are lead-silver deposits, fluorspar veins and breccia zones, pyritic gold veins, and telluride veins. These four types are irregularly distributed around the sodic granite porphyry stock in a rough zonal arrangement and appear to be genetically related to that stock. At the outer edge of the telluride zone there are a few lead-silver veins and a few tungsten-bearing veins, both of which appear to be later than the telluride ores. Three factors have caused, or at least influenced, the irregularity of these zones: (1) The stock was intruded at a moderately steep angle from the southwest, and its thrusting force produced faults and open breccia zones in the area adjacent to the steeply pitching roof, thus affording open channels to the early solutions that rose close to the stock; (2) the large competent granodiorite stock to the south was not sufficiently fractured to admit ore-forming solutions except near its borders; and (3) the strong northwesterly faults (breccia reefs) formed early in the Laramide revolution served as channels for some of the ore-bearing solutions and thus exerted an influence on the distribution of the ores.

Lead-silver deposits.—The lead-silver deposits include both veins and irregular and pipelike bodies in or bordering fluorspar breccia zones. Most of them occur in Silver Plume granite within an area of about a quarter of a square mile on the southwest border of the sodic granite-quartz monzonite porphyry stock. This area lies in the central part of the fluorspar belt. The chief veins of this group are the Buckhorn and the Mount Pleasant, both of which strike northwest and dip steeply. The pipelike and irregular bodies of lead-silver ore are in the Alice and the Argo mines. In the Alice, a steeply pitching pipe of lead-silver ore, 8 to 20 feet broad and 3 to 8 feet wide, lies along the footwall of an irregular fluorspar vein from 1 to more than 8 feet wide and has been explored to a depth of 400 feet below the surface. In places the ore body is cut by fluorspar veinlets, which clearly indicates that the fluorspar is later. In the Argo mine scattered masses of lead-silver ore a few inches to several feet in diameter are found in a zone 8 to 10 feet wide in the center of the Argo fluorspar breccia zone. Apparently the lead-silver ore was deposited in a vein or pipelike body and was then strongly brecciated and surrounded by later fluorspar.

In the lead-silver ores the same suite of minerals is found in the veins and in the pipelike and irregular bodies. Abundant argentiferous galena and gray copper and variable amounts of chalcopyrite, sphalerite, and pyrite are mixed with a gangue of glassy to milky quartz and some fluorspar. Gold seems to be mainly associated with the chalcopyrite, but a little is found in the pyrite. Shipments of this lead-silver ore have ranged in tenor from 0.06 to 1.25 ounces of gold and 2.8 to 47 ounces of silver to the ton, 1 to 40 percent of lead, and 0 to 5 percent of copper.

In the southern part of the district, south and southwest of Nugget Hill, there are a few lead-silver veins of another type, which have been somewhat productive. These lead-silver veins strike east-northeast, dip steeply southeast, and contain argentiferous galena, sphalerite, and pyrite in a gangue of horn quartz, ankerite, and some barite. This ore commonly contains 0 to 1.7 ounces of gold and 4 to 118 ounces of silver to the ton. Sorted lead ore from the Tippecanoe vein carried 187 ounces of silver to the ton and 25 percent of lead. These veins are probably later than the telluride veins, for in some of the telluride veins of the Gold Hill district just to the south the same type of lead-silver ore is later than the horn quartz that contains the tellurides.

In a zone half a mile wide lying a mile east of the stock on Porphyry Mountain there are several northeastward-trending pyritic gold veins, which contain seams of lead-silver ore. Galena, sphalerite, and chalcopyrite are the chief ore minerals of these seams, and the tenor commonly ranges from 0.15 to 1.3 ounces of gold and 0.28 to 7.2 ounces of silver to the ton, but shipments from the Longfellow mine contained 0.3 to 8.7 ounces of gold and 35 to 155 ounces of silver to the ton.

Fluorspar deposits.—The fluorspar deposits consist of breccia zones and veins that form a northwestward-trending belt in granite and granodiorite about 2 miles long and half a mile wide on the southwest side of the

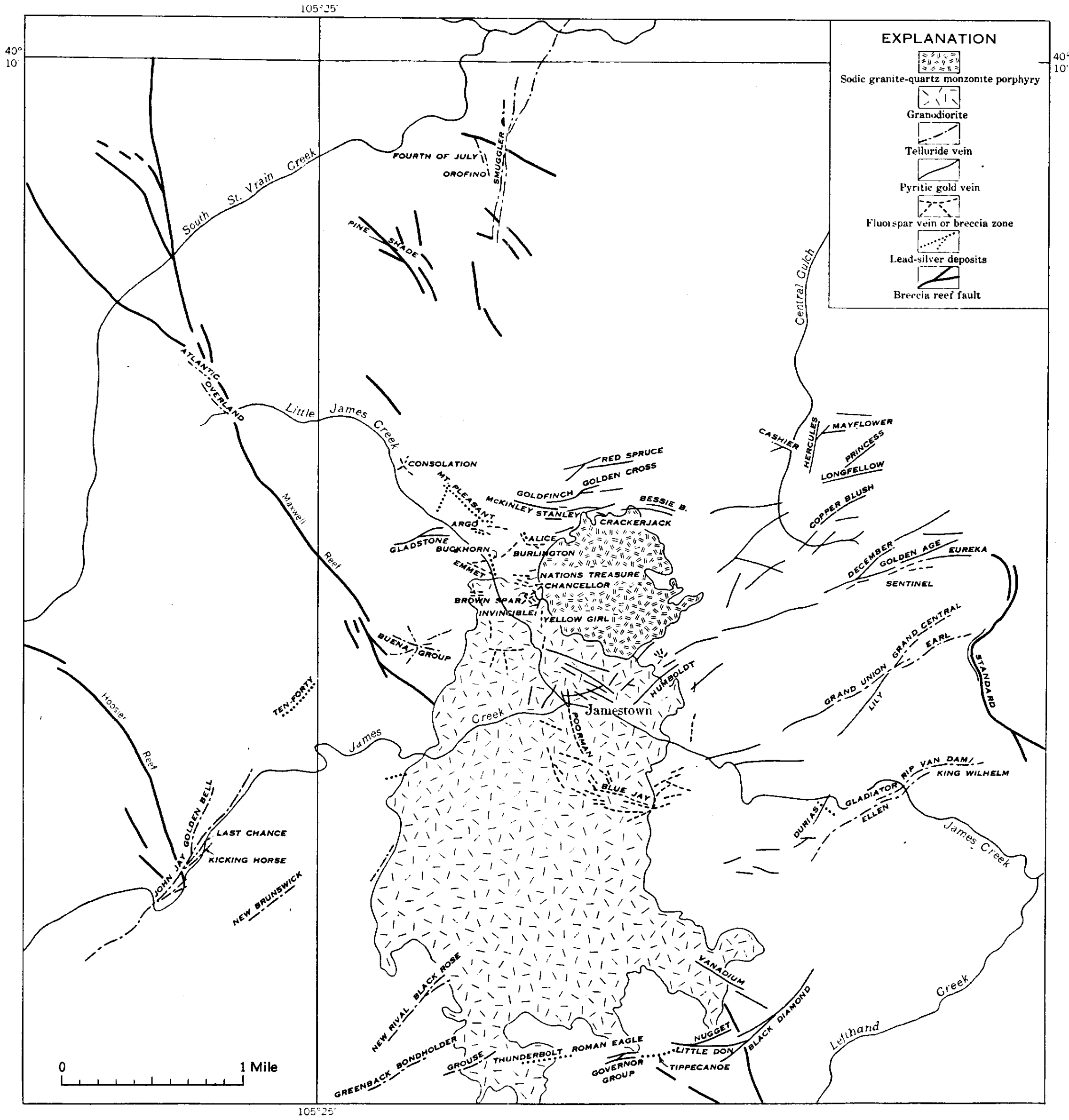

FIGURE 77.—Sketch map of the Jamestown district, showing principal veins and the zonal arrangement of the ore deposits around the granite-quartz monzonite porphyry stock of Porphyry Mountain.

sodic granite porphyry stock (fig. 77). Most of them strike northwest, but a few trend north or northeast; all dip steeply, most of them to the south. The belt seems to have been an early fault zone, probably due in large measure to the forces produced by the intrusion of the sodic granite porphyry stock.[81]

The veins and breccia zones are filled with purple to deep violet fluorspar, both granular and coarsely crystalline, and contain some quartz, clay minerals, disseminated pyrite, and small amounts of galena, gray copper, sphalerite, and chalcopyrite. Minute grains of pitchblende are found in some of the deposits, notably the Blue Jay vein. In many of the deposits coarsely crystalline fluorspar has been brecciated and cemented by fine-grained sugary fluorspar mixed with variable amounts of quartz, clay minerals, sericite, brown carbonate, and small amounts of pyrite, galena, and sphalerite. In the breccia zones the fine-grained fluorspar and associated minerals surround fragments of granite or granodiorite a fraction of an inch to several feet in diameter and in places fragments of lead-silver ore that represent earlier veins or chimneys. There has been some replacement of the granite breccia fragments by fluorspar, and in many places the ground-up granite matrix, which has been altered to a mixture of clay minerals, sericite, and quartz, appears to have been replaced also.

The breccia zones range from 10 to 70 feet in width and from 50 to 350 feet in length (fig. 78). Many of them are parts of larger barren breccia zones 50 to 200

[81] Goddard, E. N., The influence of Tertiary intrusive structural features on mineral deposits at Jamestown, Colo.: Econ. Geology, vol. 30, no. 4, pp. 370–386, June–July 1935.

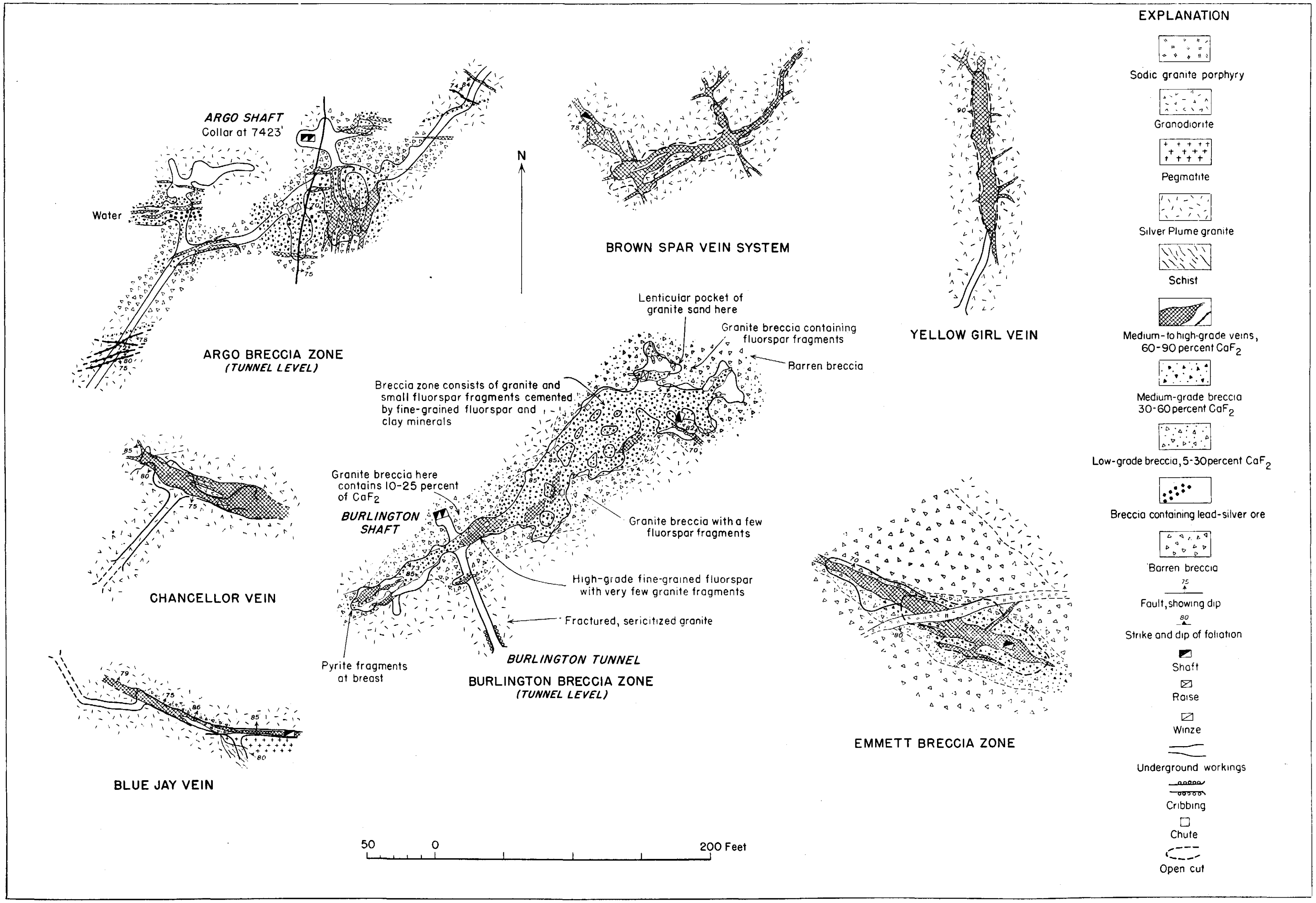

FIGURE 78.—Maps of representative fluorspar deposits of the Jamestown district.

feet wide and 500 to 2,000 feet long. Most of the spar is low-grade, containing 5 to 60 percent of CaF_2, but many of the breccia zones enclose relatively high-grade veins or pockets that contain 50 to 85 percent of CaF_2. The fluorspar veins range from a few inches to 16 feet in width and from 150 to 1,000 feet in length. They are mostly of higher grade than the breccia zones, and in many of them material containing 60 to 85 percent of CaF_2 has been mined, but in some places the veins are of very low grade. In 1943 crude ore containing 45 to 73 percent of CaF_2 was being mined from both veins and breccia zones. Both types of deposit have a high silica content. It has ranged from 5 to 12 percent in shipping ore and from 12 to 35 percent in milling ore. In some of the lower-grade parts of the breccia zones it is probably much higher.

Because of its large percentage of fine-grained material and its high silica content, most of the Jamestown fluorspar ore must be milled to produce a product of commercial grade. Nearly all the fluorspar mined prior to 1942 was used in the steel industry, which demanded a grade of 85 percent of CaF_2 and 5 percent or less of silica. Some of this was hand-sorted, and some was treated in the 25-ton Lehman mill at Jamestown. Since 1942 the ore has been treated in two flotation mills to produce acid spar and some metallurgical spar. In some of the fluorspar deposits the content of galena, chalcopyrite, and associated gold and silver is sufficient to make the saving of a sulfide concentrate profitable. At the Lehman mill in 1933 a galena-pyrite concentrate containing 0.28 ounce of gold and 3.6 ounces of silver to the ton and 30 percent of lead was recovered from the tables. At the Wano mill in 1942 and 1943 a sulfide concentrate containing 20 to 30 ounces of silver to the ton, 30 percent of lead, and 3 percent of copper was recovered.

Few of the fluorspar deposits have been mined to a depth of more than 300 feet below the surface, but none have been found to bottom at this depth. In the Alice mine a relatively short fluorspar vein is continuous to a depth of at least 400 feet beneath the surface, and in the Emmett mine the vein in the 480-foot level is of about the same size and grade as in the upper levels. On the basis of these data the reserves of fluorspar ore are estimated to be as follows: Indicated (probable) ore within 300 feet of the surface, 305,000 short tons containing 45 to 75 percent of CaF_2 and 170,000 short tons containing 20 to 45 percent of CaF_2; inferred (possible) ore between 300 and 500 feet beneath the surface, 340,000 short tons containing 45 to 75 percent of CaF_2 and 160,000 short tons containing 20 to 45 percent of CaF_2.

Pyritic gold veins.—The pyritic gold veins fill the later fault fissures, which trend northeast and dip southeast. Most of them appear to be younger than the early lead-silver deposits, and they in turn are older than the telluride veins. The vein filling consists chiefly of glassy, milky, or sugary quartz and coarse-grained pyrite and chalcopyrite. Roscoelite is intergrown with the quartz in some of the veins in the southern part of the district. Galena and sphalerite are present in some veins and are locally abundant. The gold occurs free or is intimately associated with chalcopyrite and less intimately with pyrite. The most productive veins are in a zone half a mile wide, 1½ to 2 miles east of the sodic granite porphyry stock, but there are also numerous low-grade veins along the north and south borders of the stock and a few small veins within the stock itself. Another group of low-grade veins lies in the vicinity of Nugget Hill, 2 to 2½ miles south of the stock. The veins commonly range in width from a few inches to 3 feet, but some of the veins of the southern group are mineralized zones 10 to 30 feet wide. The length ranges from 300 feet to more than a mile.

The grade of these veins is extremely variable. Very rich free-gold ore from the Golden Age mine is said to have contained 500 to 2,000 ounces of gold to the ton. Forty-three and three-quarters pounds of high-grade ore shipped in 1888 contained 1,103 ounces of gold and 170 ounces of silver to the ton; however, pyritic ore from the same vein may contain as little as 0.35 ounce of gold to the ton. Most of the ore shipped from veins of the eastern group has contained 0.5 to 5 ounces of gold to the ton, and similar amounts of silver. Much of the ore from the Longfellow and Copper Blush veins has had a high silver content. Ore shipped to the Boulder Sampler from the Longfellow mine in the eighties contained 0.3 to 8.7 ounces of gold and 35 to 155 ounces of silver to the ton and 0 to 24 percent of copper. Ore shipped from the Copper Blush vein in 1911 contained 0.5 ounce of gold and 7.75 ounces of silver to the ton and 5 percent of copper.

In the veins around the sodic granite porphyry stock the primary ore commonly contains 0.1 to 0.3 ounce of gold to the ton and about the same amounts of silver, but oxidized parts of these veins may contain several ounces to the ton. Primary ore in the Invincible mine contained as much as 8 ounces of gold and 11 ounces of silver to the ton. Most of the oxidized ore mined from these veins has contained 0.5 to 4 ounces of gold and 0.5 to 3 ounces of silver to the ton. Pyritized parts of the sodic granite porphyry stock, particularly on the flat top of Porphyry Mountain, contain a little gold in places. Assays from test pits and trenches on top of the mountain have ranged from 0.02 to 0.22 ounce of gold and 0.01 to 0.69 ounce of silver to the ton.

The pyritic gold ores from the southern group of veins is also of very low grade. Ore from veins of the Nugget group mined and milled during the period 1901–9 contained 0.14 to 0.24 ounce of gold and 0.03 to 0.05 ounce of silver to the ton, but some earlier shipments contained as much as 0.8 ounce of gold. A shipment of high-grade ore, probably oxidized, contained 47 ounces of gold and 11 ounces of silver to the ton.

Telluride veins.—The telluride veins also have a northeasterly trend, but some of the most important of them strike north-northeast and dip west instead of southeast. They are younger than the pyritic gold veins, for in the Golden Age mine the Sentinel telluride vein cuts the Golden Age pyritic gold vein. Most of the telluride veins lie in an outer zone 1½ miles to 3 miles from the sodic granite-quartz monzonite porphyry stock (fig. 77), but there are some exceptions; for example, the Buena group, an outstanding source of telluride ore, is only three-quarters of a mile west of the stock, and in the Stanley mine on the northwest border of the stock sylvanite is found coating pyrite cubes in pyritic gold ore.

The telluride veins range in width from a fraction of an inch to as much as 10 feet, and in the Buena mine some ore bodies at vein junctions are as much as 10 or even 30 feet wide. The veins range in length from a few hundred feet to more than a mile, but only small parts of the longer ones are productive.

The veins contain gray jaspery (horn) quartz, finely disseminated pyrite, and a variety of telluride minerals. In some of the veins appreciable amounts of free gold are associated with the tellurides. Commonly the veins are made up of numerous interlacing seams of horn quartz, a fraction of an inch to 18 inches wide, in which the tellurides are unevenly distributed; the intervening wall rock is nearly barren. The most abundant tellurides in the district are krennerite (or calaverite) and petzite, but there are also significant amounts of sylvanite and altaite and small amounts of hessite, coloradoite, native tellurium, and rickardite (?). In most of the veins two or more telluride minerals are microscopically intergrown, and rarely is any one telluride exclusively present. One outstanding exception is the ore from the Buena mine, where in much of the ore krennerite appears to be the only telluride, except for very small amounts of petzite. Minute grains of free gold are scattered through some of the tellurides, and apparently gold was the latest ore mineral deposited. Very small amounts of galena, sphalerite, and chalcopyrite are commonly associated with the telluride ore. Associated with the ore in the Rip Van Dam, King Wilhelm, and Gladiator veins are small amounts of roscoelite, and in the John Jay vein there are small amounts of brown carbonate.

The telluride ores show a great range in grade, the grade depending on what minerals are present and on whether the whole vein is shipped or the high-grade horn quartz seams are sorted out. Large shipments have commonly ranged in grade from 0.5 to 15 ounces of gold and 0.5 to 25 ounces of silver to the ton. The ratio of gold to silver depends on the telluride minerals present and ranges from 10 : 1 to 1 : 2 but averages about 1 : 1. High-grade telluride ore sorted and shipped in sacks weighing 50 to several hundred pounds commonly ranges in tenor from 10 ounces of gold and 10 ounces of silver to as much as 286 ounces of gold and 40 ounces of silver to the ton. According to old timers, considerable amounts of high-grade ore in the early days had a value of $5 to $10 to the pound.

Size of ore shoots.—Most of the ore shoots in the district are small, commonly ranging from 50 to 200 feet in length, 30 to 100 feet in breadth, and 1½ to 10 feet in thickness. Outstanding exceptions are the Alice, which is a steeply pitching pipelike lead-silver ore body measuring 400 feet in length, 10 feet in breadth, and 5 feet in thickness; the Buena "big stope," a telluride ore body about 150 feet long, 60 feet in breadth, and 30 feet thick; and a compound shoot on the Smuggler telluride vein, which had a pitch length of about 500 feet, a stope length of about 200 feet, and a thickness of 1 to 3 feet. The shoots range in pitch from nearly horizontal to vertical, and the degree and direction of pitch depend largely on local conditions. Within many of the shoots, particularly in the telluride veins, there are small "pockets" of unusually high-grade ore, which commonly range from 10 to 30 feet in length, 2 to 20 feet in breadth, and a few inches to 18 inches in thickness.

In the fluorspar veins and breccia zones the ore bodies show a very great range in size. High-grade bodies have been small for the most part, ranging from 20 to 150 feet in length, 10 to 100 feet in breadth, and 1 to 20 feet in thickness. However, in recent years, much larger bodies of lower grade have been mined in the breccia zones and some veins. These range from 150 to 480 feet in length, 120 to 350 feet in breadth, and 3 to 60 feet in thickness, and their full length has not yet been exposed. In most of them the long axis is nearly vertical.

Relation of ore to depth.—Ores in the Jamestown district have been mined over a vertical range of about 2,350 feet. The deepest workings are only about 500 feet below the surface, and in many of the mines the workings are only 100 to 200 feet deep. In none of the mines accessible to the writers have the veins been found to bottom with depth; in most of them the vein is as strong in the bottom level as at the surface. It therefore seems probable that if structural conditions are favorable ore bodies may be found well beneath the present workings. There is some evidence, however, that the early lead-silver ore bodies near the Porphyry Mountain stock grade into pyritic gold ore at a depth of about 400 feet.

Wall-rock alteration.—Throughout the district the veins are bordered by zones of sericitic wall rock, which commonly extend a few inches to 3 feet from the vein. In some places the veins are bordered by silicified wall rock, which also commonly forms a part of the vein.

Finely disseminated pyrite is common in silicified wall rock and in sericitized wall rock bordering the ore bodies or the wider parts of veins. Ore bodies are usually bordered by relatively wide zones of strongly sericitized wall rock or by silicified wall rock, both being commonly accompanied by disseminated pyrite, but these conditions do not invariably indicate proximity to ore. In the fluorspar deposits, clay minerals, chiefly hydrous mica and nontronite(?) as well as sericite, are mixed with the ore and were apparently derived from alteration of the crushed and brecciated granite.

Supergene enrichment.—The greater part of the ore mined in the district has been primary ore, but in some of the mines a noteworthy amount of secondary ore formed by supergene enrichment has been mined. Most of the enrichment has been limited to the oxidized zone and is due to the leaching of soluble material, such as pyrite, chalcopyrite, and tellurium, the gold being left behind. By this process of residual enrichment many of the low-grade pyritic gold veins became of commercial grade near the surface. The oxidized parts of the telluride veins have been somewhat enriched, but in many of the telluride veins primary minerals remain within a few feet of the surface. Complete oxidation along the veins extends to depths ranging from 5 to 60 feet beneath the surface, and partial oxidation has extended to depths of 60 and even 120 feet. The depth is largely dependent on the openness of the vein and on the topography and is greatest beneath flat areas that are remnants of old erosion surfaces. In the lead-silver deposits evidence of supergene enrichment is conspicuous only for 10 to 20 feet below the surface, but even there oxidation is not complete. In this zone galena has been altered to argentiferous cerussite and the copper minerals to azurite and malachite. Some sooty chalcocite of supergene origin is found at a depth of 50 feet in the Argo mine but has not been noted more than 100 feet below the surface anywhere in the district.

Structural control of ore bodies.—The general distribution of ore deposits in the district seems dependent on a variety of factors. The fissures and breccia zones occupied by the fluorspar and early lead-silver deposits are believed to be related to forces accompanying the intrusion of the sodic granite-quartz monzonite porphyry stock.[82] Many of the northeastward-trending fissures occupied by later veins appear to have been first opened by forces accompanying the intrusion of the granodiorite stock, though they were later reopened by other forces. Many of the productive veins are grouped close to the strong breccia-reef faults, and it seems probable that these faults served as deep circulating channels for some of the ore-forming solutions. Large solid areas of strong rocks, such as granite and granodiorite, seem to have resisted the forces that formed vein fissures, as almost no veins of importance are found in such areas. On the other hand, in large schist areas, the schists and gneisses yielded readily to the stresses, but in most places the faulting was parallel to the foliation, and tight gougy faults were formed rather than open fissures. However, in areas where the schist and gneiss have been intimately injected by granite the rock is more competent, and open fractures tend to form, especially in the granite layers. Thus we find that nearly all the important ore deposits in the district are limited to areas of mixed schist and granite.

The local distribution of ore within the veins depends largely on three factors. Listed in the order of their importance, they are: The presence of vein junctions, the irregularity of the veins, and the physical character of the wall rock. These factors are illustrated in figure 79. Vein junctions are by far the most important, and fully 75 percent of the output in the district has come from vein junctions of one type or another. The most effective type of junction is that in which one vein cuts across an early fault or vein; the principal ore bodies in the Smuggler and Buena mines occur at such junctions. Splits or junctions of contemporaneous veins have also been favorable places, for example, in the John Jay and Golden Age mines. In many of the veins ore bodies are found at places where the vein takes an abrupt change in dip or strike, as discussed on page 95, and numerous ore bodies are also found where the wall rock changes from schist to granite, or from either schist or granite to porphyry. All these factors tended to produce openings that were available for the deposition of ore, and the most ideal conditions were combinations of three factors, as is well illustrated in the "big stope" ore body of the Buena mine (fig. 80).

BUENA MINE (GOLD-TELLURIDE)

The Buena mine, the most productive in the district, differs from the other mines in having a large number of veins striking in various directions and in having ore in large stockwork bodies at vein junctions.

The mine is on the south side of a steep gulch, 2,000 feet east of the top of Buena Mountain and about a mile N. 70° W. of Jamestown. The workings range in altitude from 7,500 to 8,050 feet and comprise seven levels, with two extensive crosscut tunnels, one small crosscut, and numerous raises, winzes, open cuts, and small shafts, totaling about 6,000 feet. The mine was discovered in September 1879 and is generally credited with a total output valued at about $2,000,000. The output from 1901 to 1942 has amounted to 36,794 ounces of gold, 2,728 ounces of silver, and 205 pounds of copper, having a total value of about $1,154,000.

The Buena workings are in coarse-grained Silver Plume granite, which contains roughly rectangular blocks of black fine-grained biotite schist a few feet to

[82] Goddard, E. N., op. cit., pp. 380–385.

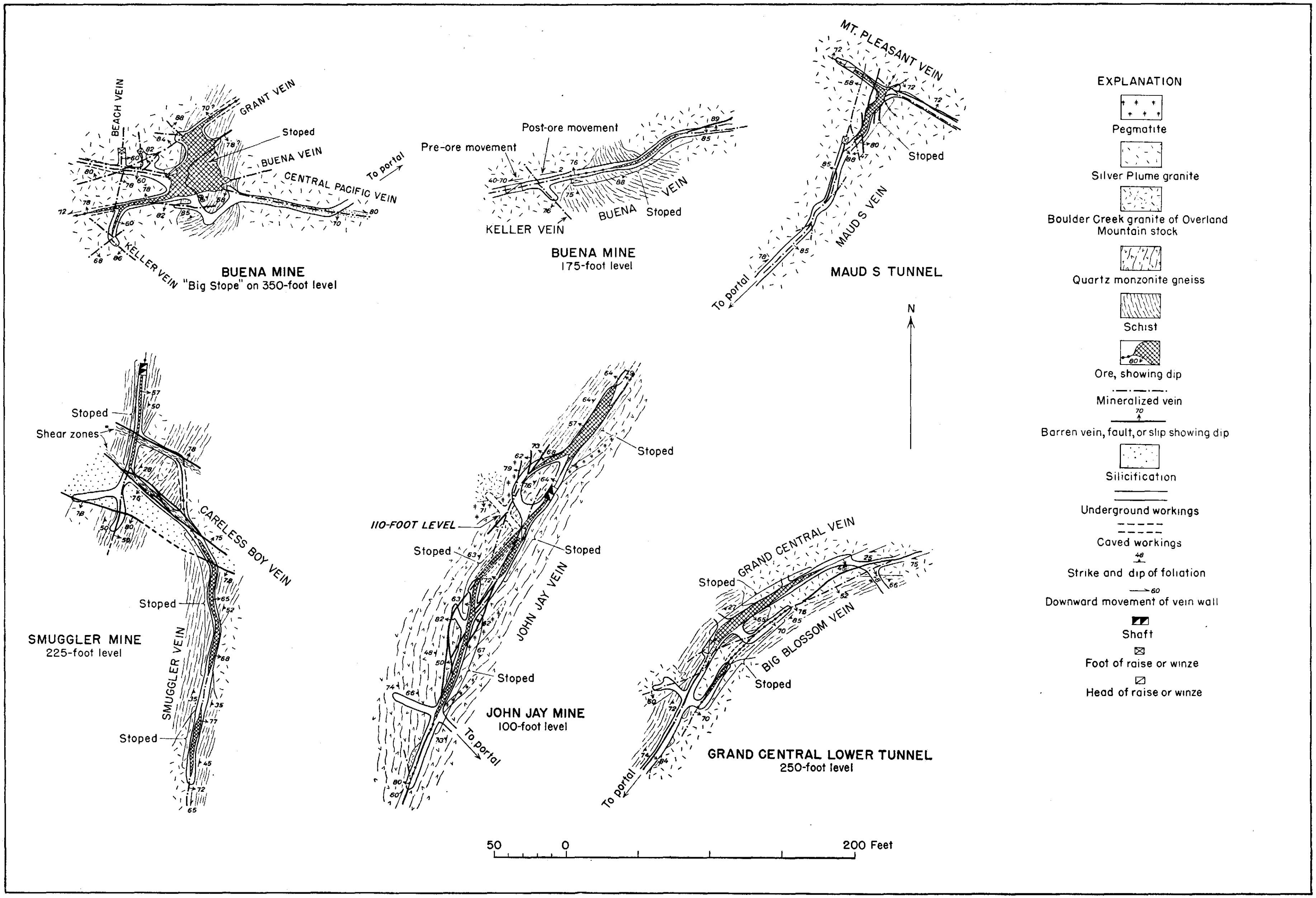

FIGURE 79.—Parts of representative mine maps showing features controlling the localization of ore bodies in the Jamestown district.

50 feet wide and 20 to 200 feet long. The foliation of the schist strikes north to northeast and dips 50° to 90° NW. Six important veins and several minor ones are exposed in the Buena workings. Their distribution is shown best on the map of the 350-foot level (fig. 80). On the basis of age, composition, and trend, these veins are classified into three groups. The earliest group includes veins having an approximate north-south trend and easterly dip. They are small veins that contain no ore except where they join northeastward-trending veins. Displacement along them has been very small, commonly only 2 or 3 inches, the east sides moving southward in most places. These veins are, for the most part, only a few inches wide and are filled with various amounts of purple fluorspar, milky quartz, and coarse-grained pyrite. This group includes the York vein, striking N. 15° W. and dipping 65° E., the Beach vein striking N. 10° E. and dipping 60° E., and two other small veins to the east of the York vein (fig. 80). Veins of northwesterly trend and southwesterly dip cut the north-south veins. These veins are relatively strong and persistent, but like the early group they contain no ore except at the junctions with the northeasterly veins. The northwesterly fissures are along reverse faults, the southwest or hanging walls of which moved upward to the northwest at rather steep angles. The amount of displacement was commonly 8 to 10 feet. The chief veins of this group are the Central Pacific, which strikes about N. 80° W. and dips about 60° S., and the Keller "streak," which has an average strike of N. 45° W. and a dip of about 80° SW. The latest and most important vein fissures are those of northeasterly trend and steep northwesterly dip. These fissures contain ore-bearing veins, and wherever these veins join with veins of other systems they form important ore bodies; in many places ore extends along these veins for considerable distances beyond the junctions. These fissures are mostly along normal faults, the northwest wall of which moved down and to the southwest at a steep angle. The displacement was commonly not more than 5 or 6 feet. The chief veins of this type are the Buena, which strikes about N. 75° E. and dips about 75° N., the Grant, which has an average strike of N. 50° E. and a dip of about 75° N., and the North Grant, which strikes about N. 60° E. and dips almost vertically. The latter, which is 40 to 80 feet northwest of the Grant, was developed after the writers' field work was completed and is not shown on figure 80.

The Buena vein ranges in width from a few inches to 1½ feet but averages about 10 inches. The displacement along the vein fissure is 1 to 6 feet, the north wall having moved down to the west at angles of 40° to 72°. The vein consists of sericitized granite, in places slightly silicified, which contains finely disseminated pyrite and numerous small seams of silicified granite, horn quartz, purple granular fluorspar, and gouge slips. The silici-

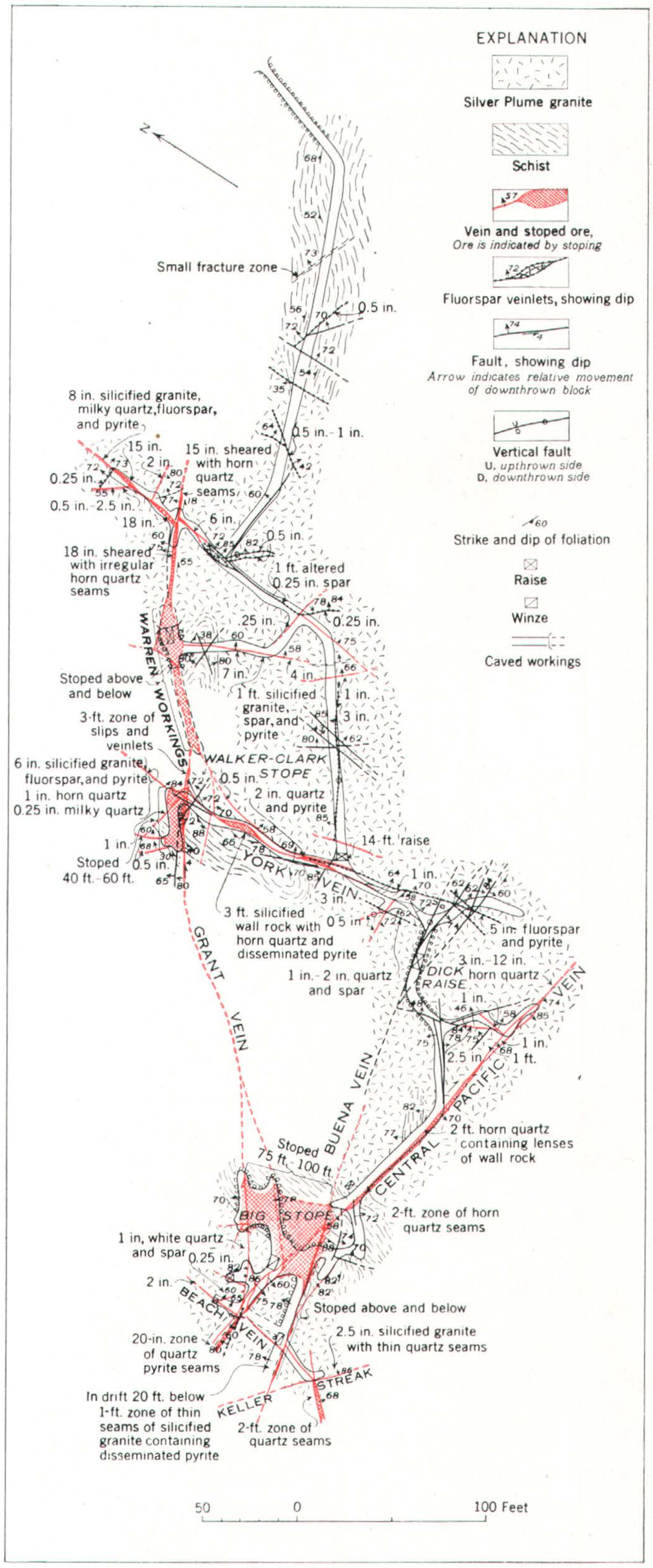

FIGURE 80.—Plan of the 350-foot level of the Buena mine, Jamestown district.

fied seams consist of small fractures with a thin border of silicified granite on either side. The gold tellurides, chiefly krennerite, occur as tiny blades along these fractures or as groups of blades in the small horn quartz seams and mixed with the fluorspar.

The Grant vein is exposed chiefly on the 350-foot level northeast of the Central Pacific and cannot be definitely identified on the surface because of debris. In the vicinity of the Central Pacific the Grant vein seems to break up into a number of small veins. It ranges in width from a few inches to 3 feet and is made up of sericitized or silicified wall rock containing disseminated pyrite and numerous small veinlets of horn quartz, a quarter of an inch to 2½ inches wide. The telluride minerals occur both in the horn quartz seams and along fractures in the wall rock. Grooves on the wall and displacement on earlier veins indicate that the southeast or footwall has moved northeastward and downward at angles of 4° to 18°, and the total displacement has amounted to 3½ to 4 feet. Several rich ore bodies were found on the Grant vein at junctions with other veins; it was apparently an important factor in the localization of ore in the Big Stope.

The North Grant vein was not seen by the writers, but it is reported to be of the same character as the Grant. Two rich ore bodies were found between these two veins in the lower levels in the northeastern part of the mine.

The Central Pacific vein is the strongest and most persistent vein in the mine but contains no ore except at and near its junction with the Buena vein. Displacement of the walls has amounted to about 10 feet, the hanging wall having moved up to the west at about 80°. The vein ranges in width from 6 inches to 6 feet. In places it is merely a zone of gouge slips, but in other places it contains numerous horn quartz seams and locally consists of a single horn-quartz seam 1 to 2 feet wide. Pyrite is sparingly disseminated in the vein, and fluorspar is present near the junctions with other veins.

The other veins in the mine are small and contain little ore except near their junctions with the Buena and Grant veins. However, several good ore bodies have been localized by such junctions. In addition to the Keller, Beach, and York veins previously mentioned there are numerous small veins a quarter of an inch to an inch wide composed of silicified granite, flurospar, quartz, or pyrite, or a combination of them, which locally contain high-grade ore close to the Buena and Grant veins or are effective in localizing ore in those veins. These veins are chiefly of the northerly or northwesterly systems, but some strike northeastward.

The chief ore minerals in the Buena mine are gold tellurides, of which krennerite is by far the most abundant. Sylvanite is abundant in places, and petzite is present in small amounts. The telluride minerals are for the most part microscopically intergrown and cannot be distinguished from one another in hand specimen.

Pyrite is finely disseminated throughout the ores but apparently contains no gold. In some of the early north-south veins coarse pyrite is associated with milky quartz and apparently contains a little gold. Chalcopyrite and galena have been found in small amounts in small branch veins but have not been recognized in the main veins.

The chief gangue material is altered (silicified or sericitized) wall rock. The most abundant gangue mineral is horn quartz, which invariably accompanies the ore. In places where the ore is near or in early north-south veins, considerable flurospar and some glassy quartz make up the gangue.

The krennerite and other gold tellurides occur chiefly in small, thin blades or needles, or groups of both, and coat the walls of small fractures or slips. The best ore seems to be in the fractures that are parallel with the main vein and relatively continuous, but in the large ore bodies the ore minerals occupy fractures in wide zones of fractured wall rock. Many of these tiny fractures are fairly open, and scattered crystals of sylvanite are the only filling. The walls of the fractures are commonly silicified for one-sixteenth to one-eighth of an inch on either side. In places tiny seams of horn quartz occupy the fractures or vein fissures and enclose the tellurides, and in a few places the tellurides are found in horn quartz seams as much as an inch wide.

Most of the ore bodies in the Buena mine were pipe-like bodies of stockworks at vein junctions, but in some places on the Buena vein the ore formed in a long narrow body limited to the vein itself. There were at least nine important ore shoots in the Buena mine. Two of them were on the Grant vein, two between the Grant and North Grant, and the others were on the Buena vein or closely related to it. These ore shoots were more or less lenticular in shape, and their pitches were steep, chiefly to the northeast. They ranged from 30 to 120 feet in length, 20 to 60 feet in breadth, and 5 to 35 feet in thickness. The known ore shoots occurred from the surface to a depth of 520 feet, which corresponds to altitudes of 8,050 and 7,530 feet.

One of the largest ore shoots in the mine was the Big Stope, which measured about 120 feet in pitch length, 60 feet in breadth, and 35 feet in thickness. It pitched steeply to the west, and a flat branch extended upward to the east along the Buena vein. This shoot was at the junction of the Buena, the Grant, and the Central Pacific veins, on the west edge of a prominent schist block, in which the foliation strikes N. 5°–10° E. and dips about 85° W. This furnished an ideal condition for the deposition of ore. The veins, where they joined, broke up into numerous crossing and interlacing feeders in the strongly fractured schist and granite, which were more or less altered throughout a wide zone, and the ore was deposited in these small fractures. From the Big Stope ore extended along the Grant vein to the east, the Buena vein to the east, and westward and upward along the Buena vein to the surface.

Two other large ore shoots, comparable in size to the Big Stope, were exploited during the period 1937–42 after the writers' field work was completed, and the stopes were inaccessible when the writers returned in 1944. Both extended from the Grant vein to the North Grant, one at their junction with the York and a flat branch of the York, and the other, about 160 feet to the northeast, at the junction with other small veins of northward trend. The latter ore body is reported to have been largely in schist with granite on the hanging wall and footwall.

The chief structural factor localizing these ore shoots was the junction of two or more fissures; few if any junctions of the Buena, Grant, and North Grant veins with other veins in the mine have failed to show good ore bodies. At such junctions the wall rock is fractured for some distance from the veins, commonly 5 to 10 feet, and the ore occurs along these fractures and joints. Even in the veins the ore shoots are nearly all wider than the veins themselves. Along prominent cross fractures the ore body tends to "belly" out to a width of 20 or 30 feet where normally it is only 5 feet. The ore also seem to "make" on the under side of small flat slips having dips of 20° to 30°, and it is likely to "cut out" above them to come in against the next one. These slips seem to have served as dams to the ore-forming solutions, slowing up the circulation and causing deposition.

Another factor in the control of the ore bodies is the contact of granite with schist. The ore bodies are best developed where the main vein cuts across such contacts. In these ore bodies along schist-granite contacts, the fractures, and consequently the ore, extend out much farther into the schist than into the granite, but commonly the best ore is at the contact. In a few places on the Buena vein ore has been found some distance from any junction, and in such places the ore bodies are largely localized in the steeper and more northeastward-trending parts of the Buena vein.

Most of the ore in the Buena ore bodies is sorted or screened before it is shipped. Even in the richest shoots there is a large amount of wall rock between the rich ore-bearing fractures. Unsorted ore from the top of the shoot at the junction of the Grant and York veins contained about 0.16 to 0.20 ounce of gold to the ton, whereas the screenings contained 1 ounce. Most of the ore shipped from the Buena mine has contained between 0.36 and 6 ounces of gold to the ton and small amounts of silver, though some shipments have contained more than 200 ounces of gold to the ton. Shipments to the Boulder Sampler in 1879 and 1880 contained 1 to 268.4 ounces of gold and 1 to 54 ounces of silver to the ton. Most of the large tonnages ranged from 3 to 11 ounces of gold to the ton, with lesser amounts of silver. According to W. B. Clemens, who worked in the Buena mine for many years, the Big Stope ore body averaged about 1.75 ounces of gold to the ton. In Mineral Resources for 1926 [83] the statement is made that "James Warren, Jr., a lessee on the Wano group, shipped seven cars of ore assaying from 1.55 to 7.30 ounces of gold to the ton." This ore also averaged 1.75 ounces of gold to the ton. The ore shipped in carload lots from the Walker-Clark stope in 1934 contained 0.75 to 6 ounces of gold to the ton and included two carloads that averaged about 5 ounces. The average yearly grades from 1901 to 1942 have ranged from 0.36 to 4.68 ounces of gold to the ton, but during most of that period it has been between 0.5 and 1.5 ounces. The ratio of gold to silver is from 1 : 0 to 2 : 1.

SMUGGLER MINE (GOLD-TELLURIDE)

The Smuggler mine, another of the most productive telluride mines in the district, is at Balarat, in Long Gulch, 3 miles north of Jamestown, and is the northernmost mine in the mineral belt. It is developed by a shaft 488 feet deep (568 feet on the incline), with eight levels and about 6,000 feet of workings. A crosscut tunnel connects with the first level. The collar of the shaft is at an altitude of 7,525 feet.

The Smuggler mine was discovered in April 1876, and the value of its total output is estimated to be about $1,000,000. Available data that are far from complete show a total of about $825,000. The output from 1901 to 1936 has been relatively small, amounting to 2,365.75 ounces of gold and 1,358.8 ounces of silver.[84]

The two chief veins in the Smuggler mine are the Smuggler and the Careless Boy (pl. 28). The latter is an early barren "vein" or breccia reef, which strikes about N. 65° W. and dips about 75° SW. The Smuggler, which is the principal ore-bearing vein, has a general north-south trend and an average dip of 70° E., and cuts diagonally across the earlier vein. The chief wall rocks are Silver Plume granite and biotite schist, but pegmatite is exposed locally in the workings. The Smuggler vein cuts through a large lenticular area of schist, which is surrounded by granite and cut by numerous irregular granite dikes.

The Careless Boy "vein" or breccia reef is a strong fault or shear zone 4 to 35 feet wide, which has several interlacing branches. In most of the workings it is strongly silicified, but at the surface and on the lower levels it is a soft shear zone. In places it contains small

[83] Henderson, C. W., Gold, silver, copper, lead, and zinc in Colorado: Mineral Resources U. S., 1926, pt. 1, p. 747, 1927.

[84] Data furnished bp C. W. Henderson, U. S. Bureau of Mines, Denver, Colo.

amounts of bull quartz and hematite, and close to the Smuggler vein it contains some disseminated pyrite and a small amount of ore. The wall rock bordering the Careless Boy has been chloritized in places. Grooves on the walls of the Careless Boy fissure seem to indicate that there have been two or more periods of movement, one in which the northeast wall moved southeast and down at 35°–50°, and one in which the northeast wall moved west. The amount of displacement could not be accurately determined but may be as much as 75 feet in places.

The Smuggler vein has an average strike of N. 8° E., but where it crosses the Careless Boy, on all but the lowest levels, it turns abruptly to N. 20°–45° W. and follows the earlier fault for a distance of 10 to 80 feet before resuming its northerly course. On the two lowest levels, however, it cuts directly across the Careless Boy. The dip is very irregular, ranging from 45° E. to 82° W. The vein fissure is not strong but is surprisingly persistent. It or associated fissures have been traced for more than 6,000 feet. On the surface, both north and south of the shaft, the vein splits, and branch veins show in places in the workings. Grooves on the walls and displacements of schist-granite contacts indicate that the east, or hanging wall, moved down and to the south at an angle of 65°–75° for a distance of 5 to 6 feet.

The Smuggler vein ranges in width from a fraction of an inch to 3 feet and consists chiefly of a zone of silicified or sericitized granite containing numerous interlacing seams of horn quartz a fraction of an inch to 18 inches in width. In places there is only a single horn-quartz seam, and where the vein lies in schist and trends parallel to the foliation it consists of only a fraction of an inch of gouge or a few inches of sheared schist. In the ore bodies there is commonly a foot or two of granite breccia cemented or partly cemented with horn quartz in addition to numerous horn-quartz stringers. Gold tellurides, free gold, and finely disseminated pyrite are irregularly distributed in the horn quartz. Some calcite has been noted in the vein at the south breast in the bottom level. The wall rock is commonly sericitized a few inches to several feet on either side of the vein and locally is somewhat silicified.

The chief ore minerals in the Smuggler vein are gold tellurides and free gold. Pyrite is the only other abundant metallic mineral, although in places minute grains of sphalerite, galena, and chalcopyrite are present. The horn quartz ranges from white to dark gray, or almost black in places. Pyrite is finely disseminated through the horn quartz in most places and locally in the wall rock. In parts of the vein a late barren brown horn quartz fills cavities and fractures in the ore. The tellurides occur as thin blades or needles scattered through the horn quartz. In some of the ore free gold is fairly abundant, forming minute grains in tiny cavities in or bordering the tellurides. In most places the ore occurs in spots scattered irregularly through the horn quartz of the vein, but locally it forms high-grade streaks consisting of horn quartz containing 25 to 30 percent of gold tellurides evenly distributed through it in small bars (fig. 74, F.).

Microscopic study of the ore shows that the small masses and blades of gold telluride are made up of two or more telluride minerals more or less intergrown. Petzite and altaite are the most abundant, but sylvanite is locally abundant. The minute grains of free gold 1 millimeter or less in diameter either border or are intergrown with the tellurides.

The records of the Boulder Sampler from 1878 to 1892 give considerable data on the tenor of the Smuggler ore. The low-grade ore shipped in large tonnages contained 1.15 to 24.25 ounces of gold and 2 to 17 ounces of silver to the ton. One shipment of 16 tons contained 13 ounces of gold and 10 ounces of silver to the ton. The high-grade ore, shipped mostly in lots of a few to several hundred pounds, contained from 25 ounces of gold and about the same amount of silver to as much as 638 ounces of gold and 597 ounces of silver to the ton. The average yearly tenor of ore shipped from 1901 to 1921 ranged from 1.15 to 29 ounces of gold and from 2 to 8.25 ounces of silver to the ton. The average tenor of the ore shipped from 1876 to 1921 was about 10.7 ounces of gold and 9.4 ounces of silver to the ton.

As shown on plate 28, there is one large compound ore shoot on the Smuggler vein, which extends irregularly from the surface to the bottom level, and numerous small ore shoots, which are scattered along its north and south borders. The main ore shoot pitches about 60° S. and has a pitch length of about 550 feet, a maximum stope length of about 350 feet, and a width of 1 to 5 feet, but within this large ore body there are numerous small barren areas. The small shoots pitch from vertical to 60° S., have a pitch length of 50 to 100 feet, and a stope length of 30 to 80 feet.

The localization of the main ore body seems to have been controlled largely by the junction of the Smuggler and Careless Boy veins. The Careless Boy vein probably served as a dam or baffle to ore-forming solutions moving up along the Smuggler vein from the south, for miners who have worked in the mine say that the richest ore bodies occurred near to and on the south side of the Careless Boy. Other factors influencing the localization of ore bodies in the mine seem to be alternations of schist and granite in the wall rock and abrupt changes in strike and dip of the vein. Along nearly all the ore bodies in the mine schist is found on one wall and granite on the other, or schist and granite alternate at close intervals along the same wall; rarely do shoots occur in granite alone or schist alone. Movement along the vein fissure (east wall down and to the south) tended to produce openings for deposition of ore in the steeper parts and in parts with northerly trends adjacent to those with northwesterly trends. In the compound ore shoot all these factors were effective.

GOLDEN AGE MINE (PYRITIC GOLD)

The Golden Age mine has been the leading source of free gold and pyritic gold ore in the district and is famous in Boulder County for its extremely rich specimens of free gold. It has also had an appreciable output of gold-telluride ore.

The mine is on a high spur of Golden Age Hill, 2,000 feet northeast of the top and 1.7 miles northeast of Jamestown. The workings consist of a main shaft 525 feet deep (800 feet on the incline), 6 small shafts, two crosscut tunnels, and more than 5,800 feet of levels. The altitude of the main shaft collar is 8,175 feet, that of the upper crosscut tunnel 7,920 feet, and that of the lower crosscut tunnel 7,650 feet. The Golden age mine was discovered in May 1875. The total value of output is estimated by local mining men to be about $1,000,000. According to the mint report, the value of the output in 1882 was $65,350, of which $41,000 was in gold and $2,350 was in silver. However, for the year 1880, according to the mint report, the value of the output was only $4,955.15, of which $155.15 was in silver. The output from 1901 to 1936 has been small, amounting to 1,026.75 ounces of gold and 209.90 ounces of silver.[85]

[85] Data furnished by C. W. Henderson, U. S. Bureau of Mines.

There are two main veins in the Golden Age mine—the Golden Age, which contains free gold and pyritic gold ore, and the Sentinel or Telluride, which contains telluride ore. The Golden Age vein strikes from N. 60° E. to east and dips 36°–56° SE. The Sentinel vein strikes N. 60°–68° E. and dips 55°–85° SE. These two veins cross approximately 265 feet beneath the collar of the shaft; there the Sentinel cuts through the Golden Age and is clearly later (fig. 81). The veins are bordered by several different wall rocks. On the surface the walls consist of a complex mixture of pegmatite, aplite, and schist, but a short distance below the surface this mixture is followed by Silver Plume granite containing lenses of schist. The foliation of the schist strikes N. 45°–85° E. and dips 26°–78° SE. The Golden Age vein follows a dike of intermediate quartz monzonite porphyry 3 to 30 feet thick. The vein follows the footwall of the dike from the surface to an inclined depth of 100 feet, where it forks; at greater depth, a branch of the vein lies on either wall (see fig. 81). On the lower-tunnel level the dike pinches out toward the southwest and appears to be narrowing downward.

The Golden Age vein has been traced on the surface for about 2,200 feet and has been explored to a depth of 800 feet down the dip and 525 feet vertically. It occupies a normal fault, the hanging wall of which has moved nearly straight down the dip, but the displacement has been only a few feet. The vein is made up of two or more quartz seams, which range in thickness

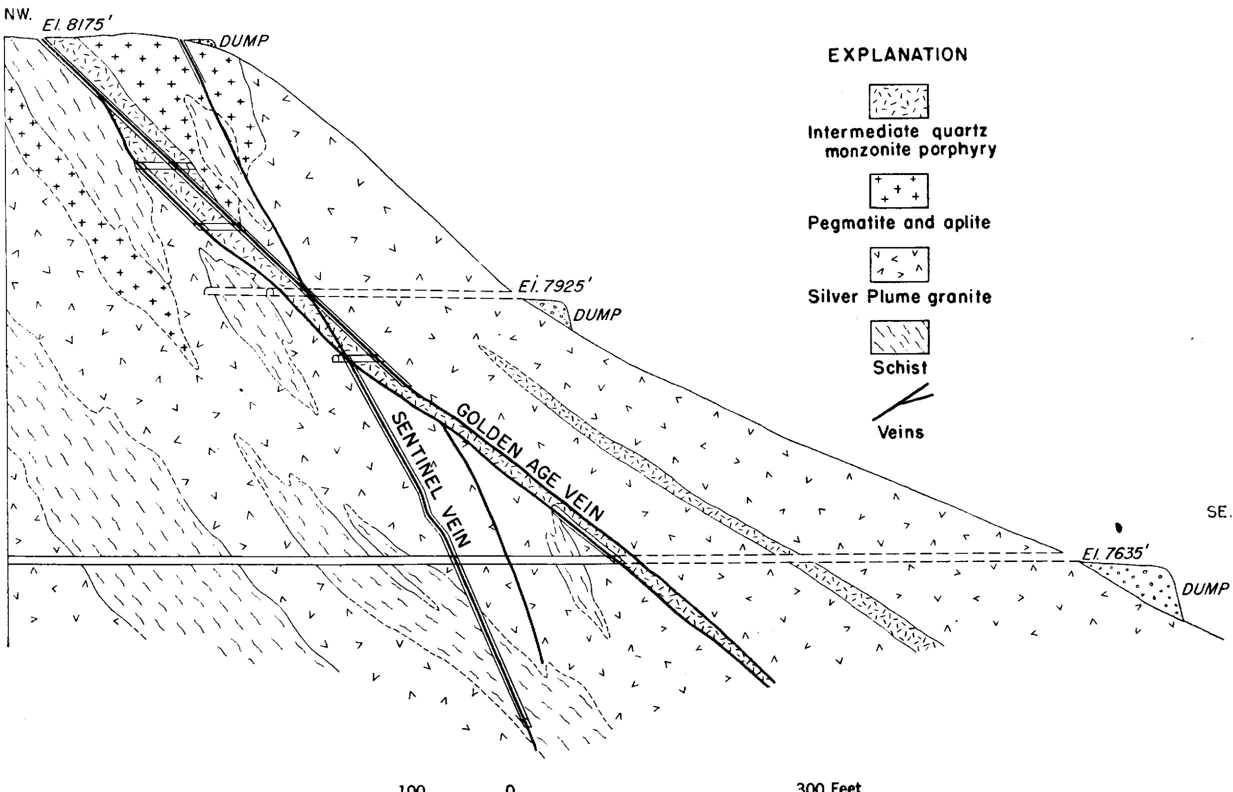

FIGURE 81.—Section of the Golden Age workings, Jamestown district.

from 1 inch to 2 feet but are commonly only a few inches thick. In places where the porphyry dike is only 3 to 5 feet thick veinlets extend irregularly through the dike from one wall to the other. The quartz is milky to glassy and in places shows comb structure.

The chief ore minerals of the Golden Age vein are free gold, pyrite, and chalcopyrite. In places small grains of galena and sphalerite are present. The free gold was found in a zone extending from the surface to a depth of about 300 feet. According to Farish[86] it was bright yellow and embedded in white quartz and ranged in size from coarse grains to nuggets weighing several ounces. One specimen contained 70 ounces of gold "nearly all in one piece." Farish also stated that the gold was commonly not accompanied by the sulfides; however, parts of the vein, particularly on the lower levels, contain abundant pyrite and moderate amounts of chalcopyrite. The gold in sulfide ore seems to be closely associated with chalcopyrite.

The Sentinel vein has been traced on the surface for about 2,000 feet and has been explored to a depth of 800 feet down the dip, or 720 feet vertically beneath the surface. It dips about 75° SE. in the vicinity of the Golden Age mine, but to the northeast its dip decreases to 55°. According to Farish, the Sentinel vein cuts through the Golden Age vein and displaces it about 30 inches. He says that in places the Sentinel vein turns and follows the Golden Age vein a short distance before cutting through it, and this apparently is what has happened on the upper tunnel level, for only one vein is exposed at the place where the two veins should cross. On the lower tunnel level the Sentinel vein lies 165 feet north of the Golden Age vein, but 40 feet west of the winze the Sentinel splits, one branch turning to a S. 40° W. trend and finally joining the Golden Age. Grooves on the walls of the Sentinel vein in the lower tunnel seem to indicate that the hanging wall moved downward.

The Sentinel vein consists of one or more small streaks of horn quartz a fraction of an inch to 3 inches thick, which contain finely disseminated pyrite and the ore minerals. According to Farish, the chief ore minerals are petzite, sylvanite, and free gold. A specimen of ore that was said to have come from the bottom of the winze was examined by Goddard and showed a half-inch seam of horn quartz containing abundant small aggregates of petzite.

The Golden Age mine has been famous throughout Boulder County for its very rich free-gold ore. Shipments to the Boulder Sampler from 1882 to 1888 seem to be representative of the tenor of this ore. A few shipments ranging in weight from 2¼ to 43¾ pounds contained 1,103 to 2,285 ounces of gold and 170 to 276 ounces of silver to the ton. Other small shipments contained from 16 ounces of gold and 5 ounces of silver to 1,010 ounces of gold and 99 ounces of silver to the ton. The ratio of gold to silver in this high-grade ore ranged from 2:1 to 10:1.

The low-grade pyritic gold ore in the Golden Age vein has a tenor ranging from 0.38 to about 4 ounces of gold to the ton; the silver content is variable but averages about the same as that of gold. In 1932 ore from the top of the stope on the Golden Age vein above the lower tunnel level averaged 1.6 ounces of gold to the ton, and 9½ tons shipped in 1933 contained 0.38 to 0.82 ounce of gold to the ton.

Only a few data are available on the tenor of the telluride ore in the Sentinel vein. The Boulder Sampler has recorded the following sample shipments:

	Ore (pounds)	*Gold (ounces per ton)*	*Silver (ounces per ton)*
October 1885	40	97	51
September 1886	710	46.2	13
October 1886	78	219	86

Farish stated that first-class telluride ore yielded $10 to $17 to the pound.

The rich free-gold ore in the Golden Age vein seems to be limited to a zone within 300 feet of the surface, above the junction of the Golden Age and Sentinel veins, and it is suggested by Goddard[87] that much of this free gold may have been concentrated by supergene waters.

Because of the inaccessibility of the upper workings, few data could be obtained on the character of the high-grade ore shoots. Men who have worked in the mine say that the gold occurred in small high-grade pockets with nearly barren vein material between. According to Farish, one small stope on the footwall yielded $25,000 worth of amalgamated bullion, with tailings rich enough to ship to the smelter. From a map of the workings it appears that most of this high-grade ore was limited to a block of ground lying between the surface and the fourth level and extending for 150 feet to 200 feet east and west of the shaft. Farish reports that the richest ore was at the junction of the two Golden Age streaks about 60 feet below the surface. In the lower workings there are several stopes on the Golden Age vein from which low-grade pyritic gold ore has been mined. These range from 25 to 140 feet in length and from 20 to 50 feet in breadth. The ore bodies in the Sentinel vein were apparently small for the most part, but George[88] stated that a drift extending for 300 feet eastward, 75 feet below the lower tunnel level, "was in pay ore the entire distance."

ALICE MINE (LEAD-SILVER)

The Alice mine is on a sloping terrace on the west side of Porphyry Mountain, a mile N. 26° W. of Jamestown

[86] Farish, J. B., A Boulder County mine: Colorado Sci. Soc. Proc., vol. 3, pp. 316–322, 1890.

[87] Goddard, E. N., Geology and ore deposits of the Jamestown district, Colo. (in prepartion).

[88] George, R. D., Geology of the Golden Age. Unpublished report.

at an altitude of 7,450 feet. It is one of the chief lead-silver mines in the district but has also supplied a substantial amount of gold and fluorspar. The shaft was caved for many years prior to September 1936, when the St. Joe Mining & Milling Co. took over the property and reconditioned it. In 1940 the mine was acquired by the General Chemical Co.

The workings consist of a shaft 400 feet deep, with levels at 100-foot intervals, and a crosscut tunnel 150 feet long, which joins the shaft 50 feet below the collar. Levels extend southwestward 30 to 80 feet to reach the ore body.

The Alice claims were patented October 10, 1893, but there are no data on the output from 1893 to 1901. From 1913 to 1927 the mine was one of the most productive in the district. During that period its output was 406.59 ounces of gold, 73,416 ounces of silver, 1,065,996 pounds of lead, and 92,348 pounds of copper, having a gross value of approximately $150,000, in addition to several thousand dollars worth of fluorspar.

The Alice mine is entirely in Silver Plume granite. It is 750 feet northwest of the border of the Porphyry Mountain stock and is therefore well within the zone of alteration surrounding the porphyry. Thus the granite is more or less sericitized and locally fractured and silicified. All of the ore has come from a single pipelike ore body, which is located on the southeast or footwall side of a very irregular fluorspar vein (fig. 82). This vein has an average strike of N. 15° W. and a dip of 70°–80° W. It tends to zigzag along two fracture systems, one striking N. 45° W. and the other N. 10° E. The fluorspar vein is very irregular in width, swelling and thinning abruptly from 1 to 8 feet. In many places small branch veinlets extend into the wall rock. The vein has been explored for a length of 120 feet on the 200-foot level, and there it appears to be pinching out at both ends. This vein is composed of dark purple sugary fluorspar, which is nearly pure in places, but along the borders it contains fragments of granite, pyrite, milky quartz, and galena, 1 to 6 inches in diameter.

The lead-silver ore body, on the footwall side of the fluorspar vein, was a pipelike body of oval cross section, its longest axis pitching about 70° SW. Its horizontal length was about 8 to 20 feet and its width 3 to 8 feet; it was continuous from the surface to the 400-foot level. In places fragmental masses of ore were found in nearby parts of the fluorspar.

The ore minerals are galena, gray copper (tennantite), chalcopyrite, and pyrite. The first two are argentiferous, but most of the silver is in the gray copper. Chalcopyrite contains most of the gold, but pyrite contains a little. According to Lew Markt, sylvanite was found in some cavities in coarsely crystalline white to pale-purple fluorspar. Variable amounts of glassy to milky quartz are intergrown with the ore minerals.

According to Markt and Charley Clark, both of whom mined in the Alice mine, the pipe consisted of nearly solid ore throughout, and the individual ore minerals seemed to be segregated into large rounded or irregular masses. In the upper workings gray copper and galena predominated, but below the 300-foot level they largely gave way to chalcopyrite and some pyrite, and the ore shoot was very irregular. Chalcopyrite ore was said to be still abundant in the bottom level when the burning of the shaft caused work to be abandoned.

The Alice ore shows much variation in grade. The ore that is high in gray copper has a high silver content, and the galena ore contains relatively little silver. According to Charley Clark, the pure chalcopyrite ore

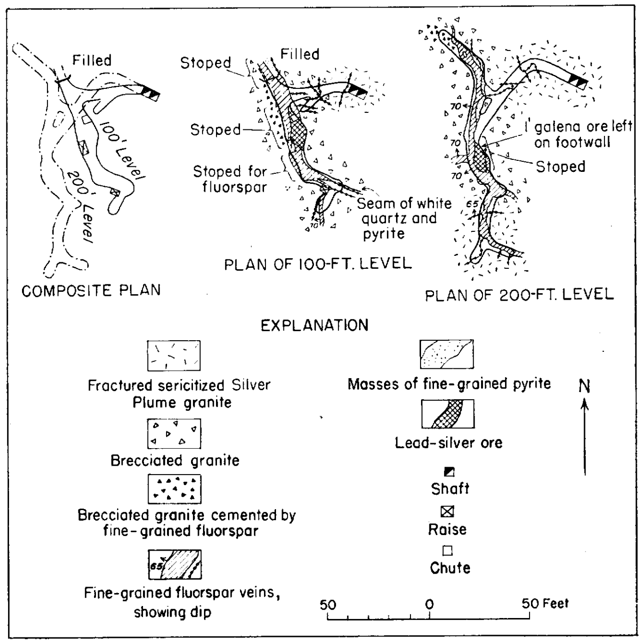

FIGURE 82.—Plan of the 100-foot and 200-foot levels of the Alice ore body, Jamestown district.

averaged about 4.5 ounces of gold to the ton, and the pyrite contained only 0.05 to 0.50 ounce of gold. There are no data on the grade of individual shipments, but ore mined from 1913 to 1927 averaged 0.18 ounce of gold and 32 ounces of silver to the ton, 23 percent of lead, and 2.2 percent of copper. The variation in grade is illustrated by the yearly averages given below, which were furnished by C. W. Henderson of the United States Bureau of Mines.

	Gold (ounces per ton)	*Silver (ounces per ton)*	*Lead (percent)*	*Copper (percent)*
1915	0.18	47	37	3.2
1916	.20	40	23	2.4
1917	.12	15	11	.9
1918	.25	42	5.8	6.0
1919	.69	19	21	.4

BURLINGTON MINE (FLUORSPAR)

The Burlington mine is in a small gulch on the west side of Porphyry Mountain, 5,000 feet N. 34° W. of

Jamestown at an altitude of 7,354 feet. It explores one of the largest fluorspar breccia zones in the district. It has been actively operated by the General Chemical Co. since 1942. The ore is treated in the company's flotation mill near Boulder to produce acid spar. The total production is not known, but 23,861 tons of crude ore were produced during the period May 1942–December 1943,[89] and probably a few thousand tons were produced earlier.

The workings consist of a shaft 160 feet deep and two levels aggregating about 1,000 feet (fig. 83). The upper level connects with a tunnel.

The Burlington breccia zone strikes about N. 50°–55° E. and is nearly vertical. As exposed on the surface and in the upper level, it consists of an irregular zone about 350 feet long and 7 to 50 feet wide. It is composed chiefly of granite fragments a fraction of an inch to 18 inches in diameter and smaller fragments of both fine and coarsely crystalline fluorspar cemented by a fine-grained mixture of fluorspar grains, clay minerals, and quartz. Some large quartz fragments are scattered through the zone, and pyrite is disseminated throughout. Within the zone there are short discontinuous veins as much as 10 feet wide of higher grade fluorspar containing very few granite fragments. In the second level the fluorspar-bearing zone is largely consolidated into a nearly continuous vein more than 325 feet long and having a maximum width of 23 feet. This vein is composed of fine-grained fluorspar containing small fluorspar fragments mixed with some clay material. A few small granite fragments are present. Along the borders this material grades into low-grade breccia in which granite fragments are abundant. Throughout the workings the fluorspar-bearing zone is bordered by a zone a few feet to more than 20 feet wide of granite breccia containing only small amounts of fluorspar, and this in turn grades into fractured, sericitized granite. Fragments of quartz, pyrite, and galena are locally abundant in the fluorspar zone, and small amounts of fine fragmental quartz and pyrite are mixed with the fine-grained fluorspar.

The Burlington fluorspar ore ranges in grade from low to medium. The fluorspar breccia contains about 37 to 60 percent of CaF_2 and the vein material from 60 to 75 percent. Ore mined from the upper level during 1942 averaged 53 percent of CaF_2, and that mined from the lower level during 1943 averaged about 58 percent. The silica content is high and averages about 30 percent. The sulfide minerals, chiefly pyrite, make up about 4 to 5 percent of the ore.

The Burlington ore body is apparently becoming higher in grade but somewhat narrower with depth. The character and size of the ore body on the second level seems to indicate that it will extend to at least a few hundred feet and perhaps several hundred feet below the present workings, and it seems likely that a fairly large tonnage of ore awaits development at greater depth.

[89] Data furnished by General Chemical Co.

EMMETT MINE (FLUORSPAR)

The Emmett mine is on the south side of Little James Creek, 5,000 feet N. 41° W. of Jamestown at an altitude of about 7,350 feet. It is the deepest fluorspar mine in the district. It is operated by Harry M. Williamson & Son under lease from the Boulder Fluorspar & Radium Co. The total production is not known but has probably been more than 20,000 tons of crude ore. During 1942–43, H. B. Williamson reported that 16,776 tons were mined and treated in the Wano mill at Jamestown to produce both acid and metallurgical spar.

The workings consist of a vertical shaft 480 feet deep (fig. 84), which connects with a crosscut tunnel and five lower levels. The collar is in a large glory hole 20 feet below the surface.

The mine explores a rather high-grade fluorspar vein that strikes about N. 65° W. and dips steeply northeast and is enclosed within an extensive barren breccia zone in Silver Plume granite. In the glory hole the vein was bordered by about 5 to 10 feet of granite breccia cemented by fluorspar, but in the lower levels this fluorspar-bearing breccia is largely absent. The vein is cut by a postore granite porphyry dike, which strikes nearly east and dips steeply southeast and is exposed in all the levels of the mine. The barren breccia zone strikes about N. 65° W. and dips steeply and can be traced for about 2,300 feet.

The Emmett vein ranges in width from about 6 to 18 feet. At the surface it had a length of about 130 feet, but in the 180- and 280-foot levels it is more than 200 feet long. As shown on figure 84, a segment of the vein at its western end is out of position, though no clear-cut fault could be found to account for the displacement.

The vein is filled with abundant coarse-grained fluorspar fragments a fraction of an inch to 2 feet in diameter cemented by fine-grained fluorspar, clay minerals, and quartz. In many places the fluorspar fragments are closely packed and form fairly high-grade ore. Quartz fragments are locally abundant, especially in the southeastern part of the vein, and in places there are some granite fragments. The fine-grained fluorspar is a mixture of fragmental material and a second generation of fluorspar that is very irregular in its distribution. Pyrite is disseminated throughout, and small amounts of galena, chalcopyrite, sphalerite, and gray copper are locally present. In places a fine-grained mixture of ankerite and hematite have been deposited after the second generation of fluorspar. The ore shows no marked change from the surface to the 480-foot level,

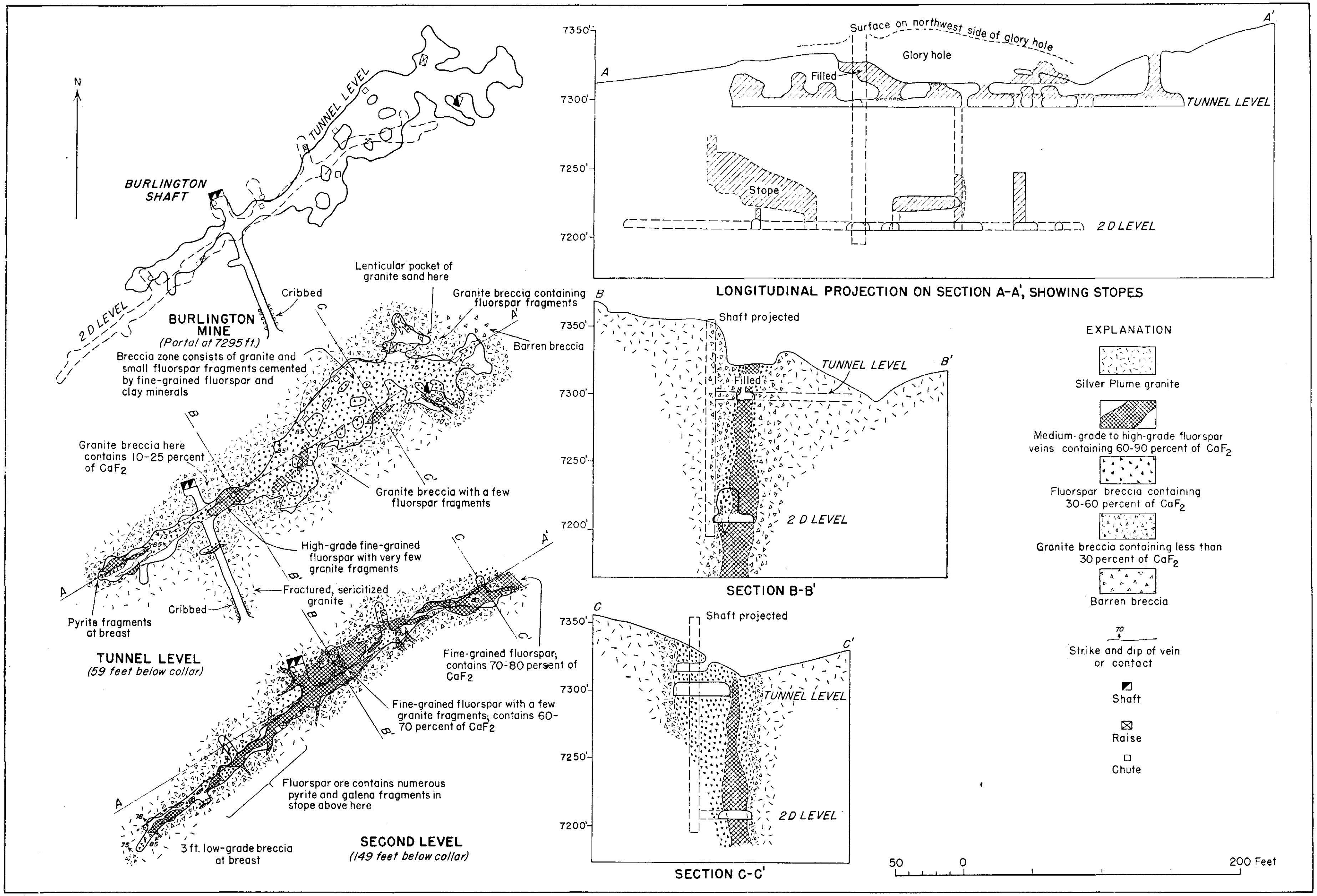

FIGURE 83.—Plan of the tunnel level and second level and sections of the Burlington mine, Jamestown district.

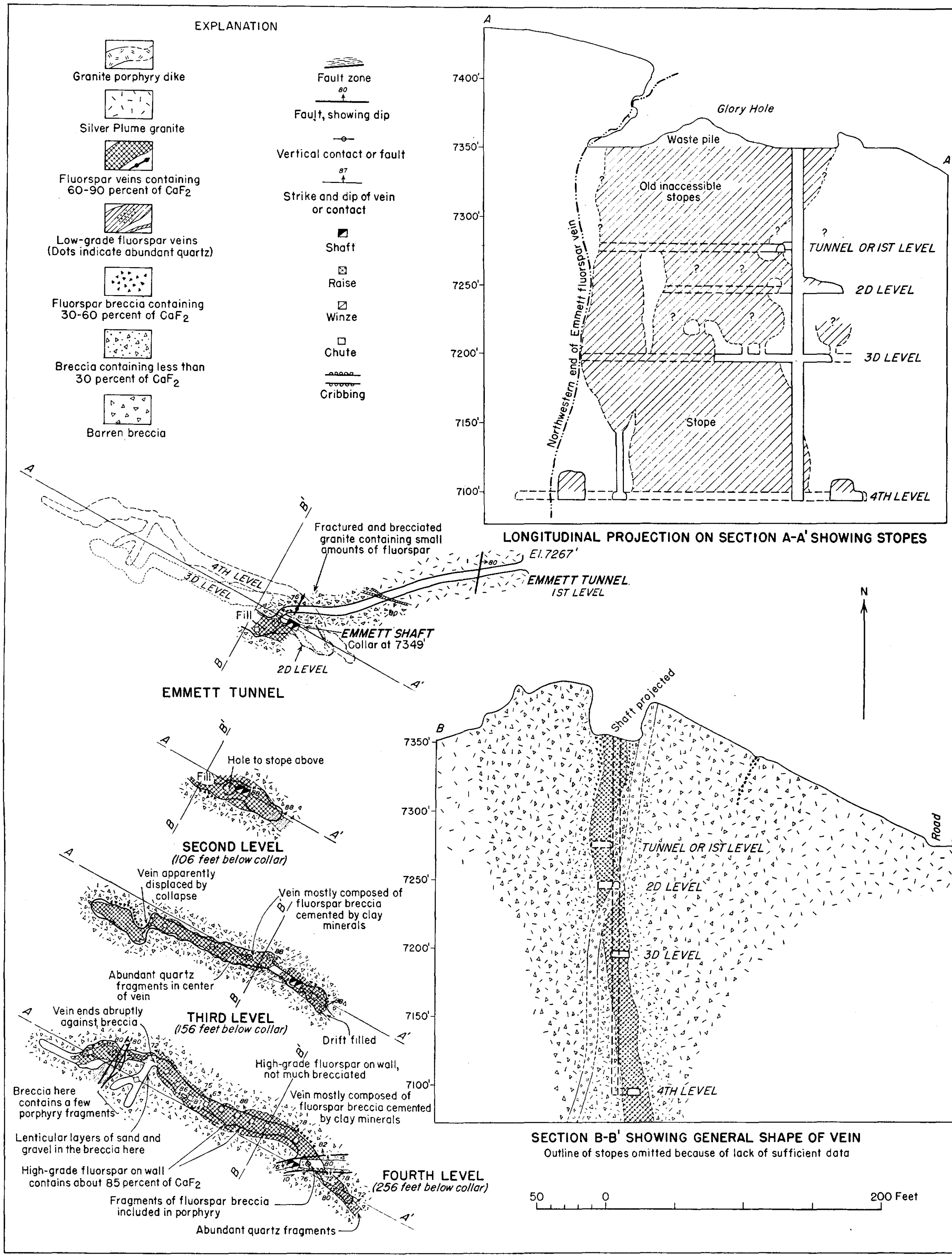

FIGURE 84.—Plan of the Emmett tunnel and the second, third, and fourth levels and sections of the Emmett mine, Jamestown district.

except that the grade is reported to be somewhat higher in the lower levels.

Ore mined from the Emmett mine during 1942–43 has ranged in grade from 56 to 76 percent of CaF_2. According to H. B. Williamson, ore from the third level averaged 65 percent of CaF_2, and that from the fourth level averaged 72 percent. He also reports that samples from the fifth and sixth levels indicate a grade of about 65 percent of CaF_2. The silica content ranges from about 15 to 25 percent.

A fairly large block of ore was being developed between the fourth and sixth levels in 1944, and it seems likely that the ore body may extend to even greater depth.

BLUE JAY MINE (FLUORSPAR)

The Blue Jay mine is in McCorkle Gulch, 3,000 feet S. 20° E. of Jamestown at an altitude of about 7,100 feet. The workings consist of two caved tunnels, each about 150 feet long, and two shafts, one (now caved) about 50 feet deep, and one about 20 feet deep. There are also numerous open cuts and pits along the vein.

The Blue Jay vein is the most persistent fluorspar vein in the Jamestown district. It strikes N. 70°–88° W. and dips 75°–86° N. It is about 1,000 feet long and is part of an extensive vein system that can be traced for nearly 3,000 feet. It ranges in width from 6 inches to 16 feet but averages about 4 feet. At its eastern end it joins a system of veins striking N. 65° E., but this junction could not be observed. Near the middle part of its extent the vein splits and reunites within 120 feet; it is at this split that it reaches its maximum width. In places where the dip decreases the vein widens; this relationship is believed to indicate that the north or hanging wall has moved up a few feet.

The wall rock throughout most of the vein's extent is granodiorite that has been partly altered to sericite, clay minerals, and chlorite and consequently forms very loose ground in many places. For a distance of 1 to 3 feet from the vein the wall rock is almost entirely sericitized. The eastern part of the vein is in granite and some pegmatite, both of which are partly sericitized next to the vein.

The vein material is everywhere very similar. It consists of strongly brecciated deep violet coarsely crystalline fluorspar cemented by a very fine grained mixture of fluorspar, quartz, ankerite, clay minerals, and brown iron oxide. In places brown chalcedony is mixed with the cementing material. Very fine grained pyrite and some galena are disseminated in the matrix. The brown iron oxide is most abundant in vein material close to the surface and is probably derived from oxidation of the pyrite. Minute sparsely scattered grains of pitchblende have been identified in the cementing material by radiographs. In places the vein contains fragments of wall rock, and rarely fragments of white "bull" quartz intergrown with coarse-grained fluorspar and orthoclase are found, which apparently represent a pegmatitic facies of the sodic granite porphyry. The fluorspar fragments commonly range in diameter from a twentieth of an inch to a half an inch, but in places they are several inches in diameter.

The grade of ore shipped from the Blue Jay mine prior to 1941 is not known, but it probably ranged from about 72 to 85 percent of CaF_2. Twenty-five tons shipped in 1941 contained 67 percent of CaF_2. A number of samples taken by H. B. Williamson ranged in grade from 70 to 90.75 percent of CaF_2 and from 7.70 to 24 percent of silica, and one sample contained 57 percent of CaF_2 and 36 percent of silica. Parts of the vein in which fragments of wall rocks are abundant are estimated to contain only 40 to 50 percent of CaF_2. Some of the ore can probably be shipped as metallurgical spar, but most of it will probably have to be milled.

OTHER MINES

Data on other mines are given briefly below.

ARGO (FLUORSPAR)

Development.—Shaft 100 feet deep; tunnel 600 feet long connects with shaft 90 feet below collar. Lower level 66 feet below tunnel.

Production.—More than 10,000 tons of crude fluorspar ore. In 1943, 2,356 tons of crude ore averaging 57 percent of CaF_2.

Veins.—Argo breccia zone 250 feet long and 60 feet wide; strike, N. 80° E., dip, 85° N.; made up of altered granite fragments cemented by fine-grained fluorspar mixed with clay minerals. Contains veins of higher grade fluorspar.

Wall rock.—Sericitized granite.

Ore and sulfide minerals.—Chiefly deep violet, fine-grained fluorspar, some galena, sphalerite, pyrite, tennantite, chalcopyrite, and enargite. Sulfides occur in breccia fragments in fluorspar.

Gangue minerals.—Altered wall rock, quartz, sericite, and clay minerals.

Ore shoots.—Whole breccia zone low-grade ore. High-grade veins 1 to 10 feet wide and 25 to 150 feet long.

Tenor.—Ore from lower levels contained 52.4 to 69.2 percent of CaF_2 and 21.53 to 32.06 percent of silica. Lead-silver ore sorted from fluorspar contained 0.06 to 0.3 ounce of gold and 7 to 26 ounces of silver per ton, 22 to 40 percent of lead, and 0 to 5 percent of copper.

BLACK ROSE

Development.—Two tunnels and shaft 70 feet deep, aggregating about 1,500 feet.

Production.—About $60,000.

Veins.—Three veins explored in workings, join to south on New Rivel property. Two strike about N. 35° E. and dip steeply west, one called Dopp vein; third strikes N. 78° E. and dips steeply southeast. Whole system can be traced for distance of 1,600 feet over vertical range of 500 feet. Veins few inches to 5 feet wide. On N. 35° E. veins, northwest wall moved down to northeast at 75°; on N. 78° E. vein, southeast wall moved down to northeast.

Wall rock.—Injection gneiss, schist, and some Boulder Creek granite. Foliation of gneiss and schist strikes N. 75°–80° E. and dips 65° SE. to vertical.

Ore and sulfide minerals.—Petzite, krennerite, pyrite, chalcopyrite, and some altaite. Rusty gold in oxidized zone.

Gangue minerals.—Horn to sugary quartz and silicified wall rock.

Ore shoots.—On N. 78° E. vein ore shoot is 100 feet in stope length, 30 to 50 feet in breadth, and 1 to 5 feet in thickness. On Dopp vein ore shoot is 85 feet in stope length, 30 to 40 feet in breadth, and 2 to 4 feet in thickness. Localization of ore is controlled chiefly by junctions.

Tenor.—Ore in Dopp vein averaged 3.07 ounces of gold and 4.6 ounces of silver per ton. Small lots contained as much as 300 ounces of gold and 350 ounces of silver per ton.

BROWN SPAR (FLUORSPAR)

Development.—Shaft 300 feet deep and 3 levels aggregating 500 feet.

Production.—Probably more than 10,000 tons of crude fluorspar ore. In 1943, 6,974 tons averaged 62 percent of CaF_2.

Veins.—Main vein strikes N. 70°–80° E., dips steeply southeast, and is intersected by short irregular veins of northwest, northeast, north, and east trends.

Wall rock.—Altered granodiorite.

Ore and sulfide minerals.—Chiefly violet fluorspar (mostly fine-grained), some pyrite and galena.

Gangue minerals.—Quartz, wall rock, clay minerals, and ankerite.

Ore shoot.—At intersection of main vein with other irregular veins, 60 to 100 feet in stope length and 7 to 25 feet thick; extends from surface to depth of more than 300 feet, nearly vertical.

Tenor.—In lower levels ore contained 52 to 84.4 percent of CaF_2, average 62 percent. Silica content, 10 to 25 percent.

BUCKHORN

Development.—Patented 1873. Shaft 425 feet deep with 4 levels, caved for many years.

Production.—1927–32: Gold, 332.43 ounces; silver, 987 ounces; lead, 28,872 pounds; and copper, 56 pounds.

Vein.—Strike, N. 15°–20° W.; dip, about vertical (covered at surface); few inches to 5 feet wide; on southwest side joined by small parallel veinlets having northerly trend.

Wall rock.—Silver Plume granite near border of granodiorite stock.

Ore and sulfide minerals.—Pyrite, chalcopyrite, and galena, some gray copper and sphalerite. Gold associated with pyrite and chalcopyrite, silver with galena and gray copper.

Gangue minerals.—Quartz and silicified granite, some fluorite.

Ore shoots.—Lead-silver ore in pockets 10 to 15 feet long at junctions of small veinlets with main vein.

Tenor.—1879–88: Ore contained 0.3 to 5 ounces of gold and 2.8 to 10 ounces of silver per ton and 0 to 36 percent of lead. 1927–31: Ore contained 0.2 to 1.29 ounces of gold and 0.1 to 5 ounces of silver per ton and 0 to 26 percent of lead.

CHANCELLOR (FLUORSPAR)

Development.—Patented 1907. Three short tunnels, a glory hole, several open cuts, and a crosscut tunnel with 850 feet of workings, which explores vein 150 feet below outcrop.

Production.—During years 1919, 1924, and 1927–30: 1,817 short tons of metallurgical fluorspar. 1910–34: 54 tons of gold ore containing 215 ounces of gold and 42 ounces of silver, 1 ton of lead-silver ore containing 356 pounds of lead, 16 ounces of silver, and 18 ounces of gold. 1942–43: 5,547 tons of crude fluorspar ore.

Veins.—3 nearly parallel veins strike N. 70° W. to west and dip steeply. Nearly all production from southern vein, 3 to 20 feet wide and 150 feet long.

Wall rock.—Altered granodiorite and some altered granite.

Ore and sulfide minerals.—Chiefly coarse-grained and fine-grained violet fluorspar, a little pyrite, galena, and gold.

Gangue minerals.—Quartz, wall rock, and clay minerals.

Ore shoots.—On southern vein, shoot 120 to 150 feet in stope length, more than 150 feet in pitch length, and 3 to 20 feet in thickness. Small shoots on other veins.

Tenor.—60 to 85 percent of CaF_2 1942–43, average 63 percent of CaF_2.

GRAND CENTRAL-BIG BLOSSOM

Development.—4 tunnels on vein, two short crosscut tunnels, three shafts, all aggregating more than 2,000 feet. Range in altitude, from 7,200 feet to 7,450 feet.

Production.—More than $30,000.

Veins.—Grand Central and Big Blossom, parallel veins 15 to 40 feet apart; strike, N. 34°–58° E.; dip, 45°–85° SE. Grand Union joins Grand Central on west and cuts across to Big Blossom; strike, N. 55°–77° E.; dip, 60°–80° SE. Veins from fraction of inch to 6 feet wide. Southeast walls moved steeply down to southwest.

Wall rock.—Complex mixture of Silver Plume granite, schist, injection gneiss, pegmatite, aplite, and dikes of intermediate quartz monzonite porphyry.

Ore and sulfide minerals.—Gold tellurides, free gold, and finely disseminated pyrite.

Gangue minerals.—Horn quartz and silicified wall rock.

Ore shoots.—On lower-tunnel level, 3 small ore shoots, 20 to 80 feet long, 12 to 40 feet in breadth, and 1½ to 6 feet thick. Localized at vein junctions and in flatter and more eastward-trending parts of veins.

Tenor.—Low-grade ore contained 0.9 to 3.8 ounces of gold and 1.0 to 1.4 ounces of silver per ton; medium-grade contained 5.2 to 24.6 ounces of gold and 3 to 35 ounces of silver per ton; high-grade contained 125 to 1,656 ounces of gold and 24 to 30 ounces of silver per ton.

JOHN JAY

Development.—Original discovery 1875. Shaft 350 feet deep with 5 levels; also numerous small tunnels, shafts, and pits.

Production.—Prior to 1883, $95,000. 1902–35: Gold, 452 ounces and silver 110.99 ounces. Total more than $140,000.

Veins.—John Jay vein: Average strike, N. 40° E.; in John Jay workings, strike is N. 15°–35° E. and dip is 57°–80° W.; 10 inches to 9 feet wide and 7,500 feet long; west wall moved north and down at 48° to 60°; displacement 36 to 45 feet. Vein cuts breccia reef 650 feet south of main shaft. Golden Bell vein joins John Jay at shaft; strike, about N. 10° E. and dip, 80°–88° W.

Wall rock.—Quartz monzonite gneiss having foliation about parallel to vein, pegmatite, aplite, and granite.

Ore and sulfide minerals.—Sylvanite, krennerite, altaite, pyrite, and a little native tellurium and coloradoite.

Gangue minerals.—Quartz (chiefly horn) and silicified wall rock, some ankerite.

Ore shoots.—Most of ore came from shoot extending from surface to 20 feet below 160-foot level; stope length 275 feet, breadth 180 feet, and thickness 2 to 9 feet; localized in vicinity of junction with Golden Bell vein. Other small ore bodies.

Tenor.—1878–92: Lower-grade ore contained 1.8 to 30 ounces of gold and 1 to 10 ounces of silver per ton; high-grade contained 30 to 499 ounces of gold and 10 to 199 ounces of silver per ton.

1902–32: Ore averaged 3.06 ounces of gold and 1 ounce of silver per ton. Most of ore in 1933 contained 0.22 to 8.85 ounces of gold and 0 to 8.75 ounces of silver per ton.

LONGFELLOW

Development.—3 shafts, 3 tunnels, and more than 1,500 feet of levels. Main shaft 400 feet deep, discovery shaft 200 feet deep. Crosscut tunnel connects with bottom of shaft.

Production.—More than $75,000. 1902–35; 1,595.78 ounces of gold, 33,698 ounces of silver, and 229 pounds of copper.

Vein.—Longfellow: Strike, N. 70°–81° E.; dip, 70°–88° S.; few inches to 5 feet wide and 1,000 feet or more long. South wall moved down to southwest 3 to 5 feet.

Wall rock.—Silver Plume granite and dikes of pegmatite.

Ore and sulfide minerals.—Chalcopyrite and pyrite, some galena, sphalerite, and gray copper. Free gold in oxidized zone.

Gangue minerals.—Quartz and silicified granite, a little barite and fluorite.

Ore shoots.—Most of ground between 100- and 200-foot levels has been stoped for length of 350 feet. Near discovery shaft ore body is about 100 feet in stope length and 100 feet high. Other smaller ore bodies. Maximum thickness about 5 feet. Ore localized by pegmatite dikes and by changes in strike of vein.

Tenor.—Ore contained 0.3 to 4.7 ounces of gold and 16 to 40 ounces of silver per ton and trace to 28 percent of copper. 1901–32 average: 0.3 ounce of gold and 6.4 ounces of silver per ton.

NUGGET GROUP

Development.—Claims patented 1885. Seven tunnels aggregating about 2,750 feet over vertical range of 600 feet. Also glory hole 300 feet long, 75 feet wide, and 50 feet deep.

Production.—1901–17: Gold, 235.06 ounces; silver, 376 ounces; lead, 97 pounds.

Veins.—Little Don: Strike, N. 82° W. in western part, gradually swings to N. 48° E.; dip, 72°–88° SE.; forms zone of small veinlets and disseminated pyrite 20 to 30 feet wide, widens to 120 feet northeast of Nugget mine; can be traced for length of 5,500 feet. Nugget vein: Strike, N. 75°–80° E.; dip, 70°–90° N. in mine, swings to N. 55° E. east of mine; 1 inch to 3 feet wide, in places forms zone 10 to 15 feet wide; joins Little Don near west end of glory hole.

Wall rock.—Schist containing pegmatite dikes. Foliation strikes N. 65°–88° E., dips steeply southeast.

Ore and sulfide minerals.—Chiefly pyrite, some galena.

Gangue minerals.—Quartz, sericitized wall rock, fluorite, and roscoelite.

Ore shoots.—Large ore shoot mined from beneath glory hole. On Nugget vein ore shoot is 75 feet in stope length, 20 to 25 feet in breadth, and as much as 7 feet thick. Other small ore shoots.

Tenor.—1882–91: Some shipments contained 0.1 to 1.5 ounces of gold and 0.5 to 4 ounces of silver per ton, and a few contained 7.4 to 47 ounces of gold and 11 to 17 ounces of silver per ton. Average for 1901: 0.24 ounce of gold and 0.05 ounce of silver per ton. Average for 1909: 0.12 ounce of gold and 0.03 ounce of silver per ton.

RIP VAN DAM

Development.—Original discovery 1875. Numerous tunnels, small shafts, pits, and open cuts over vertical range of 450 feet. Lowest tunnel follows vein for 1,100 feet.

Production.—$15,000 up to 1883. 1904–21: Gold, 515.28 ounces; silver, 1,166 ounces.

Vein.—Rip Van Dam: Average strike, N. 60° E.; average dip, 75° SE.; 1 inch to 4½ feet wide and 2,000 feet long.

Wall rock.—Schist, granite, injection gneiss, pegmatite, and small dikes of quartz monzonite porphyry.

Ore and sulfide minerals.—Gold tellurides, free gold, and finely disseminated pyrite. Very small amount of sphalerite, galena, chalcopyrite, and gray copper.

Gangue minerals.—Horn quartz and silicified wall rock.

Ore shoots.—Localized in more easterly parts of vein, also by vein junctions and changes in character of wall rock. Those on lower tunnel small.

Tenor.—Low-grade ore contained 0.7 to 10 ounces of gold and 2 to 15 ounces of silver per ton; medium-grade contained 20 to 234 ounces of gold and 64 to 741 ounces of silver per ton, in lots of 50 to several hundred pounds; high-grade contained 551 to 1,408 ounces of gold and 726 to 2,083 ounces of silver per ton, in lots of a few pounds.

YELLOW GIRL (FLUORSPAR)

Development.—Open cut 105 feet long and 20 to 40 feet deep; two upper tunnels, lower tunnel aggregating 950 feet explores vein 120 feet below outcrop.

Production.—Prior to 1909, 1,700 tons of fluorspar ore; 1942, 6,021 tons; 1943, 154 tons.

Vein.—Yellow Girl: Strike, N. 5°–10° W.; dip, steeply west; 340 feet long and 1 to 22 feet wide; splits to north.

Wall rock.—Altered granodiorite.

Ore and sulfide minerals.—Chiefly coarse-grained and fine-grained purple fluorspar, some pyrite, and a little galena.

Gangue minerals.—Quartz, wall rock, clay minerals, and carbonate.

Ore shoot.—125 to 180 feet in stope length and 3 to 22 feet thick; extends from surface to depth of more than 120 feet.

Tenor.—Ore contains 55 to 75 percent of CaF_2; 1942 average, 58 percent.

LARAMIDE DEPOSITS OUTSIDE THE MINERAL BELT

AUGUSTA LODE

The Augusta lode, on Cub Creek half a mile above Evergreen, has been described briefly by Lindgren,[90] who noted that its character was different from the pre-Cambrian copper deposits nearby. (See p. 67.) It lies along a northwesterly fissure belonging to the early breccia-reef system and probably is related closely to the weakly mineralized Floyd Hill-Bergen Park fracture zone. Some ore containing copper and silver has been shipped from it, but its total output is small. Its principal workings consist of an open cut and a shaft 130 feet deep. The lode is a sharply defined quartz-fluorite vein containing yellow zinc blende and chalcocite and showing distinct crustification. It strikes north-northwest and dips 70° WSW. In most places its mineralized part is less than a foot thick.

QUIGLEY MINE

The Quigley mine is about 15 miles west of Loveland and is on the divide between the North Fork of Thompson River and Big Thompson River in sec. 5, T. 5 N., R. 71 W. The country rock is Silver Plume granite (Mount Olympus variety), and the deposit itself is in

[90] Lindgren, Waldemar, Notes on copper deposits of Chaffee, Fremont, and Jefferson Counties, Colo.: U. S. Geol. Survey Bull. 340, p. 170, 1908.

a quartz vein trending north-northwest. In the Jerry Quigley tunnel a mass of high-grade oxidized copper ore was mined, but there is little evidence of additional copper mineralization nearby. On the south slope of the ridge, on what is known as the Perry Sullivan mine, the same vein was exploited for its gold content, but little success attended the operation. Some cuprite was noted at the contact of the quartz vein with granite, and it is believed that much of the ore mined in the Quigley deposit was of this character. The vein cuts granite pegmatite and follows a fault that displaces the Fountain formation on the North Fork of Little Thompson River a few miles to the southeast (pl. 1). The mineralization is regarded as belonging to the "breccia reef" type characteristic of an early stage of the Laramide revolution.

DAILEY OR JONES PASS DISTRICT

The Dailey or Jones Pass mining district is in the southern part of the Fraser quadrangle, a few miles southwest of Berthoud Pass. It includes the headwaters of the west fork of Clear Creek on the eastern side of the Continental Divide and part of the headwaters of the Williams Fork River on the western side of the Divide. The Victory highway, U. S. No. 40, a splendid automobile road, crosses the eastern edge of the district. In 1935 a wagon road was completed which extended westward over Jones Pass, altitude 12,452 feet, to the west portal of the transmountain water diversion tunnel on Bobtail Creek; it could be traversed by automobiles with difficulty. Supplies, however, must still be carried to several of the mines by pack train. The western part of the district can also be reached by trail from Leal post office in the valley of the Williams River about 10 miles northwest of Jones Pass.

The district includes an area of about 10 square miles, and nearly all of it lies above an altitude of 10,000 feet. Dikes and a small stock of granite porphyry occur in the southeastern part of the district, on and near Red Mountain, but intrusives of the Laramide have not been observed to the west. The Urad molybdenum mine on Red Mountain has contributed most of the output of the district, which is small. The chief minerals found in the veins outside the Urad mines are sphalerite, galena, pyrite, and silver minerals. The trend of most of the veins developed is north and northeast, but cross veins striking north to northwest are common. Most of the high-grade ore shoots are lenticular or chimneylike, but shoots of low-grade pyritic quartz, which were not commercial in 1932, persist for several hundred feet along the strike in some of the veins. The shoots of high-grade ore are commonly less than a foot thick, but the low-grade pyritic ore may be 4 to 8 feet thick for some distance.

BOBTAIL MINE

The Bobtail mine, at an altitude of 10,400 feet, is on Bobtail Creek, a continuation of the Williams River, 1.3 miles southwest of Jones Pass. Several cabins in poor repair and a 10-stamp mill are on the eastern side of the stream across from the mouth of the main tunnel, which was approximately 500 feet long in 1929. The Bobtail vein itself strikes from N. 80° E. to N. 60° E., and is developed through the adit. The country rock is entirely Silver Plume granite, and no porphyry formed during the Laramide revolution is known in the nearby region. The vein, which occupied a narrow sheeted zone, is nearly everywhere less than 12 inches thick and contains pockets and seams of ore 1 to 6 inches thick separated by nearly barren sheared granite. Near the mineralized parts of the vein the granite is bleached and manganese-stained. The ore is a typical complex lead-zinc ore made up chiefly of pyrite and sphalerite (blackjack) with sporadic masses of galena. The gangue is chiefly massive quartz with a little late horn quartz and some small seams of white ankerite. The longest continuous seam of ore exposed was approximately 100 feet long and 6 inches thick.

READY CASH MINE

The Ready Cash mine is on the eastern side of Bobtail Creek Valley, 0.8 mile southwest of Jones Pass, at an altitude of approximately 11,200 feet. In 1929, when visited by the writers, the mine was opened by three adits. The output of the mine is not known, but a small amount of high-grade silver ore has been shipped. The country rock is entirely Silver Plume granite, the typical "corn rock" of the Silver Plume mining district. No porphyry was observed near the mine, nor was any found in the float along the valley sides. Schist and injection gneiss of the Idaho Springs formation appear on Williams Fork about a mile west of the mine, but none was seen nearby.

Three veins have been cut by the middle adit—the Mud vein, striking from N. 20° to 30° E. and dipping steeply to the west, the Ready Cash vein, 50 feet farther east, striking N. 17° E. and dipping 71° E., and the Helping Hand vein, about 100 feet farther east, striking N. 8° E. An easterly branch of the Ready Cash vein strikes from N. 45° to 60° E. and joins the Helping Hand vein about 600 feet northeast of the cabins. A chimney of high-grade silver ore is said to have been mined out at the junction. Another ore body was found in the Ready Cash vein just north of its junction with this branch vein, but south of the junction the Ready Cash fissure is mineralized very little. The ore found in the Helping Hand vein is chiefly galena with an appreciable content of silver. The vein filling in the Ready Cash commonly consists of brecciated granite cemented

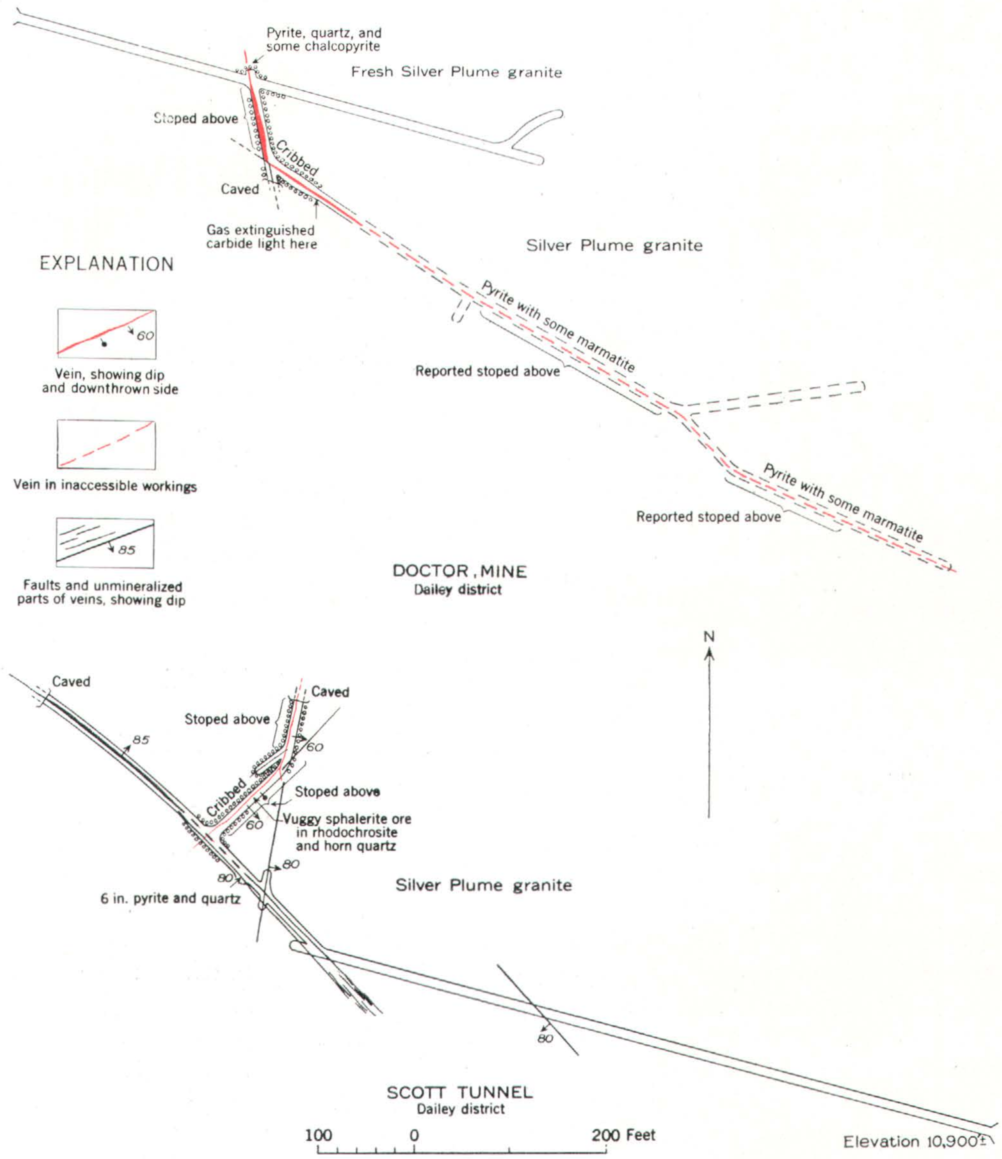

FIGURE 85.—Plan of the Doctor mine and Scott tunnel, Dailey district.

by horn quartz, with blackjack, galena, some rosin jack, gray copper, and a little ankerite. The high-grade ore assayed about 115 ounces of silver to the ton, according to A. C. Trout, the owner. The granite is strongly bleached and altered near the vein. Where seen by the writers, the ore-bearing part of the vein was approximately 6 inches wide, but according to Trout the ore shoot ranged in width from 3 to 24 inches and pitched about 45° S.

SCOTT TUNNEL

The Scott crosscut tunnel is 1.3 miles N. 80° E. of Jones Pass at an altitude of about 10,900 feet. The tunnel is more than 1,100 feet long, but in 1932, when visited by Lovering, the breast was not accessible. As shown in figure 85, the tunnel extends west-northwest into the mountain, crosscutting the Silver Plume granite which forms the country rock of the mine for a distance of 700 feet, and thence following a barren sheeted zone of northwesterly strike for 370 feet to a point where it was caved in 1932. Fifty feet beyond the point where the crosscut enters the northwesterly sheeted zone, a barren fissure striking N. 10° E. is cut. Eighty feet farther northwest a vein striking N. 45° E. has been followed northeastward to its junction with the N. 10° E. vein. At this junction the northeasterly fissure becomes barren, the vein material continuing northward along the N. 10° E. vein. The granite is strongly altered in the area of mineralization, and the ground is very "heavy." Southwest of the intersection the northeasterly vein dips 60° SE., and the unmineralized fissure dips 80° E. North of the intersection the N. 10° E. vein dips 60° E. The vein has been stoped for an undetermined distance above the level, but the stopes were very wet and in bad condition in 1932. The vein itself could not be seen, but ore found on the dump had a width of 3 to 15 inches and was made up of nearly solid sulfides, chiefly dark sphalerite and galena with minor amounts of pyrite. The sulfides were cut by seams of quartz and rhodochrosite.

DOCTOR MINE

The Doctor mine is 1½ miles N. 75° E. of Jones Pass, at an altitude of 10,850 feet, and is entirely in Silver Plume granite. The mine is opened by two adits—a short upper tunnel and a lower tunnel, which is reported to extend east-southeast into the mountain for a distance of 1,100 feet. When examined by the writers, only a small part of the drift along the vein could be entered, as the air was so poor that a carbide lamp could not burn.

In 1932 there were several cabins about 100 yards south of the portal of the main crosscut tunnel and a small steam mill equipped with jaw crushers, ball mills, and tables.

The ore on the upper level occurs in a vein striking N. 15° E. and dipping steeply east (fig. 85). It is a lead-zinc ore containing a small amount of chalcopyrite and much pyrite. Fifty feet below, on the main adit level, the ore in this vein is extremely pyritic; very little chalcopyrite or galena was noted, but dark sphalerite in a few places made up approximately one-sixth of the ore. The vein fissure is a channel for a heavy flow of water; the wall rock on each side is much altered, and the ground is "heavy." The north-northeasterly vein intersects a west-northwesterly vein about 90 feet from the main crosscut, but because of the bad air the writers were unable to examine this vein in detail. According to Mr. E. P. Snyder, the former superintendent of the property, the northwesterly vein contained a maximum of 15 percent of zinc and 2 to 10 ounces of silver and about 0.04 ounce of gold to the ton, the highest of 100 assays showing 0.075 ounce of gold. Pyritic concentrates of this ore contained an average of about 0.2 ounce of gold to the ton, some zinc, and less than 1 percent of copper. The gangue is chiefly quartz, but some manganiferous ankerite is also present.

On the upper level the north-northeasterly vein is 3 to 4 feet thick, and some rich massive chalcopyrite ore was found north of the junction with the northwesterly vein. No ore was found to the south, however, and no ore is known on the northwesterly vein west of the junction. The flow of water at the intersection of the two veins is very strong, and the grade of ore exposed in the mine and on the dump offers little incentive to sink a shaft and pump out the water.

PUZZLER AND SCOTIA VEINS

The Puzzler vein is 3½ miles due east of Jones Pass, about half a mile northwest of the hairpin curve where U. S. Highway 40 starts its ascent from the valley of Clear Creek for Berthoud Pass. The vein is opened by a shaft, a level 200 feet long, and an adit 650 feet long, which is 70 feet below the shaft collar. The country rock in both levels is injection gneiss and Silver Plume granite; the foliation of the gneiss strikes about N. 50° W. and dips 40° NE. The vein itself strikes northeast at the shaft and dips 58° NW., but 50 feet northeast of the shaft the course of the vein changes abruptly to N. 82° E. Coincident with this change the seam of ore thickens and contains much more silver and gold than to the southwest. The vein is 2 to 3 feet thick and consists chiefly of greenish-blue quartz containing abundant disseminated pyrite and some secondary silver minerals. Native silver was observed resting on pink and brown ankerite crystals in vugs. According to E. P. Snyder, the lessee, the ore from the upper level, taken from the stope on the easterly fork, assayed 66 ounces of silver and 0.60 ounce of gold to the ton and contained no lead, zinc, or copper. Almost no sign of ore was seen along the lower adit until the change in course was reached, and even there the vein quartz was of comparatively low grade and was barren in many places. Near the breast, about 650 feet from the portal. a gougy seam between the vein and hanging wall contained visible molybdenite and was said to assay about 2 percent of MoS_2.

About 1,000 feet east of the Puzzler shaft a strong vein known as the Scotia strikes N. 20° E. If the Puzzler maintains its easterly course the two should intersect about 1,200 feet from the shaft. So far as is known this intersection has not been sought. About 250 feet west of U. S. Highway 40 the Scotia vein is exposed in a prospect on the Jones Pass road. There it strikes N. 10° E., dips 80° E., is about 5 feet wide, and is made up chiefly of brecciated, vuggy vein quartz containing a small amount of barite, calcite, manganosiderite, galena, chalcopyrite, and pyrite. According to Snyder, it contains less than half an ounce of gold to the ton. As the vein is followed along the strike, it apparently thickens where it shifts toward the northeast but pinches where it resumes its north-south trend.

URAD MINE

The molybdenite deposit at Camp Urad,[91] on Red Mountain, about 10 miles west of Empire, was first developed and mined by the Primos Chemical Co. in 1914 and 1915. In 1917 a deep crosscut tunnel (altitude 10,150 feet) was begun, and during World War I it was completed to a position beneath the upper workings, but the quantity and grade of mineralized rock did not encourage further development. Several thousand tons of molybdenite were produced up to 1918.

In 1942, because of the war demands for molybdenum, the Molybdenum Corporation of America, under contract with the Defense Plant Corp., undertook development of the deposit by raising 1,100 feet from the lower tunnel to the lower levels of the old Urad mine (altitude 11,250 feet). This raise was completed in 1943, and a 200-ton mill was erected. The property was finally purchased by the Molybdenum Corporation of America, and production started early in 1945.

In the vicinity of the mine, Silver Plume granite and some schist have been intruded by a small stock of granite prophyry of Tertiary age. The outcrop of the porphyry near the top of Red Mountain contains considerable pyrite, which has weathered to give the rock a dark-brown to red color. The surrounding rock is highly altered near the contact and contains small amounts of pyrite.

The molybdenite, associated with quartz and pyrite, occurs chiefly in veins and seams in the highly altered rock near the contact. Small amounts of rhodochrosite, galena, sphalerite, and fluorite have been found in stringers within the mineralized ground but not in sufficient quantity to constitute a serious milling problem. In the upper workings, the veins, which were the only source of ore in the earlier operations, are as much as 3 or 4 feet wide and have a molybdenite content of about 1 percent. The veins occupy a series of curved fractures, somewhat in the form of nested inverted cones, that partly encircle the porphyry stock on the south and west sides and dip steeply toward the center. Some of them curve from a westerly to a northwesterly course and finally enter the porphyry core. In addition to the conelike fractures, there are steeper radial fractures and joints.

In places the veins and other mineralized fractures are spaced closely enough to form rather large blocks of possible low-grade ore. The future of the deposit as a substantial source of molybdenite depends on the size and grade of such blocks around the periphery or within the edges of the intrusive body. Development work in 1944 was not advanced far enough to foretell the outcome, but the mineralized ground exposed in the raise 500 to 600 feet below the old workings looked promising.

ALLENS PARK DISTRICT

Prospecting in the vicinity of Allens Park during the eighties resulted in the discovery of gold and silver ores of low grade.[92] Sporadic but unsuccessful attempts to placer the boulder gravels of North St. Vrain Creek have been made at various times since.[93] According to local information, both northwesterly and northeasterly veins are present in the district, but during a brief visit the writers were unable to find any of the northeasterly veins. As shown on plate 2, the country rock of the region is chiefly Silver Plume granite. A zone of northwestward-trending breccia reefs passes through Allens Park. It is a continuation of the Maxwell breccia reef. The reefs strike about N. 75° W. and dip about 75° S. Grooves along the sides of the silicified breccia and wall rock and the displacement of the diabase Iron dike a mile southeast of Allens Park indicate that the north wall moved downward to the west at an angle of about 45°. The hematitic silicified breccia typical of these reefs was found in a number of shafts and pits near Allens Park, and in a few places small amounts of pyrite and chalcopyrite line vugs in the reefs. Only minor amounts of gold and silver are present in the primary ore, but the value of the vein material has been increased by secondary enrichment close to the surface, where its tenor has been sufficiently high to excite the interest of prospectors from time to time. It seems unlikely, however, that commercial ore deposits will be found in the breccia reefs in this region.

A weathered shear zone striking northeast was shown the writers as an example of the northeasterly silver veins, but the only signs of mineralization seen were a few thin seams of hematite, probably related to the nearby breccia reef. The northeasterly "vein" was reported to contain 2.5 ounces of silver to the ton but no gold.

At the intersection of the Iron dike and the main breccia reef 1½ miles southeast of Allens Park, a shaft was sunk and was reported to have cut low-grade cobalt ore at a depth of 100 feet. No cobalt ore was noted on the dump, however, but the sheared diabase of the Iron dike is cut by innumerable thin seams of hematite. About 1,000 feet southeast of the old "Cobalt mine" shaft the Iron dike is cut by an andesite porphyry dike striking northeast and dipping steeply to the northwest.

LAKE ALBION DISTRICT

The Lake Albion mining district is 5 miles west-southwest of Ward and includes parts of secs. 17, 18, 19, and 20, T. 1 N., R. 73 W. The Snowy Range mine, at

[91] Worcester, P. G., Molybdenum deposits of Colorado: Colorado Geol. Survey Bull. 14, pp. 47–50, 1919. Horton, F. W., Molybdenum, its ores and their concentration: U. S. Bur. Mines Bull. 111, pp. 66–67, 1916. Vanderwilt, J. W., The occurrence and production of molybdenum: Colorado School of Mines Quart., vol. 37, no. 4, p. 34, 1942. Vanderwilt, J. W., editor, Mineral resources of Colorado: State of Colorado Min. Res. Board, pp. 225–226, 1947. Burbank, W. S., oral communication.

[92] Van Diest, P. H., Mineral resources of Boulder County: Colorado School of mines Bienn. Rept., pp. 25–31, 1886.

[93] Lee, H. A., Report of State Bureau of Mines, Colorado, 1901–2.

the southeastern edge of Lake Albion, supplied a moderate quantity of lead-gold ore prior to 1910. The grade of the ore mined was not sufficiently high to stand shipping charges without concentration, and considerable difficulty was experienced in milling the ore because of the presence of asbestos in the gangue. In an old mill, which was modeled after the graphite mills in New York, an air blast was employed to separate the fibrous asbestos from the heavier ore minerals and was moderately successful. It is reported that the cost of mining and treating the ore just about equaled the returns from its sale. In 1909 the air-blast mill was remodeled, and wet methods were introduced, but so much difficulty was experienced in the clogging of the screens by asbestos that the operations were finally abandoned, and the property was not operated from 1910 until 1935, the date of the writers' visit. Lake Albion now furnishes part of the water supply of the city of Boulder. The mine is accessible by a good automobile road, which leaves the main Estes Park-Nederland highway about 3 miles south of Ward. The altitude of the mine workings is approximately 11,450 feet. Because of the deep snow drifts that linger upon the road until late, it is generally impossible to reach the mine by automobile until after the middle of July, and the roads become blocked by snow again within a few months.

As shown on plate 2, the Snowy Range vein, the only productive one in the district, trends eastward through the southern part of a hornblende monzonite porphyry stock, which extends northward for nearly 4 miles and has a width of about 2 miles. Bordering the porphyry stock to the south are schists and gneisses of the Idaho Springs formation cut by a few thick sills of Boulder Creek granite, which are probably related to the small batholith found a mile farther south. Several types of porphyry occur within the stock, but the dominant variety is a sodic hornblende monzonite porphyry the texture of which ranges from coarsely porphyritic to medium granitoid. A few miles to the north the main rock of the stock is cut by quartz monzonite porphyry, and this in turn is cut by biotite hornblende monzonite porphyry.

The geology of the Snowy Range mine has been studied in detail by Wahlstrom,[94] and the following description is based largely on his work. The monzonite is cut by a syenite dike near the mine, but locally the syenite occurs in bodies showing gradational contacts with the normal hornblende monzonite. Both the syenite and monzonite are cut by narrow dikes of dark fine-grained mafic syenite containing nearly 25 percent of hornblende and diopside. Nearly all the ore in the district has been found along a single east-west vein, which cuts schist, monzonite, syenite, and quartz monzonite, but the ore has been found almost solely within the monzonite stock. In the monzonite and syenite the vein fissure is marked by a breccia zone, which attains a maximum width of 30 feet and consists of angular and rounded fragments of syenite and monzonite in a matrix composed predominantly of greenish-gray pyroxene with moderate amounts of quartz, asbestos, pyrite, chalcopyrite, and galena (fig. 86). The pyroxene is coarse-grained, and the quartz is coarse and glassy. In many places the deposit is rudely banded; layers of coarsely intergrown pyroxene along the walls of the vein contain numerous grains of galena, chalcopyrite, and pyrite and border a central seam composed chiefly of quartz. The asbestos, which is later than the pyroxene, is commonly most abundant near the middle part of the vein but occurs in seams and irregular masses throughout. According to chemical analysis[95] the pyroxene is a diopsidic aegirite; it is the earliest of the vein minerals. It was followed in turn by asbestos and by quartz, which locally replaces the pyroxene. Sulfides seem approximately contemporaneous with the quartz and have replaced the pyroxene in many places. Calcite, fluorite, and sodic orthoclase occur as minor constituents of the vein filling.

The ore has been slightly oxidized close to the surface but its occurrence in the bottom of a deeply glaciated valley precludes the existence of any considerable zone of enrichment or oxidation. As the ore found is regarded as primary, there will probably be little change in tenor with increase in depth below the surface. The ore body itself is well marked and continuous. The vein ranges in width from less than an inch to 8 or 10 feet, though locally seams extend into the wall rock making a mineralized zone through a width of 30 feet. In general, the main vein has a width of 3 to 4 feet. The sulfide content varies along the length of the vein as well as across it and seems unrelated to any recognizable structural features, but as noted above the mineralization is limited to the monzonite stock itself. According to E. E. Miller, who is quoted in Wahlstrom's report, 482 tons of lead concentrates were produced during the summer of 1909, which averaged 0.07 ounce of gold and 27 ounces of silver to the ton and 41 percent of lead, with a small amount of zinc. The Snowy Range tunnel, approximately 700 feet long, opens the mineralized breccia zone.

The Eureka tunnel, approximately 100 feet north of the Snowy Range tunnel, follows an 18-inch vein of banded pyroxene and quartz with disseminated sulfides, asbestos, and calcite for a distance of 260 feet. The Eureka vein branches from the north side of the Snowy Range breccia zone and trends northeastward.

The character of the gangue minerals of the Snowy Range vein and their localization in the porphyry body indicate a hypothermal vein. The composite porphyry

[94] Wahlstrom, E. E., The geology of the Lake Albion region, Boulder County, Colorado, University of Colorado thesis, 1931, Boulder, Colo.

[95] Wahlstrom, E. E., An unusual occurrence of asbestos: Am. Mineralogist, vol. 19, no. 4, pp. 178–180, 1934.

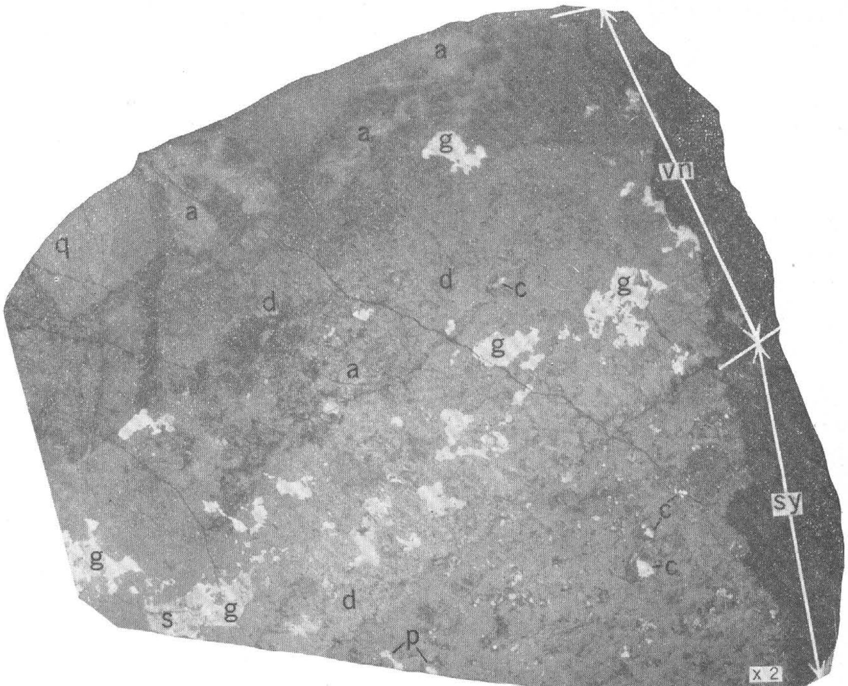

FIGURE 86.—Hypothermal ore from Snowy Range mine, Lake Albion district. The vein (*vn*) comprises diopsidic aegirite (*d*), galena (*g*), asbestos (*a*), and quartz (*q*) with minor amounts of sphalerite (*s*). The wall rock is little-altered syenite porphyry (*sy*) containing disseminated chalcopyrite (*c*) and some pyrite (*p*) near the vein.

stock probably represents the earliest porphyry intrusions in this part of the Front Range, and the ore deposit is believed to be the earliest post-Cambrian vein in the region.

MANHATTAN, MAYESVILLE, AND HOME DISTRICTS

Location and geologic setting.—The Manhattan mining district is 2 miles north of the Cache la Poudre River, in the west-central part of T. 9 N., R. 73 W., and is about 30 miles west-northwest of Fort Collins. The Mayesville district, just south of the Cache la Poudre River is about 3 miles south of the Manhattan district, and the Home mining district is about 3 miles due west. The veins in the Manhattan district were discovered about 1883 and those in the Mayesville district in 1886. The greatest activity in this region occurred between 1883 and 1890, but only a small output has been reported for this period, and little or no ore has been shipped since 1900.

The Home and Mayesville mining districts occur in an area of metamorphic pre-Cambrian rocks just southwest of a batholith of Silver Plume granite. Most of the veins of the Manhattan district lie within the granite area and are closely associated with stocks of granodiorite and hornblende-quartz monzonite porphyry (pl. 1).

A belt of intrusive porphyries, ranging in composition from granodiorite to rhyolite, extends northeastward from Radial Mountain, on the divide between Middle Park and North Park, through Cameron Pass to the Manhattan mining district. According to Gorton,[96] a large granodiorite stock of this belt, located a few miles southwest of Cameron Pass near Lake Agnes, is later than a Laramide overthrust fault and earlier than the extrusive rocks, which Lovering's work near Granby [97] indicates to be of Miocene age. The stocks of the entire belt are everywhere older than the Tertiary erosion surfaces preserved in the mountains; they are therefore believed to have been formed during the Laramide revolution and approximately contemporaneous with the porphyries of the great northeastward-trending mineral belt in the central part of the Front Range. Although the region adjoining this northern belt of intrusives has not been extensively prospected, the meager information available suggests that intrusion in it was accompanied by only feeble metalization in most places. The porphyries seen by the writers in the northern part of the belt resemble those of group 4 (see page 47 and pl. 7 and fig. 12) of the porphyries in the mineral belt, rather than the later ones that appear genetically related to important mineralization in Summit, Clear Creek, Gilpin, and Boulder Counties.

Manhattan.—Manhattan lies at an altitude of about 8,500 feet and is 1½ miles west of the main automobile road extending eastward from Livermore through Log

[96] Gorton, K. A., Geology of the Cameron Pass area, Grand, Jackson, and Larimer Counties, Colo.: University of Michigan doctoral thesis, 1941.

[97] Lovering, T. S., The Granby anticline, Grand County, Colo.: U. S. Geol. Survey Bull. 822–A, 1931.

Cabin to Rustic on the Cache la Poudre River. It is accessible by automobile almost the year round.

The predominant rock near Manhattan is Silver Plume granite, but a belt of northeastward-striking hornblende gneiss and quartz-biotite schist half a mile wide enters the district about a mile south of Manhattan. The schist is bordered on the north by a small stock of hornblende-quartz monzonite porphyry, and a stock of similar porphyry elongate in an east-west direction is found about a mile west of Manhattan. Several prominent porphyry dikes trending from east-west to northwest occur near the stock and are reported to be present in the region to the north. The veins of the district trend west to west-northwest and include the Gold King, Emma, Prodigal, Monte Cristo, and Colorado. The Prodigal and Emma are entirely in granite, but the Colorado and Monte Cristo follow a strong west-northwesterly monzonite porphyry dike, and the Gold King cuts across the contact between the hornblende monzonite porphyry stock and the granite a mile west of Manhattan. It is reported that the Cache tunnel is at an altitude of about 8,000 feet on the north slope of the Cache la Poudre River 1½ miles south-southwest of Manhattan and follows the northward-trending Cache vein toward the Monte Cristo workings, but in 1932 the tunnel was said to be inaccessible and was not visited by the writers.

The veins are mined for their gold. They strike from N. 70° W. to N. 80° E. and are nearly vertical. Most of them crop out on a prominent Tertiary erosion surface correlated with the Overland Mountain erosion surface, and their gold content is much richer close to the surface than at depth. The unoxidized ore consists of coarse-grained white quartz containing disseminated pyrite and a small amount of chalcopyrite. The tenor of the primary pyritic ore is probably indicated by the ore from the Cache vein about 250 feet from the portal of the Cache tunnel and 70 feet below the surface of the gulch, but more than 500 feet below the general level of the Overland Mountain erosion surface. This ore is reported to have contained 0.25 to 0.35 ounce of gold to the ton, although oxidized ore in the veins cropping out on the ancient erosion surface is reported to have contained 1.5 to 15.0 ounces of gold to the ton and commonly to have assayed about 4.0 ounces to the ton at a depth of less than 30 feet from the surface. Oxidized ore is uncommon below a depth of 50 feet, but partly oxidized sulfides occur locally to a depth of about 125 feet. The partly oxidized ore at this depth is said to assay 1.0 ounce to 1.5 ounces of gold to the ton across a vein width of 18 to 24 inches.

It seems evident that the commercial ore in the district is due to the secondary enrichment of low-grade pyritic ores and that the enrichment is closely related to the Tertiary erosion surface.

Mayesville.—The abandoned settlement of Mayesville is just south of the Rugh ranch, in sec. 6, T. 8 N., R. 73 W., in the valley of a small northward-flowing tributary of the Cache la Poudre River. The predominant bedrock is hornblende gneiss, in which small bodies of pegmatite and injection gneiss are common. The gneisses strike from N. 20° W. in the western part of the district to northeast in the eastern part of the district and are nearly everywhere vertical. The general trend of the veins is east-west, but some of the branches from the stronger veins strike N. 60° W. to N. 60° E. The largest vein in the district, according to Mr. Morton, who worked in the area during the eighties, is the Crown Point, near the crest of the hill about three-quarters of a mile southeast of the Rugh ranch. This vein strikes N. 80° E. and dips 45° N. It ranges in width from 18 inches to approximately 5 feet. According to Mr. Morton, the ore at the surface averaged about 0.90 ounce of gold to the ton, but at the bottom of a shaft 160 feet deep on the incline, the tenor was less than 0.35 ounce to the ton.

At Mayesville itself oxidized limonite-stained vein matter was seen on several small dumps, but there was no evidence of extensive work, and no sulfide minerals were found. About 1½ miles southwest of the Rugh ranch, at an altitude of 8,370 feet, the Little Bobby vein is exposed in a shaft and a short adit. It strikes N. 70°–80° E. and dips about 50° N. It comprises 12 inches of crushed gougy rock and 4 feet of iron-stained sheeted pegmatite adjacent to the main shear zone. The country rock of the vein where exposed in the pits and adit is slightly altered pegmatite, but a short distance to the north or south the pegmatite gives way to fresh hornblende gneiss striking N. 20° W. The vein matter is chiefly a limonite-stained drusy breccia seamed with medium-grained white quartz. Some chalcopyrite, pyrite, and galena are disseminated through the vein, but no marked concentration of these minerals was found. According to Mr. Morton, a channel sample across the vein about 6 feet below the surface contained 0.30 ounce of gold to the ton and grab samples from the better-looking vein matter contained approximately 0.90 ounce to the ton. Most of the ore was found close to a branch vein diverging to the southwest at a small angle.

It is probable that the veins in the Mayesville district contain a low-grade primary lead-copper-gold ore of noncommercial grade. Locally, especially at intersections or at the points of divergence of branch veins, the ore may be of commercial grade within the zone of secondary enrichment, which probably does not extend more than 100 feet below the surface.

Home.—The Home district, a few miles west of the Mayesville district, was not studied by the writers. Tunnel dumps on the south bank of the Cache la Poudre indicate the exploration of veins in this neighborhood, and specimens of ore reported to come from the region nearby suggest a pyritic copper mineralization accompanied by more intense wall-rock alteration than in the Manhattan and Mayesville districts.

DEPOSITS OF THE "REDBEDS COPPER" TYPE

Certain types of copper deposits, commonly associated with the Pennsylvanian and Permian redbeds, have been formed by deposition from solutions that have leached the rocks of minute amounts of copper, originally disseminated throughout the formation, and concentrated them into deposits rich enough to attract the prospector. The essentials for the formation of ore deposits of this group are the presence of primary disseminated copper minerals in a permeable bed, their solution by ground water, and deposition in some locality traversed by a large quantity of the copper-bearing solutions. Sulfide deposition may take place close to the outcrop, owing to the reduction of the copper compounds in solution by organic matter, or it may take place at depth through reaction with organic material indigenous to the beds through which the ground water moves.

Carbonates may be precipitated at any depth through reaction with calcareous matter, but oxides and native copper are usually localized near the surface and are due to supergene enrichment. In the Red Gulch district, near Cotopaxi, the organic matter responsible for deposition is found in the lignitic material that has been replaced by the copper minerals. The appearance of copper ore in the breccia of the Williams Range thrust fault above the Palmer ranch is probably due to the reaction between dilute copper solutions and the organic matter contained in the Cretaceous shale of the fault breccia.

RED GULCH COPPER DEPOSITS

The Red Gulch district is in the southwestern part of the Front Range, about 9 miles due north of the Cotopaxi station on the Denver & Rio Grande Western Railroad. The general altitude of the region is about 8,000 feet, approximately 1,600 feet higher than Cotopaxi. At the time the district was visited by Goddard and B. S. Butler of the U. S. Geological Survey, there had been little activity for many years; most of the following description is therefore taken from Lindgren's account.[98]

As far as known, the copper deposits in the redbeds are limited to the Red Gulch area and are not far from the Red Gulch fault, although no direct relation is known to exist between the fault and the ore deposits. Their existence has been known for 70 years or more, but active exploration did not begin until 1907, when several companies began operating in the camp. A few carloads of ore were shipped during that year, principally from the Red Gulch and Copper Prince mines, but the activity was short-lived.

The deposits themselves contain chalcocite, malachite, and azurite and occur at several horizons in Pennsylvanian and Permian rocks, ranging from coarse conglomerate through sandstone to shale. Woody fragments are common in the beds, and seams of lignitic material are present locally. The prevailing color of the formation is a deep brownish red, which is due to the presence of abundant ferric oxide, but the beds that contain the copper are bleached to gray or greenish gray. A few hundred to a thousand feet west of the north-south Red Gulch fault the beds begin to dip more steeply eastward, and at the fault they have at many places assumed a vertical position. Only a few minor transverse east-west faults are present. The only rock intrusive into the redbeds is a thoroughly oxidized east-west dike, a quarter of a mile north of Springfield; it is said to contain a little silver, but it has no apparent connection with the copper deposits.

The copper deposits of this district are in the main similar to those in the redbeds of New Mexico, Arizona, and western Colorado and share with them certain disadvantages of exploitation. As far as known, the bodies of low-grade disseminated copper ores in redbeds have rarely been handled profitably anywhere, but an appreciable output has come from picked ore in the Nacimiento deposits of New Mexico. The rich chalcocite in the coaly shale there made a high-grade shipping ore, but exploration to date has failed to develop large ore bodies.

Mine descriptions.—The Copper Prince mine is a short distance northwest of the abandoned camp of Copperfield, on a slope of heavy red conglomerate made up of well-washed pre-Cambrian rocks. Bunches of oxidized copper ore and chalcocite were found in pits sunk in the conglomerate. Without exception the ore seen was associated with coaly material derived from fossil wood. Chalcocite occurred most abundantly in a coaly shale bed below the conglomerate exposed in a small shaft.

The Colorado Copper Co. sank a shaft on the hill about 1,000 feet east of the creek at Copperfield and 150 feet above it; the depth attained in September 1907, which is probably close to its total depth, was about 250 feet. The rocks between the creek and the shaft dip eastward at moderate angles and consist of red shale with one intercalated bed of conglomerate. Near the shaft they dip at a steeper angle, and the shales grade into reddish-brown limestone. At the fault contact with the granite, about 100 feet east of the shaft, the strata are vertical. Copper stains appear in various

[98] Lindgren, Waldemar, Notes on copper deposits of Chaffee, Fremont, and Jefferson Counties, Colo.: U. S. Geol. Survey Bull. 340, pp. 170–174, 1908.

places, especially in the belt of quartzitic rock that lies near the contact, but no ore bodies were found.

At Springfield, half a mile north of Copperfield, the Red Gulch Gold and Copper Mining Co. was operating just east of the creek in 1907. An inclined shaft 150 feet deep was sunk on a bed of carbonaceous shale dipping 70° E. and containing chalcocite; some rich chalcocite ore was shipped. The Red Gulch fault lies within a few hundred feet of the creek. On the west side shales and conglomerates dip gently east, but near the shaft the dip gradually steepens to 70°. The ore-bearing bed is 4 feet thick and lies on a footwall of heavy red conglomerate. The hanging wall consists of about 50 feet of red shales with some intercalated conglomerate. The shales are capped by about 200 feet of gray partly silicified nearly vertical limestone, which adjoins the great fault that brings the pre-Cambrian granite complex to the surface. The dark-gray soft ore-bearing shale contains seams of a compact bituminous coal as much as an inch or more thick. The chalcocite follows the coal seams very closely, and specimens show a peculiar ore of intimately intergrown chalcocite and coal. Polished sections show minute veinlets of the chalcocite in coal. The coal also contains 0.114 percent of vanadium oxide (V_2O_3). The chalcocite forms smooth nodules 1 or 2 inches in diameter in the shale. Sections of these nodules show that the bedding planes of the shale continue through them, and it is plain that they replace the coaly shale. The pure chalcocite is said to contain at most 10 ounces of silver to the ton. Narrow seams of barite were observed that cut both ore and coal. No ore occurs in the red shale, the conglomerate, or the limestone, and the fault itself is also barren.

Half a mile north of Springfield the Acme and Queen Princess properties were located on a gently dipping cupriferous dark-gray or dark-green shale. At the Queen Princess two ore-bearing beds 12 feet apart were opened. The surface shows very little copper. About 15 inches below the outcrops green stains and narrow seams of sooty chalcocite were found, but the ore was of low grade. The shale of the Red Gulch mine lies probably 200 feet above this horizon, but no copper is reported from it at this place.

BLAIR ATHOL MINE

The Blair Athol mine is in the SW¼ sec. 15, T. 13 S., R. 67 W., about 6½ miles northwest of Colorado Springs. A good road leads from Colorado Springs to a point just north of Glen Erie, and from there an old and little-used wagon road leads to the mine. The property was examined by E. B. Eckel of the United States Geological Survey in 1932, and at that time it had been abandoned for many years. It is known that some ore has been shipped and that the property has been worked sporadically over a long period of time, though it is doubtful whether the operations have ever proved profitable to the investors. The copper content is very low.

The deposit has been developed by an open cut about 75 feet long, 50 feet wide, and 15 feet deep. It is in the upper part of the Lyons sandstone of Permian age, which here strikes N. 20° E. and dips 45°–55° E., although the regional strike is nearly due north. The upper part of the Lyons is a white to buff fine-grained sandstone of uniform texture, made up of well-rounded grains of quartz; it is characteristically veined with quartz along small closely spaced irregular joints, which gives the rock a false appearance of brecciation. The beds underlying the copper deposit and immediately west of the open pit are more strongly silicified than the ore-bearing zone.

The mineral deposit consists of white sandstone irregularly impregnated with small amounts of oxidized copper minerals. The ore occurs in small nodules and as copper stains in the sandstone, and most of it lies along bedding planes or in nearly vertical easterly fractures. The chief ore mineral is malachite; it is associated with minor amounts of azurite and oxides of iron and manganese. Vugs of chalcocite, rarely more than a centimeter in diameter, may form the centers of the malachite nodules. Although the ore minerals in most places occur only in minor amounts and not as solid masses of ore, the widespread presence of thin films of the green, blue, or black copper minerals in the highly colored sandstone may give a false impression of rich copper ore. The zone of copper mineralization extends about 200 feet along the strike of the sandstone and is less than 150 feet wide. Some float showing copper minerals was found in the bed of the stream flowing past the Blair Athol mine, but no signs of mineralization were seen in the lower beds of Lyons sandstone or in the Fountain formation between the Lyons sandstone and the Pikes Peak granite to the west.

A strong fault cuts the Fountain formation near its contact with the granite, but there is no evidence of copper mineralization along the fault, and there are no hydrothermal veins in this region. It is believed that the concentration is local and due to deposition from solutions that had dissolved minute amounts of copper from minerals originally present in the Lyons sandstone of this locality. The Blair Athol deposit is a typical redbeds copper deposit but seems much less promising than those in Red Gulch described above.

PALMER RANCH COPPER PROSPECT

The Palmer ranch is about 20 miles northwest of Dillon, on the east side of the Blue River. High-grade copper ore, consisting of malachite, azurite, and cuprite cementing white quartz breccia, occurs high up on the slope of the Williams River Mountains about 2 miles northeast of the ranch. The breccia is in the fault zone that marks the contact of the Cretaceous shales and the overlying pre-Cambrian gneiss and schist where the Williams Range thrust fault comes to the surface. Very little exploration has been done, but the character of the ore and the coincidence of its occurrence at the outcrop of the thrust fault suggest that it is due to precipitation of cupriferous solutions in the fault breccia. Pre-Cambrian gold-copper veins are known to the north (see p. 71), and it is probable that material from similar deposits was incorporated in the fault zone and was subjected to leaching by waters circulating through the fault breccia. It is believed that the gold placer ground on the Palmer ranch was derived through the erosion of gold-bearing copper ore from similar zones in the Williams Range thrust fault nearby. No output has been made from the deposit.

POST-LARAMIDE DEPOSITS

The extremely productive Cripple Creek district contains the only ore deposits formed after the Laramide revolution that have been commercially important in the Front Range. Only a small output is credited to a few veins, notably the Carbonate King near Guffey, that cut Tertiary rocks outside the district. Because of the disparity in output and development of the Tertiary deposits, generalization concerning this group as a whole would have to be based almost entirely on the Cripple Creek district and might prove misleading in guiding work outside that area. It seems better, therefore, to give a few notes on the deposit near Guffey and follow them with a description of the major district.

MINING DISTRICTS

GUFFEY DISTRICT

CARBONATE KING MINE

By E. B. Eckel

The Carbonate King mine is situated in Park County, sec. 1, T. 15 S., R. 73 W., about 2 miles north of Guffey and 20 miles west of Cripple Creek. It is opened along a small gold vein in Tertiary andesite. The surrounding area has been little studied, and the following information is based on a brief visit in 1932.

The old Carbonate King inclined shaft, now caved, was 300 feet deep, and from its bottom a drift followed the vein northwestward for about 600 feet. One ore body was found close to the shaft and another near the breast of the drift. According to Mr. A. B. Dell, of Guffey, who worked in the mine, the surface ore near the shaft contained about 1 ounce of gold to the ton. No data are available on the tonnage or gold content of the ore bodies in the bottom drift.

The Susannah shaft, owned by the Susannah Mining Co. and worked in 1931, is on the same vein almost directly over the breast of the Carbonate King drift, or 600 feet northwest of the old shaft. It was only 70 feet deep, and according to Mr. Dell the ore found in it contained about 0.165 ounce of gold to the ton. As the shaft is vertical, with its collar located directly on the outcrop of the vein, which dips 75° E., it evidently left the vein entirely a few feet below the surface. An adit has been driven northwestward along the vein for about 200 feet from a point near the collar of the Susannah shaft. The ore developed in this adit was said to contain 1 to 3 ounces of gold to the ton, but little or no stoping had been done, and the mine was not in operation in 1932.

The country rock is moderately fine grained augite-biotite monzonite somewhat similar in appearance to the biotite andesite that appears to the east in the western part of the Pikes Peak quadrangle. It contains abundant subhedral crystals of andesine and augite with a few flakes of brownish biotite in a medium-gray fine-grained holocrystalline groundmass of orthoclase. Magnetite and apatite are abundant. Greenish spots in the rock are probably relics of augite or hornblende that have been partly resorbed. The relation of the andesite to other rocks in the area was not studied by the writer, but during a short visit in 1944 Lovering and Goddard ascertained that it was a small stock cutting lava and pre-Cambrian rocks, and that the Carbonate King vein followed the eastern edge of the stock. (See plate 1.)

The Carbonate King mine is on a 5-foot quartz vein, which trends N. 34° W. and dips 75°–80° NE. The vein is at least 1,500 feet long. Its only valuable metal is gold, which is said by Mr. Dell to occur both native and as sylvanite. Neither mineral was seen by the writer. The vein contains considerable pyrite and a little calcite and is said to contain some copper minerals, but none were observed on the dumps or in the vein. Sericite in small amounts is the only product of wall-rock alteration observed. The material on the dumps shows much limonitic material, but oxidation is believed to have been slight.

The deposit is undoubtedly of Tertiary age and is probably related to the local intrusive center. Though some pockets of rich ore have been discovered and others probably exist, the ore on the whole seems to be irregularly distributed.

CRIPPLE CREEK DISTRICT

LOCATION AND HISTORY

The Cripple Creek district,[99] in the southern part of the Front Range, about 20 miles southwest of Colorado

[99] Lindgren, Waldemar, and Ransome, F. L., Geology and ore deposits of the Cripple Creek district, Colo.: U. S. Geol. Survey Prof. Paper 54, 1906. Loughlin, G. F., and Koschmann, A. H., Geology and ore deposits of the Cripple Creek district, Colo.: Colorado Sci. Soc. Proc., vol. 13, no. 6, pp. 217–235, 1935. Koschmann, A. H., New light on the geology of the Cripple Creek district, Colorado, and its practical significance: Address delivered at the annual meeting of the Colorado Mining Assoc., Denver, Colo., Jan. 25, 1941.

Springs, is one of the most famous gold camps in the world. It is distinctly different from the other districts of the Front Range in having ore deposits associated with an extinct volcano of Miocene age and in having had an exceedingly large output of gold-telluride ores.

The chief towns are Cripple Creek and Victor, both of which are connected by railroad and good automobile roads with Colorado Springs, where the bulk of the ore of the district was treated in the Golden Cycle 1,500-ton mill.

The historic rush of prospectors to Pikes Peak in 1859 resulted in no important discoveries, and it was not until 1874 that prospecting was carried on in the Cripple Creek district. A report that H. T. Wood, while connected with the Hayden survey, had found gold near Mount Pisgah brought a number of men into the district, but no valuable deposits were found. Occasional prospecting was carried on in the district from 1880 to 1890 by Bob Womack, who found some good ore and located the El Paso claim in Poverty Gulch. In 1891, E. M. De la Vergne and F. F. Fisbee bought the El Paso and located the El Dorado claim. The first real "strike," however, was made by W. S. Stratton, who sampled a ledge of granite on the slope of Battle Mountain and found it to assay $380 to the ton. On July 4, 1891, he located the Independence claim, which later became one of the richest mines in the district.[1]

Early in 1892 the hills were swarming with prospectors, and on February 26 the town of Cripple Creek was incorporated. In October ore was being shipped from 17 mines. The district was connected by railroad with Colorado Springs in December 1893 and with Florence in the following year. In 1894 a serious strike of mine workers greatly curtailed output, but development continued; in 1895 the Portland mine had reached a depth of 600 feet and the Independence mine a depth of 470 feet.

The maximum yearly output was attained in 1900, when 878,067 ounces of gold valued at $18,149,645 was shipped. Between 1901 and 1911 output fluctuated and declined to an annual value of $10,563,000, after which it increased for a few years, reaching $13,683,000 in 1915, when the discovery of an extremely rich shoot in the Cresson mine materially increased the annual output. In 1917 the output of the district began to decline because of World War I conditions and the exhaustion of several large shoots. Since 1920 the value of the annual output has averaged less than $4,000,000 a year, and since 1928 it has gradually declined until in 1932 it was only $2,395,000, nearly half of which was recovered from old dumps. The rise in the price of gold from $20.67 to $35 in the fall of 1933 greatly stimulated activity in the district, and the gold output steadily increased from 109,185 ounces in 1933 to 145,215 ounces in 1938. In the next few years the production declined somewhat, and in the fall of 1942 activity in the district was sharply curtailed by the gold-mining limitation order. As a result, the output in 1943 dropped to 45,105 ounces of gold. Henderson[2] says: "From 1891 * * * through 1943 it [the Cripple Creek district] has yielded a total of 18,465,849 fine ounces valued at $399,879,197, or 48 percent of the State total output of gold."

Early in the district's history ground water became a serious problem, and numerous tunnels were driven to drain the workings. The Roosevelt drainage tunnel, started in 1907 and completed in 1908, drained a large part of the district to an average altitude of about 8,100 feet and greatly facilitated deep mining.

The Carlton drainage tunnel,[3] about 31,600 feet long, was begun in the summer of 1939 and completed in the summer of 1941. Its portal is near Oil Creek between Middle and Cripple Creeks, at an altitude of 6,893 feet. The tunnel is driven in a N. 49°54′ E. direction to the granite-breccia contact about 350 feet beyond the Portland shaft, which is connected with the tunnel by a lateral. Other laterals are planned to connect the Cresson and Vindicator shafts with the tunnel, and thus it will drain the most productive part of the south basin at a level about 1,125 feet below the Roosevelt tunnel.

GEOLOGY

Nearly all the mines of the Cripple Creek district lie within a denuded composite crater, formed by volcanic eruptions and subsidence in Miocene time in an area of slight relief. Although the original volcano may have towered to a height far above that of the present knobs, it has since been reduced by erosion to a group of rounded hills, which range in altitude from 10,700 to 9,500 feet. The land surface rises irregularly toward Pikes Peak and other high peaks to the northeast and southeast of the crater; to the south and southwest it slopes evenly in a series of ridges for about 3 miles and then drops steeply from an altitude of about 9,000 feet to less than 7,000 feet. The bedrock surrounding the crater consists mainly of granite, which encloses small to large masses of schist and gneiss and is capped in places by masses of volcanic rock and by Tertiary sandstone, grit, and conglomerate derived mainly from the granite. The volcanic rocks include some andesite and rhyolite, but the bulk of them belong to the alkaline group that constitutes the Cripple Creek volcano and its outliers. The rhyolite and andesite are extensive in the region west of the district but within the productive area are represented only by small masses in the southwestern part. These rocks were formed long before the alkaline rocks of the Cripple Creek volcano

[1] Rickard, T. A., The Cripple Creek gold field: Inst. Min. Metallurgy Trans., vol. 8, pp. 49–55, 1899.

[2] Henderson, C. W., Mote, R. H., and Cushman, R. V., Minerals Yearbook, p. 337, 1943.

[3] Koschmann, A. H., oral communication.

and have no direct relation to the ore deposits. Fragmental volcanic material (breccia) largely fills the ancient volcanic throat but does not extend beyond the walls of the crater, except in a few places on its north side. Many types of alkaline intrusives cut the breccia but make up only a small part of the total volume of the throat.

PRE-CAMBRIAN, PALEOZOIC, AND MESOZOIC ROCKS

Much of the town of Cripple Creek is underlain by schist and gneiss, small masses of which are enclosed in the granite throughout the region. The quartz-biotite-feldspar gneiss conspicuous in and near Cripple Creek was mapped as the Womack gneiss by Lindgren and Ransome. This rock, together with the interlayered quartz-sillimanite schist, is identical in its mineral composition, degree of metamorphism, relative age, and general appearance with the Idaho Springs formation and is correlated with it by the writers.

The principal rock of the region north, south, and east of the volcano is the Pikes Peak granite, which forms a large batholith extending from the foothills about 10 miles south of Cripple Creek northward to Mount Evans and occupies most of the southern part of the Front Range. Near the contacts with schist the Pikes Peak granite commonly shows a prominent gneissic structure and resembles the Boulder Creek granite. Farther from the schist a slightly developed gneissic structure is present in many places. South of Cripple Creek this gneissic structure trends northeast and dips northwest at a moderately steep angle. In most exposures, however, the rock is the typical pink coarse-grained granite poor in ferromagnesian minerals. A fine-grained red aplitic facies of the Pikes Peak granite batholith occurs in the vicinity of Red Mountain, north-northwest of Cripple Creek.

The Pikes Peak granite is cut by the Cripple Creek granite, which is correlated on the basis of lithologic and age relations with the Silver Plume granite of the northern part of the Front Range. The Cripple Creek granite is the dominant rock southwest, west, and northwest of Cripple Creek. It also forms a granite "island" in the north-central part of the volcano and is present farther to the northeast (pl. 29). Dikes of aplite and pegmatite occur in both granites throughout the district. Those in the Pikes Peak granite commonly follow the gneissic structure or a direction at right angles to it.

A large mass of pre-Cambrian olivine syenite occurs west of Red Mountain and is apparently later than the Pikes Peak granite. It is a stocklike mass lying between the Pikes Peak and Cripple Creek granites and comprises several facies. The main part of the mass consists of a sodic syenite made up of coarse-grained microperthite, olivine, and pyroxene; olivine gabbro, pyroxene syenite, and pyroxene granite are also present. In mineral composition it is unlike any other pre-Cambrian intrusive in the Front Range. The unusual association of quartz with abundant microperthite and olivine suggests the possibility of its derivation by syntexis or pyrometasomatism. Its occurrence in a belt of schist and gneiss between two granite batholiths strengthens the plausibility of this explanation.

Numerous dark-gray to black diabase dikes cut all the granite, gneiss, and schist but have nowhere been found cutting Paleozoic or later rocks, and they are earlier than the volcanic rocks. Their pre-Cambrian age is not established, however, and they may be Laramide or even later.

The pre-Cambrian rocks have been deeply eroded to a gently undulating surface. Paleozoic and Mesozoic sedimentary rocks are exposed in the valley of Oil Creek southwest of the district (pl. 1) and originally extended over it; many remnants of them remain south and southwest of the district.

TERTIARY ROCKS

The oldest rocks nearby that were formed after the Laramide revolution are the interbedded flows and tuffs of Oligocene or Miocene (?) age that crop out extensively west of the Cripple Creek district. They are in part older than and in part contemporaneous with the Florissant lake beds, which are late Oligocene or early Miocene. (See p. 41.) The earliest Tertiary rock within the district is rhyolite, which was erupted after the deposition of the Florissant lake beds and spread over an area extending from Florissant as far east as Cripple Creek. Remnants of this rhyolite cap pre-Cambrian granite on Grouse Hill and Little Pisgah Peak in the southwestern part of the district. Rhyolite and rhyolite breccia were erupted from a local vent a mile and a half west of Little Pisgah Peak. An eruption of andesite apparently followed the rhyolite near Little Pisgah Peak, but its source is outside the district. Only two remnants of this andesite breccia are found within the area.

The gravels and sands that consolidated into the High Park beds of conglomerate are later than these eruptions. They accumulated in valleys or local basins in the vicinity of Grouse Hill and Little Pisgah Peak south of the district and at High Park, 5 miles west of Cripple Creek. These beds are red or brownish red and range from well-stratified to poorly stratified grits composed chiefly of waste from granite but containing some pebbles of pre-Cambrian quartzite and Tertiary rhyolite and andesite. In the vicinity of Grouse Hill and Straub Mountain two layers of grits are separated by a layer of rhyolite, and the total thickness is 200 to 300 feet. Pebbles of rhyolite are contained in the upper grit layer. Thus the grits are in part older and in part younger than the rhyolite, but both rocks fill an old shallow granite-floored valley that extended through the present site of Victor into the area now occupied by the Cripple Creek volcano.

After the deposition of the gravels and sands the complex igneous activity of the Cripple Creek volcano began. Several stages of local subsidence, eruption, intrusion, and fissuring occurred, ending with the formation of the ore deposits. The predominant rock both in the tuffs and the intrusives is phonolite, but several related calcialkalic rocks are present. They all contain considerable quantities of soda-rich pyroxene or amphibole and of the feldspathoid minerals, especially sodalite, noselite, hauynite, analcite, and nephelite.

CRIPPLE CREEK VOLCANO

The composite Cripple Creek volcano occupies a roughly elliptical area of northwesterly trend between the towns of Cripple Creek and Victor. It is about 4 miles long and 2 miles wide. In its north-central part an "island" of granite appears and farther west a smaller "island" of schist. These islands are high places along a continuous rib of pre-Cambrian rock that divides the crater. The area north of the islands is a minor crater referred to as the Globe Hill crater. Northwest of the volcano at Mineral Hill, Copper Mountain, and Rhyolite Mountain there are smaller areas that also represent minor craters. Beacon Hill, southwest of the main crater, is also a minor eruptive center. The major and minor craters are filled to depths of as much as 3,400 feet mainly with consolidated fragmental volcanic material (breccia and tuff), the product of a series of explosive eruptions that alternated with periods of local subsidence during the earlier stages of the volcano's activity. The early eruptions were followed by no less than twelve stages of intrusion, represented in approximate order by two varieties of latite-phonolite, two of syenite, two of phonolite, one of trachydolerite, four of lamprophyres and related basic types, and one of basaltic rock. Minor explosions took place at intervals during or between intrusive stages and locally shattered the intrusive rocks, so that their boundaries and structural relations are obscure. The latest of the basaltic intrusions was preceded by a pronounced local explosive eruption that formed within the main crater a small crater of basaltic breccia known as the "Cresson blowout." Most of the ore bodies of the Cresson mine have been found along or within this blowout.

Breccia.—The word "breccia" has locally become a general term to designate the fragmental rock that fills the Cripple Creek crater, but most of the rock is sufficiently fine-grained to be more aptly called a tuff Nearly all of it is altered to some degree. The freshest is a soft, rather crumbly red, purplish, or bluish-gray rock, in part fine-grained and part containing small to large rock fragments. Much of the breccia, especially in the mines, has been bleached by alteration to a light yellowish-gray. The rock fragments are mainly varieties of latite-phonolite. Near the shattered margins of large masses of phonolite there are gradations from slightly dislocated rock into typical breccia. Near the margins of the crater, fragments of granite, gneiss, and schist are prominent, and in places there is a gradation from shattered granite into distinct breccia, suggesting here the brecciation of the free surfaces of the country rock through repeated violent shocks rather than expulsion from the crater and fall. In some places large slablike masses of granite approximately parallel to the contact are found a few hundred feet away from it, suggesting subsidence. The many small fragments of granite, gneiss, and schist and their constituent minerals that are thinly scattered throughout the breccia seem to indicate an explosive origin. The fragmental material is cemented principally by a dolomitic carbonate, which, with small crystals of pyrite, has replaced the original dark-colored mineral fragments and impregnated the other mineral grains. Carbonized wood and fossil leaves have been found in several places in the crater far below the surface. They, together with fossil footprints, raindrop impressions, and ripple marks, suggest pronounced subsidence of the surface on which they were formed,[4] or the presence of a deep steep-walled open crater.

Through the crater much of the breccia has no definite structure or is poorly bedded, but in places it is distinctly well-bedded. The bedding is nearly horizontal in some places, particularly in the northeastern part, but is considerably tilted in others. In the northeastern part, notably in the vicinity of the Pinnacle mine, deposition apparently began on a nearly horizontal floor, with the accumulation of coarse rubble from the adjoining highlands. This rubble was overlain by feldspathic sandstone or arkose derived from the highlands. The contact of these sediments with the surrounding granite, where exposed underground, is steep and undulating and gives the impression that it was downfaulted while still unconsolidated. This sandstone is overlain by volcanic tuff and breccia, some of which was clearly deposited under water on alluvial flats and in playas. The cumulative evidence afforded by these rocks as a whole suggests intermittent subsidence, which began before any eruption of lava or ash and continued throughout the main stage of eruptive activity. The "crater" may therefore be more aptly described as a volcanic basin, or caldera.

Dike rocks.—Three or more varieties of porphyritic rock intermediate in composition between typical latite and phonolite are classed as latite-phonolite and include

[4] Koschmann, A. H., New light on the geology of the Cripple Creek district, Colorado, and its practical significance. Address delivered at the annual meeting of the Colorado Mining Assoc., Denver, Colo., Jan. 25, 1941, pp. 5–6.

rocks described as andesite, trachytic phonolite, and syenite porphyry in the reports prior to 1906. They form large dikes and irregular sheets, mainly in the eastern part of the breccia mass but also in the western part and in the minor crater. The common variety has a dark gray to reddish groundmass with short white phenocrysts of plagioclase and with or without crystals of pyroxene or hornblende.

One large intrusive mass or irregular stock, three small masses, and a large number of dikes are formed of syenite. The dike rock is rather dark gray, medium-grained to fine-grained and consists largely of pearly-lustered phenocrysts of orthoclase and some plagioclase and thickly scattered black prismatic crystals of pyroxene. It is one of the strongest rocks in the crater.

Phonolite is the most abundant of the Tertiary igneous rocks. It forms dikes, flows, sills, and irregular masses not only in the crater but over a much larger surrounding area. It consists of a dense, medium-gray groundmass, with a few small crystals of feldspar visible. Some of the large outlying masses contain red crystals of nephelite as much as 2 millimeters long. The phonolite has a marked platy structure, which causes it to break into thin flat fragments.

The rock that caps Bull Cliff in the central part of the crater is termed trachydolerite and has not been recognized elsewhere. It has a dark-gray to black dense groundmass with small crystals of plagioclase and pyroxene rarely 0.5 millimeter long, elongate grains of black mica 2 to 3 millimeters long, and round white grains of analcite 1 millimeter in diameter. This rock forms a sill-like mass with rude vertical columnar jointing. It is intrusive into latite-phonolite and into phonolite, but it is thought to be older than the basaltic dikes.

Four kinds of basic dikes have been recognized. They differ chiefly from true basalt in their high content of alkalic minerals and are more exactly termed trachydolerite, vogesite, monchiquite, and melilite basalt. The dikes are all very dark gray to black except where bleached to light gray or greenish gray by alteration. Each consists of a dense groundmass with phenocrysts of feldspar, pyroxene, and analcite. The vogesite is characterized by small round white grains of analcite and conspicuous black flakes of mica. The monchiquite is characterized by round white grains or spots of analcite 2 millimeters or less in diameter, black pyroxene, and red olivine. The trachydolerite forms relatively few but commonly thick dikes and is characterized by a granular appearance which is due to its large content of dark phenocrysts, including black augite, gray plagioclase, and serpentinized olivine. Melilite basalt has been found in only one dike, in the Ajax mine. It is a dark green dense rock. The vogesite and monchiquite cut all the other rocks of the crater except the Cresson blowout and its accompanying dikes. The trachydolerite is cut by monchiquite and also by phonolite. The dikes of all four kinds are chiefly limited to the main breccia area, but a few cut the adjacent granite.

Cresson blowout.—The basaltic breccia that constitutes the Cresson blowout or pipe is much darker gray than the breccia of the main crater and is more distinctly fragmental, except where it is thoroughly bleached. It contains fragments of breccia and of all the dike rocks in the surrounding ground, besides many fragments of dark-gray or greenish-gray dense basalt in a dense matrix of basalt and basaltic tuff. The fragments range mostly from less than 1 inch to 3 or 4 inches in diameter, but some, especially those of latite-phonolite, are very much larger. Some masses of latite-phonolite are so large that they may be mistaken for dikes. The matrix, like that of the surrounding breccia, is considerably impregnated by dolomite and pyrite. The basaltic breccia of the pipe is cut by short dikes and some irregular sill-like masses of basalt. These dikes are found both within the blowout and along its margin. The basalt of these dikes is nearly indistinguishable from the monchiquite and vogesite.

Rock alteration.—Alteration of the breccia and the intrusive rocks and their impregnation by pyrite, sericite, and dolomite probably took place to some extent throughout the period of volcanic activity from the time of the earlier explosive eruptions until the early stage of ore formation. Although the emanations that produced this alteration doubtless rose along the deepest trunk channels, they spread more extensively through the shallower parts of the breccia than the later ore-forming solutions; the distribution of bleached breccia, therefore, does not indicate the mineralized zones. Granite has undergone little bleaching, although it is strongly impregnated by pyrite in places, but not necessarily near ore shoots. The border of bleached rock along the productive veins in granite ranges from a mere streak to zones several feet thick. The dikes along mineralized zones have been bleached to some extent, but much of this bleaching has resulted from attack by descending sulfate waters.

Structure.—A broad, shallow, steep-sided bulge formed over the Cripple Creek-Pikes Peak area during the Laramide revolution, extending from a sharp monoclinal fold along Oil Creek northeastward to the upturned beds of Woodland Park. During this period of compression fracture zones of northwesterly and northeasterly trends parallel and oblique to the major northwest axis of the dome were among the most prominent formed. Fracture zones of north-northeasterly trend, parallel to the axes of minor folds, and east-southeasterly zones, perpendicular to them, also formed. This network of fractures later exerted much control over the growth of the Cripple Creek volcano.

Two striking features of the main crater are its irregular outline and the presence in it of the two islands of schist and granite, which separate the main crater from the Globe Hill crater. Structural evidence shows that the main crater separates downward into a group of subcraters or roots, analogous to but older than those in the Cresson blow-out. Loughlin and Koschmann have named these subcraters or local basins the Conundrum, Index, McKinney-Elkton, Queen-Ajax, Portland, Vindicator, and Isabella, after the principal mines in them. The abundance of intrusive rocks in the southeastern part of the district and the great ore output that has come from this part of the volcano suggest that it contains the principal vents of the area. The general slope of the crater walls and the position of the subcraters are shown by contour lines on plate 29. In general the walls of craters slope inward toward the center steeply, except in the eastern part and at the Abe Lincoln mine in the northwestern part, where the slope is vaguely defined but is probably rather gradual, and on the southwestern border and in parts of the Ajax mine, where the walls are steeply overhanging. The subcraters, or roots, are closely associated with major zones of persistent fissuring. Their distribution and the general shape of the composite crater or basin is shown on plate 29.

From the data gathered in underground workings, it appears that the crater has been developed along certain fissure zones in the pre-Cambrian rocks. The dominant zones trend northwest, as in the Queen, Portland, Vindicator, and Isabella mines; north-northeast, as in the Mary McKinney mine; and west-northwest, as along the south boundary west of the Elkton mine and near the Index mine. The zones of east-northeast trend are indicated by the shapes of the large syenite stocks and the Cresson blowout in the east-central part of the crater. All these directions conform to those expected from the direction of compression and uplift in prevolcanic time.

The Cresson blowout or minor crater is in the south-central part of the main crater. It is an irregular elliptical pipelike mass of basaltic breccia, with the longer horizontal axis trending east-northeast; it pitches steeply south-southeast. Its contact with the surrounding phonolitic breccia is sharp, and dikes of latite-phonolite, phonolite, and basalt are abruptly cut off by it. Its upper part is nearly circular, but with increasing depth it becomes elliptical, narrowing downward. On the lowest levels of the Cresson mine the pipe becomes constricted in the central part and divides into two roots. These roots have been developed along a fissure zone of east-northeast trend at its intersection with dike-filled fissures of north-northwest trend. The conspicuous fractures in the blowout, other than those filled by dikes, dip 45° or less in a southerly direction. These "flats," as they are called, cut the late basalt dikes and are associated with steeply dipping fractures, some of which are mineralized, that trend north-northwest and east-northeast essentially parallel to the dominant mineralized fractures outside the blowout. Some of the flats end against the steep fractures; others cut through them. The different sets apparently form one system.

The blowout was formed by a series of explosive eruptions, which rose almost vertically. The surrounding rock was not greatly disturbed by the explosions; in fact large remnants of latite-phonolite within the blowout remain in line with the dikes from which they were detached. It is probable that some contraction and settling of the basaltic breccia in the blowout took place after the explosion and that some upthrusting was produced by the explosions and by rising magma of the dikes; however, evidence for these local disturbances is much less than that for the external disturbances that affected the region as a whole. The fissures and shattered ground that contain ore bodies along and in the blowout were formed after the forces that produced the local dikes had ceased; they are not primarily due to local settling or upthrusting.

The fissures of the district differ from those of most other mining districts in their narrowness and, with few exceptions, in the lack of recognizable displacement along them. As a result, they are rarely evident at the surface, and their course and extent is discovered only in underground developments.

As shown on plate 29, the productive fissures are strongest and most abundantly developed within the volcanic crater. They are not limited to it, and one of the most productive systems, the Portland-Ajax, is at the southern edge, partly in granite and partly in volcanic rocks. Another important group is in the granite surrounding the Beacon Hill phonolite plug. Within the main crater, the productive fissures are most abundant and persistent in the part southeast, south, and southwest of the granite "island," where they occupy a crescentic area. In the center of the most productive tract and roughly bounded by lines connecting the summits of Globe, Ironclad, Bull, Raven, and Gold Hills, is an area within which few important productive fissures are known. This relatively barren ground includes the ground over and to the south of the bedrock rib that separates the Globe Hill from the main crater. To the north the Globe Hill crater has been moderately productive, but it exhibits far less fissuring than the southern part of the main crater.

As shown on plate 29, the pattern of the major fissures is faintly suggestive of fissures radiating from a point somewhere near the center of the northern edge of the volcano. In the western and southwestern parts of the district the prevailing strike is northeasterly, in the southern part it is northerly, and in the southeastern and eastern parts of the productive area a northwesterly strike predominates. In several places both northwesterly and northeasterly fissures are present together, notably east of the granite island and west of the schist island. The presence of many diagonal cross fractures, the small arc through which the trends conform to the plan, and the irregularity of the fissures makes the radial arrangement seem more apparent than real. This pseudo-radial arrangement of lode fissures is duplicated to a certain extent by the dikes, particularly by the basaltic dikes, and it is probable that a succession of similar stresses formed both the dike fissures and the lode fissures.

Most of the fissures are steeply inclined, the average dip being about 75°. Many are almost vertical, and dips of less than 50° are rare, except in "flats" associated with steeply dipping fissures. The average dip of these flats is about 20°, but it ranges from 0° to about 45°. Among the most noteworthy and productive flats are the Howard flat vein in the Mary McKinney mine and the flat vein in Stratton's Independence.

Only a few individual fissures or fissure zones in the Cripple Creek district exceed half a mile in length. The Mary McKinney, Doctor Jackpot, and Buena Vista are approximately of this length, and some of the broader zones of nearly parallel, linked, or imbricated fissures are traceable for more than a mile. Many of the most productive fissures are remarkably short, as, for example, the Captain group in the Portland mine, which contains few fissures more than 300 feet long. In general the persistence of a fissure down the dip seems to be proportional to its length. Many fissures that are exposed at the surface end downward in the upper levels of the mines, and others are found in the workings that do not reach the surface.

The character of the country rock has had considerable influence on the distribution and extent of the fissures. The fissures are most abundant in the breccia and in the Pikes Peak granite adjacent to the crater. Latite-phonolite, on the whole, seems less favorable to fissuring than breccia, but sheeted zones tend to follow dikes of phonolite or "basalt" that are parallel to the direction of fissuring. In some places where a fissure meets the contact of two rocks nearly at right angles to it, the fissure ends abruptly or narrows greatly, but where the fissure makes an acute angle with the contact, as the C. K. and N. vein does with the El Paso phonolite dike, the vein may change its course and follow the dike for some distance and then break through it.

Intersections of one fissure zone with another are general. Intersections at right angles or at 45° or intersections of vertical veins with flats are all common. In most places the fissures intersect without noticeable displacement, but the rock near the intersection is likely to be irregularly fissured and may be the site of an ore body. Where displacement has been noted it was rarely more than 5 feet, and the largest known displacement, along postmineral faults, is little more than 100 feet.

Most of the productive lodes in the district are sheeted zones in which a number of narrow approximately parallel fissures form a zone ranging from a few inches to as much as 100 feet in width. The wider belts usually comprise two or more zones of concentrated fissuring that lie close enough together to be mined as a whole. Some of the Captain veins in the Portland mine are compound sheeted zones of this sort. The majority of these fissures are mere cracks showing no evidence of tangential movement along the walls. Various types of sheeting are found in the fissure zones, as shown in figure 87. The most common types are a single narrow fissure accompanied by irregular fracturing of the adjacent rock; two main parallel fissures, usually 3 or 4 feet apart, accompanied by less regular and less persistent fractures between; numerous parallel fissures with a medial zone of very closely spaced fissures; many approximately parallel but irregular fissures with no medial zone; and a relatively wide fissure with sheeting on one side or both. Most of the lode fissures are no wider than a sheet of paper, but in places some veins are as much as 1 or even 3 feet wide. Veins of this sort, such as the Blue Bird and the Vindicator on its lowest levels, generally consist of solid low-grade fluorite and quartz locally cut by veinlets of late quartz and tellurides. The Howard flat vein shows large vuggy cavities and must have had openings 2 or 3 feet wide.

Origin of the volcano.[5]—During and subsequent to the Laramide revolution old planes of weakness in the pre-Cambrian rocks were accentuated and new ones were created. The area that had been domed during the revolution began to undergo subsidence in places appropriately bounded by the more persistent fissures. This subsidence marked the beginning of volcanic activity. The marginal parts of the subsiding areas or basins became filled with coarse debris from the steep-walled areas surrounding them. The original boundaries of the basins were essentially straight or slightly curved faults, but landslides, perhaps aided by torrential erosion, cut back the upper parts of the bounding walls and converted them into comparatively gentle slopes. The limits of the basins were thus somewhat expanded and converted in places from relatively straight fault lines to crescentic forms. The faults along which subsidence took place became buried some distance within the marginal parts of the basins as finally developed. After this early stage of subsidence, the coarse debris in the basins became covered by material of sandy texture derived from the surrounding highlands. Deposition of the sand was periodically interrupted by brief periods when the surface was covered with shallow ponds or lakes (playas) on the bottoms of which muddy sediment accumulated. The

[5] Interpretation by G. F. Loughlin, based mainly on recent work by A. H. Koschmann, op. cit. (New light on the geology of the Cripple Creek district and its practical significance.)

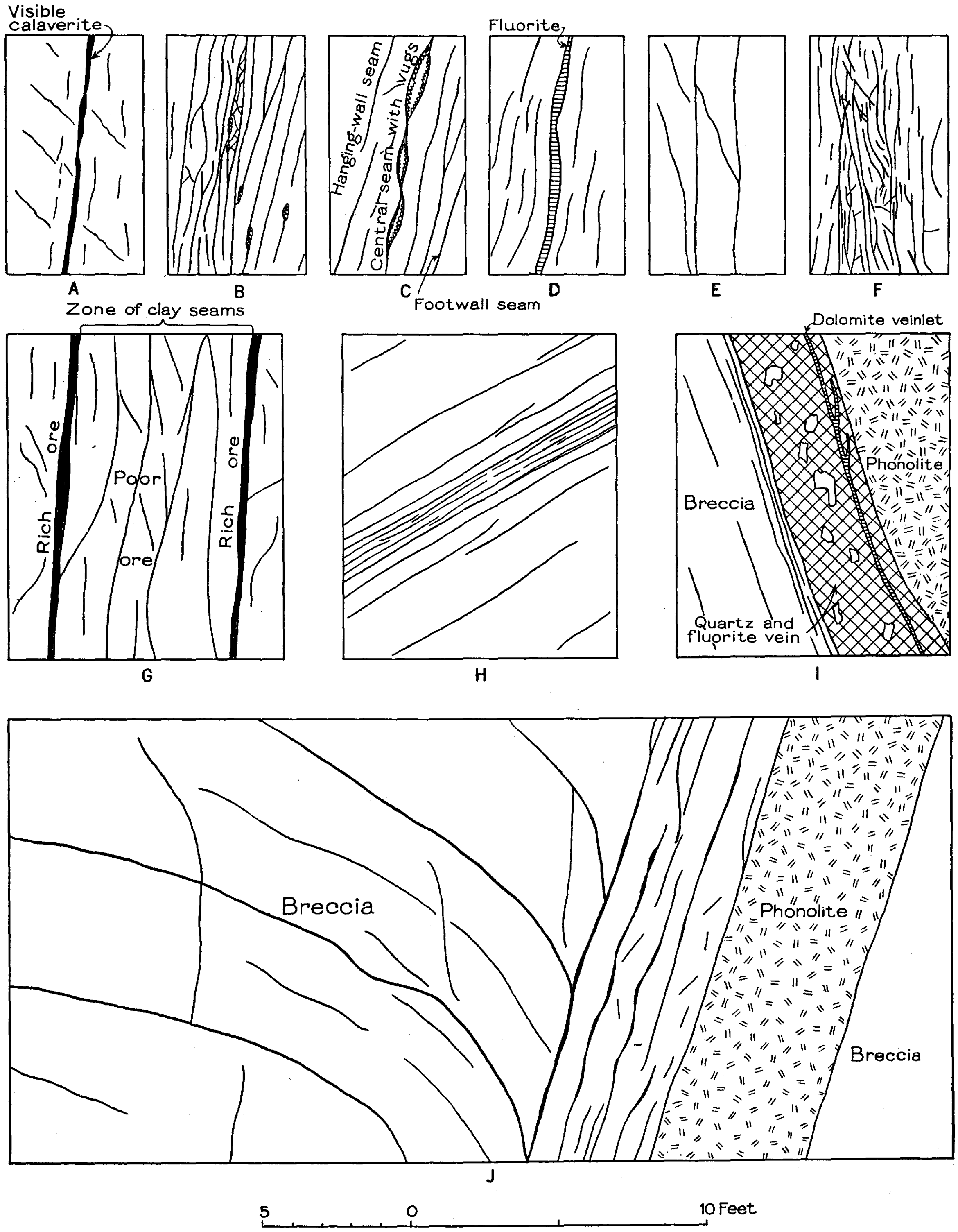

FIGURE 87.—Structural features of lode fissures in the Cripple Creek district. Figures in parentheses refer to figures in Professional Paper 54.

A, La Bella vein, Golden Cycle mine, level 9. Rock is very fresh latite-phonolite; central seam contains visible calaverite; screenings across whole width assay 2 ounces per ton. (After fig. 4.)
B, Main vein in Last Dollar mine, 40 feet above level 12. Typical sheeted and partly brecciated zone in fresh latite-phonolite; seams coated with quartz, dolomite, and calaverite. (After fig. 6–1.)
C, Last Dollar mine, level 10. Cross veins with medial vug holes. (After fig. 6–2.)
D, Last Dollar mine, west drift, main cross vein, level 5. Shows middle filled fluorite vein. (After fig. 6–3.)
E, Last Dollar mine, cross vein No. 3, at east side line, level 5. (After fig. 6–4.)
F, North face of No. 8 Captain vein, Portland mine, level 6. Shows sheeting in breccia. (After fig. 8.)
G, Legal Tender vein, Golden Cycle mine, level 10. Fresh breccia with oxidized seams; main clay seam assays 300 ounces; all seams contain ore. (After fig. 5.)
H, Howard flat vein, Anaconda mine, adit level. Close sheeting in middle part of vein, the fissures becoming gradually farther apart in the foot and hanging walls. (After fig. 7.)
I, Blue Bird vein, level 13. Shows massive vein of quartz and fluorite between phonolite and breccia. (After fig. 10.)
J, Sheeted zone and "flats" of the Apex vein, Ajax mine. (After fig. 9.)

muddy, or now shaly, layers ranged in thickness from mere films to several feet, and in some of them leaves and other organic material were deposited with the mud.

This stage was followed by one of volcanic eruptions, mostly explosive but in part marked by lava flows. These eruptions were centered in places where the floors of the basins were most fissured, principally along their margins and especially at the intersections of fissure zones. As volcanic gases rising along these intersections approached the surface they expanded with explosive force and doubtless produced vents the upper parts of which flared and the lower parts of which were steep-walled. The sediments already in the basins were destroyed at these vents, but elsewhere they were covered with thick accumulations of volcanic debris—breccia and tuff. Between successive eruptions this newly accumulated debris was reworked by streams entering the basins, and the finest material was deposited in shallow ponds or playas. It was locally ripple-marked, and where exposed to air and rain became sun-cracked and pitted with rain prints. It was even walked over by birds, whose footprints have been preserved, and doubtless by other animals.

Subsidence continued intermittently and alternated with volcanic eruptions until the earlier deposits of gravel, sand, and volcanic debris became buried to the greatest depths reached by mining—at least 3,250 feet in the Portland mine. Fossil bird tracks and rain prints have been found about 1,000 feet below the surface in the South Burns mine. At different depths the sedimentary beds, particularly those composed of volcanic material, are interlaid with massive volcanic rocks. Some of these volcanic rocks are sills intruded along the bedding, and others are believed to be lava flows poured over the basin floors and later covered by more tuff or breccia. These sills and flows grade locally into rubble or breccia and even into fine-grained structureless tuff.

The walls of the vents themselves became enlarged, and the material within them was reworked an indefinite number of times. The action itself was complex, and some of its effects are difficult to understand, for example, the reduction of volcanic rock or granite to fine debris without appreciably disturbing the position or alinement of large blocks that escaped comminution. Fine debris was forced between blocks of granite, which today are found essentially in their original positions but widely separated from the nearest granite wall of the crater. As the vents over adjoining centers of eruption expanded they tended to coalesce, and the crater today is therefore a composite of basins of subsidence and local actual vents, some of which are filled with dikes, plugs, or stocks of volcanic rock intruded after the period of explosive eruptions had ceased.

The shape of the composite crater or basin was governed locally by the strike and dip of the principal fissure zones and by the number and distribution of subordinate fissures close by. In the Portland mine, for example, early subsidence promoted slides along the margin of the basin; the breccia-granite contact, which dips steeply northeast on the lower levels, therefore assumes a gentle slope on the upper levels and rises to the surface in a series of benches. Volcanic activity and sedimentation covered these benches with tuff and breccia, and thereafter renewed activity served to churn and rechurn the material above the main fissure zone.

A short distance west of this fissure zone a large block of granite between two downward-diverging fissures was dislodged and settled, either in one mass or in fragments, below the local mine workings, its place being taken by breccia. Farther west, in the Ajax mine, the granite wall has an undulating northerly or northeasterly slope into the crater, except on the lower levels, where it overhangs; on the lowest level a large block of granite, only partly exposed, is embedded in breccia 100 feet from the overhanging contact. In the vicinity of the Elkton mine the westward-trending granite wall also overhangs at an angle of 80° and, according to available exposures, maintains that attitude from the surface to a depth of more than 1,200 feet. Where this wall is cut by the Roosevelt drainage tunnel it is followed by dikes and is weakly mineralized, which proves that the later stages of the volcanic sequence were active along it.

The late stages of settling kept open or reopened the main fissure zones that bounded the subsiding blocks and extended them upward into the breccia where they branched complexly as they neared the surface. In some places, where the boundary fissures resisted reopening, new fissures were created, branching from the boundary fissures at moderate angles and gradually curving to a nearly parallel alinement. The best exposed fissures formed in this way are the East vein-Wisconsin-Last Dollar fissure, which breaks from the main Portland fissure, and a similar one, which breaks from the boundary fissure in the Queen mine and curves northward toward the Moose mine. The late stages of settling also produced flats, which responded to tensional forces in the settling blocks.

After the settling and the tensional forces that promoted it had essentially ended, the ground surrounding the crater tended to close in on it. Whether this movement was strictly local or part of a mild north-south compression, the effect was a slight thrust, mainly against the upper part of the breccia-filled basin and particularly where the westward-trending granite wall was overhanging. This thrusting tended to keep the eastward-trending walls and fissures tight and to open those of more northerly trend. It also promoted the development of local conjugate fissure systems and the further development of flats. The intrusion of dikes, plugs, and stocks followed, the earliest and latest being guided mainly by local conditions, whereas those of phonolite, about midway in the dike sequence, invaded the surrounding region as well.

Origin of fissures.—Fissuring in the breccia and in the surrounding rocks, as is evident from the preceding paragraphs, was complex and due to a succession of forces, including the settling of newly consolidated breccia, upward thrust or later explosive eruption of rising lava, internal expansion due to the forcing of molten rock into certain fissure zones, and finally mild compression and shearing in a northerly direction. Any one or more of these forces may have acted in different parts of the breccia, and some sets of fissures are attributable to two or more of these forces. On the whole, compression modified by shearing and less commonly by torsion was most effective in forming or reopening fissures just prior to ore deposition. The various forces are described in detail and evaluated by Loughlin and Koschmann.[6] The arrangement of productive fissures throughout the district is thought to be the result of two shearing or rotational couples that resulted in a tendency for the eastern and western parts of the district to move northward with respect to the relatively rigid middle zone that contains the granite island and the granite prong south of it.

The master shear zones opened repeatedly and were followed by nearly all the different kinds of dikes and veins. They contain the most continuous ore shoots and are productive to the greatest depth. Most of them are the upward extensions of prevolcanic fissures. Along these zones there are low-grade or barren stretches attributable to steplike interruptions, tight places along the shear fractures, or tight places between intersections with other steeply dipping fissures or flats. Slight postore shearing is indicated in places by crushing or a small offset of a productive vein. The only postmineral faults showing displacement of more than a few feet are the Thompson fault in the Elkton Mountain mine and the Ajax fault in the Granite mine, which has a displacement of 120 feet.

ORE DEPOSITS

The ore deposits include veins or fissure fillings, irregular bodies due to mineralization of shattered ground, and mineralized collapse breccia. Deposits of all three groups have the same general mineral composition and show no consistent change in composition down to the lowest levels exposed.

Veins and irregular bodies.—The veins range from simple fissure fillings less than an inch thick to sheeted zones several feet thick; in a few places closely spaced veins or sheeted zones connected by minor veins have formed large irregular ore bodies 50 to 100 feet or more in any dimension, but the average vein is half an inch to 5 inches wide. Where they coincide with dikes or sheeted structures inherited from the dikes the veins are likely to be conspicuous, although ore may be limited to one or a few fractures along either the sides or the middle of the dikes. Steplike or echelon arrangement of the veins is common, and single ore shoots are prevailingly short, but some of the more productive veins have ore shoots that are relatively persistent both horizontally and vertically. The fact that the vein group as a whole trends at a considerable angle to the strike of single veins is important in prospecting, especially in the shallower workings, where fissure zones are likely to be wider and more complex than in the deeper workings. In none of the veins studied by Koschmann was there a second ore shoot entirely separated from the first by a barren zone along a single fissure.

Most of the shoots are less than 500 feet long, and few veins have been followed much beyond the ore shoot. The downward persistence of the ore shoots is roughly proportional to their horizontal extent. Steeply pitching irregular elongate forms prevail, commonly having a ratio of vertical to horizontal extent of at least 3 to 1. Many ore bodies, including some very productive ones, do not reach the surface. They were found because of their connections with other veins or through crosscuts that explored an echelon or conjugate group of veins. The flat veins, though less numerous than the steep ones, have the same general structural features.

Some large irregular bodies of ore were formed in shattered ground where two or more fissure zones intersect. They vary greatly in their relative dimensions; some are lens-shaped, with their longest dimension either horizontal or vertical, and others are pipelike and nearly vertical, with or without short branches extending along one or more of the fissure zones. They have been found at great depth in the breccia but are more numerous at moderate or shallow depth where fissures are more abundant and complex in both granite and breccia.

Collapse breccia. — The term "collapse breccia" is used for the rubblelike masses of pipelike form where shattered rock has been corroded until its originally angular fragments have become rounded and the mass as a whole has settled or collapsed to a slight or considerable degree. The well-rounded fragments grade upward and outward into shattered ground along steeply dipping fissure zones and along flats. The largest pipe of collapse breccia thus far found in the district is well exposed in the Dante mine and overlaps the east end of the Cresson blowout. A basalt dike and a vein of dense first-stage fluorspar that cross the area have been reduced to rubble but not to so great a degree as the

[6] Loughlin, G. F., and Koschmann, A. H., Geology and ore deposits of the Cripple Creek district, Colo.: Colorado Sci. Soc. Proc., vol. 13, no. 6, pp. 271–288, 1935.

breccia, and their courses are maintained through the pipe.

The rubble fragments are partly coated and cemented with quartz, dark fluorspar, and coarsely crystallized pyrite, identical with the constituents of the dense fluorspar veins and with practically all the minerals of the second stage discussed below, except appreciable quantities of telluride. Many assays of samples from the Dante pipe showed only 0.15 to 0.20 ounce of gold to the ton. The third stage, represented chiefly by yellow chalcedony and cinnabar, is conspicuous in the central part of the Dante pipe. Late movement has caused some brecciation of second-stage and even of third-stage minerals.

Stages of ore deposition.—The ore deposits were derived from the same general source as the dikes and like them were formed in several stages. Three stages of mineralization have been recognized. It is noteworthy that although quartz, fluorspar, and pyrite belong to all stages, their appearance differs in each stage. Other minerals, if present in more than one stage, are conspicuous only in one.

The first stage was characterized mainly by local intense corrosion of country rock and deposition of quartz and adularia and massive aggregates of dark-purple fluorspar and quartz with comparatively coarse grained pyrite. The quartz and adularia occur both as dense masses locally called jasper and as coatings in vugs in corroded or honeycombed granite. The constituents of the quartz-adularia aggregate may have been derived from corrosion of granite and volcanic rocks at great depth, with redeposition at higher levels. The large amount of fluorine, however, represented by the dense fluorspar, and the sulfur, represented by pyrite, were most probably original constituents of the rising solutions.

Some bodies of honeycombed granite, chiefly in the Portland, Ajax, and Elkton mines, were later permeated by telluride solutions and became rich ore, but others were not reached by the tellurides and are almost barren. The veins of dense fluorspar and quartz are as much as 2 feet thick but are barren except where fractured and veined by later minerals. In places they form an apparently unconnected steplike succession of lenticular veins. Some of them are very thin but persist for considerable distances. They have been noted rarely outside the breccia area and the major shear zones in the adjacent granite.

Except that adularia is lacking, the minerals of the second stage include those of the first but differ from them somewhat in appearance. The fluorspar is usually a lighter purple, the quartz is milky to somewhat smoky, and the pyrite is fine-grained and inconspicuous. Other minerals common to this stage are dolomite or ankerite in small rounded crystals, celestite, and the tellurides. The most common telluride is calaverite, but considerable sylvanite and krennerite are also present. The term sylvanite is frequently applied by the miners to silvery calaverite and the term calaverite to yellowish or slightly tarnished crystals, fine-grained aggregates of which may be confused with fine-grained pale-yellow pyrite. Other tellurides, which are found in small quantity are petzite, hessite, and a silver-copper telluride. The silver-copper telluride was found in considerable quantity in the Findlay vein above level 16 of the Vindicator mine. It seems probable that much of the material called gray copper by the miners but which contains as much as 2,000 or 3,000 ounces of silver to the ton may be partly or wholly silver-copper telluride. Grains or wires of free gold accompany the tellurides in places to a depth as great as 2,900 feet.

Roscoelite, the vanadium mica, is found in places as small soft drusy masses and locally adds a green coloring matter along the edges of the veins or in inclusions. A little barite and small quantities of the base-metal sulfides, principally sphalerite, galena, and tetrahedrite, have been found. The second-stage minerals occur mostly in open though narrow cracks and in vugs. In the Cresson mine rocks with a green roscoelite stain, delicate crystals of celestite, and conspicuous amounts of sulfide are supposed to be fair indications of a nearby ore shoot, but elsewhere the same minerals have been found without leading to any ore shoot. For the most part the solutions of the second stage merely filled or lined cavities with minerals that may have been derived by corrosion of the walls of the conduits in or below the crater. The mineral assemblage of this stage suggests a moderate to rather low temperature. Deposition of tellurides, which marked the end of the second stage, indicates the accession of primary magmatic constituents.

The third stage is represented chiefly by smoky to colorless quartz in small to large drusy crystals and by yellow druses of chalcedony. Fine-grained pyrite occurs in thin radiating needles resembling marcasite and in small drusy patches of pyritohedrons. Calcite occurs in small scalenohedrons, and locally cinnabar forms coatings on or near the pyrite. Rarely minute grains of fluorspar are present in barren places and cannot be regarded as a likely indication of ore. Quartz of the third stage has in places replaced celestite, dolomite, and calcite.

The third stage of deposition was comparatively insignificant. It included at least one substage in which solutions were still rising from a volcanic source, but in others the solutions may have been of superficial origin. The presence of cinnabar indicates rising solutions; the quartz, calcite, and fine-grained pyrite may be supergene but are probably also hypogene. The crusts and minute stalactites of chalcedony in vugs have evidently been deposited by meteoric water.

Oxidation.—The chief work of oxidizing water descending from the surface has been to decompose the pyrite and with the ferrous sulfate and sulfuric acid thus taken into solution to dissolve and remove dolomite and calcite and either to dissolve such minerals as analcite, sodalite, nephelite, and even feldspars, or to convert them into clay. Basaltic rocks, which contain the largest percentages of analcite, were the most readily altered to clay, and consequently they crumble quickly when exposed in the workings. Much of the iron from pyrite and small amounts of minerals from altered rocks and replaced carbonates were carried down into the reservoir of ground water and in places along ore zones, where some of the iron sulfates were probably reduced again to pyrite and marcasite. Where water courses were opened by mine workings below the level of oxidation, the water began to deposit calcium carbonate and red or brown iron oxide, either as stalactites, stalagmites, and wall coatings, or as beds of travertine and iron oxide. It also deposited gypsum and more soluble sulfates as coatings or efflorescences on the walls of drifts or stopes.

The effect of oxidation on the ore deposits has been mainly to remove the carbonate and pyrite and to leach the tellurium from the tellurides, leaving free gold either in fine specks and flakes or as pseudomorphs after telluride crystals in a soft mass of iron-stained quartz and clay, with small to considerable amounts of fluorspar and some celestite. Some of the tellurium was redeposited as green oxide, and some of the iron as the green iron-rich clay mineral, nontronite, which was a conspicuous associate of oxidized ore in the upper levels of the Cresson mine. Although most of the gold remained in the leached oxidized ore, a little was evidently dissolved and redeposited elsewhere. Small crystallized float specimens from Big Bull Mountain and a few occurrences of wire gold seem to suggest such a process, but the total amount of redeposited gold has contributed an entirely negligible part to the output of the district.

Localization of ore.—The geologic environment of the Cripple Creek ore deposits plainly indicates fracturing under a light load, and the character of the fissures and their distribution in space accord with this condition. In harmony with this origin the fissures are present in much greater number and in general are wider in the shallow workings, branching is especially common in the upper parts of many veins, gouge is rare in most of the fractures, and most of the individual fissures lack persistence. A few lodes made up of discontinuous fractures extend for considerable distances. The essential mineral deposits as well as the dikes of the district are concentrated along major fracture zones of this sort, which mark the positions of subcraters the roots of which were the sources of the mineralizing solutions. (See pl. 29.) The ores have been followed downward for a maximum vertical distance of about 3,250 feet; they show no change in mineral composition but a marked diminution in the number of veins per unit of area. The general distribution of the deposits and the downward termination of those outside the principal fissure zones indicate that solutions rose along the more open trunk channels and spread outward and upward as they reached open branch fissures in the more complexly fractured ground in the upper part of the crater. Although structural features in general controlled the localization of most of the ore, the most important factor is the relation of openings to structure; in places deposition of the first stage and the earlier minerals of the second stage was sufficient to so clog parts of a fissure that later telluride solutions were diverted elsewhere in spite of an apparently favorable structural set-up. Minor movements at the end of the second stage in places opened cracks that permitted the deposition of tellurides in otherwise unmineralized fractures, though close to those containing the early second-stage minerals.

Another important factor controlling the localization of ore shoots was the thinly fluid if not gaseous character of the gold-telluride solutions and the low pressures opposing their advance. They followed open though narrow fractures but were easily deflected to another course if confronted by a sealed or tight fissure. Ore shoots are especially common along intersections of fissures and in large bodies of shattered ground, as well as in the more permeable parts of simple fissures or sheeted zones. The most important factor determining the occurrence of the large ore shoots was the proximity of a fissure to areas overlying the major sources of mineralization. This control becomes more and more evident with increasing depth. In this district, as in so many others, the bulk of the telluride ores was deposited in open fractures just below their upward termination or under a marked constriction.

In the shallower workings and for the small ore bodies everywhere an immediate structural control can generally be found. By far the majority of the ore shoots are directly related to intersections, but many occur at junctions, and some are related to changes in wall rock. Shifts in the courses of the veins and changes in dip, though effective locally, have not been so influential in the localization of ore shoots as they have been along the deeper-seated veins of the porphyry belt.

Intersections marked by ore shoots are of many types. The occurrence of ore at intersecting steep veins or sheeted zones is well-illustrated on the Bobtail vein of the Portland mine, and by several veins in the Vindicator mine. The ore may be limited to the space between two cross veins, as on the Bobtail, or may extend some distance away from an intersection on either or both veins, as in the Vindicator. Many shoots are related to the intersections of gently dipping fractures or flats with steep veins. The ore shoots in the upper levels of the Damon mine illustrate this type well (fig. 88, *A*). Here the principal ore bodies occurred on flats below intersections with the blind Damon vein. In other places ore occurs in steep veins below their intersections with flat veins, as illustrated in the Jerry Johnson. In this mine little ore was found down to a flat seam cut 40 feet above the 300-foot level, but from there good ore extended down for some distance. Ore is found along many of the mafic dikes of the district where they are cut by cross fractures. Persistent sheeted zones may contain ore at such an intersection, as in the Dead Pine mine (fig. 88, *D*), or the ore may occur along the dike where it is cut by short cross fractures, as in the Ajax mine (fig. 88, *E*). In some places dikes probably acted as baffles to solutions rising along veins and in others served to open preexisting fissures and make them better conduits. Both relations are well-illustrated in the Elkton mine (fig. 88, *B*), where the ore of the Walter vein begins at a phonolite dike north of the Tornado shaft, extends southward to the point where the Raven dike of basalt enters the vein fissure, and continues to the point south of the Elkton shaft, where the dike leaves the vein and the vein becomes barren. Much of the best ore occurs in the part of the vein that follows the Raven dike. Occurrences of ore at splits in the vein are not as common as at intersections, but this difference may be due to the relative scarcity of splits and the abundance of intersections. Ore shoots of this sort were found in some veins of the Vindicator mine and were important in the nearby Revenue and Legal Tender veins.

The influence of wall rock on the localization of ore is striking but very inconsistent; for example, the best ore shoots occur in the breccia, probably because it was subjected to more movement than the other rocks, but where fractures cross from granite into breccia the ore may be limited to the granite area, stopping abruptly at the breccia contact. This condition is illustrated in the Ajax mine (fig. 88, *C*). A similar relation is found between granite and phonolite in the Prince Albert mine (fig. 89). In the Portland mine some of the ore shoots are also apparently related to the granite and end as the vein enters the breccia; in other veins nearby the ore "makes" in the breccia and dies out as the vein enters latite-phonolite. However, some excellent shoots occur in latite-phonolite and at its contacts with breccia, though the most productive shoots at those contacts lie within the breccia. In some places ore shoots are absent from the breccia and present in the more competent rocks. The flat ore shoot on level 7 of the Elkton mine (fig. 88, *B*) was limited to a laccolithlike mass of phonolite about 200 feet in diameter that was much broken by irregular gently dipping fractures. A more usual relation is illustrated by the big Cheyenne ore shoot of the Isabella mine. There the ore body pitched 45° NW. from a point 1,200 feet southeast of the Lee shaft on the No. 3 level to a point just below the tenth level, where it became impoverished at once on entering a large body of dense phonolite. The highest-grade ore in the mine, however, was taken out just above the phonolite mass.

Many ore shoots are found in echelon fractures that trend transverse to the course of the general zone of mineralization. This is especially evident near centers of mineralization and is well shown in the Portland and Vindicator mines.

Deep ore shoots of commercial size and grade are most likely to be found along the trunk fissure zones of the deepest subcraters. These deep ore shoots are more likely to be separated by low-grade or barren stretches along the vein zone than those at shallower levels. The limit of downward exploration is likely to be governed by the ratio of the cost of deep mining to the amount of gold recovered from the deepest shoots already mined and by structural conditions that encourage the search for another shoot of similar value.

CRESSON MINE[7]

The Cresson mine, one of the most productive in the district, is in the upper part of Eclipse Gulch, in the south-central part of the breccia area. It is developed by a two-compartment shaft 2,398.5 feet deep, which has 18 levels numbered 3 to 20; its collar is at an altitude of 10,030 feet. A lateral from level 17 connects with the Roosevelt drainage tunnel. From 1903 to 1933 the value of the mine's output was $35,331,783.95, of which $12,454,472.50 was paid in dividends.

The chief ore bodies of the Cresson mine are in the local elliptical pipe of basaltic breccia called the Cresson blowout (pl. 30). The ordinary breccia of the district is also present and is cut by dikes of latite-phonolite, phonolite, and basalt, but both breccia and dikes have been locally destroyed by the blowout. The blowout as a whole has a steep southerly dip, but below level 18 it separates into two roots. The eastern root appears to contract downward rapidly, but the western one tapers very gradually. The easternmost workings on levels 11, 17, and 18 expose the Dante collapse breccia, which overlaps the east end of the blowout. Another mass of collapse breccia is said to have been opened on level 17 southwest of the blowout.

The largest ore bodies in the mine have been found within and around the rim of the blowout, but smaller ones occur along veins to the south of it. The ore-forming solutions apparently came from beneath the roots of the blowout, rose along the bodies of collapse breccia

[7] Much of the following data is taken from Loughlin, G. F., and Koschmann, A. H., Geology and ore deposits of the Cripple Creek district, Colo.: Colorado Sci. Soc. Proc., vol. 13, no. 6, pp. 311–327, 1935.

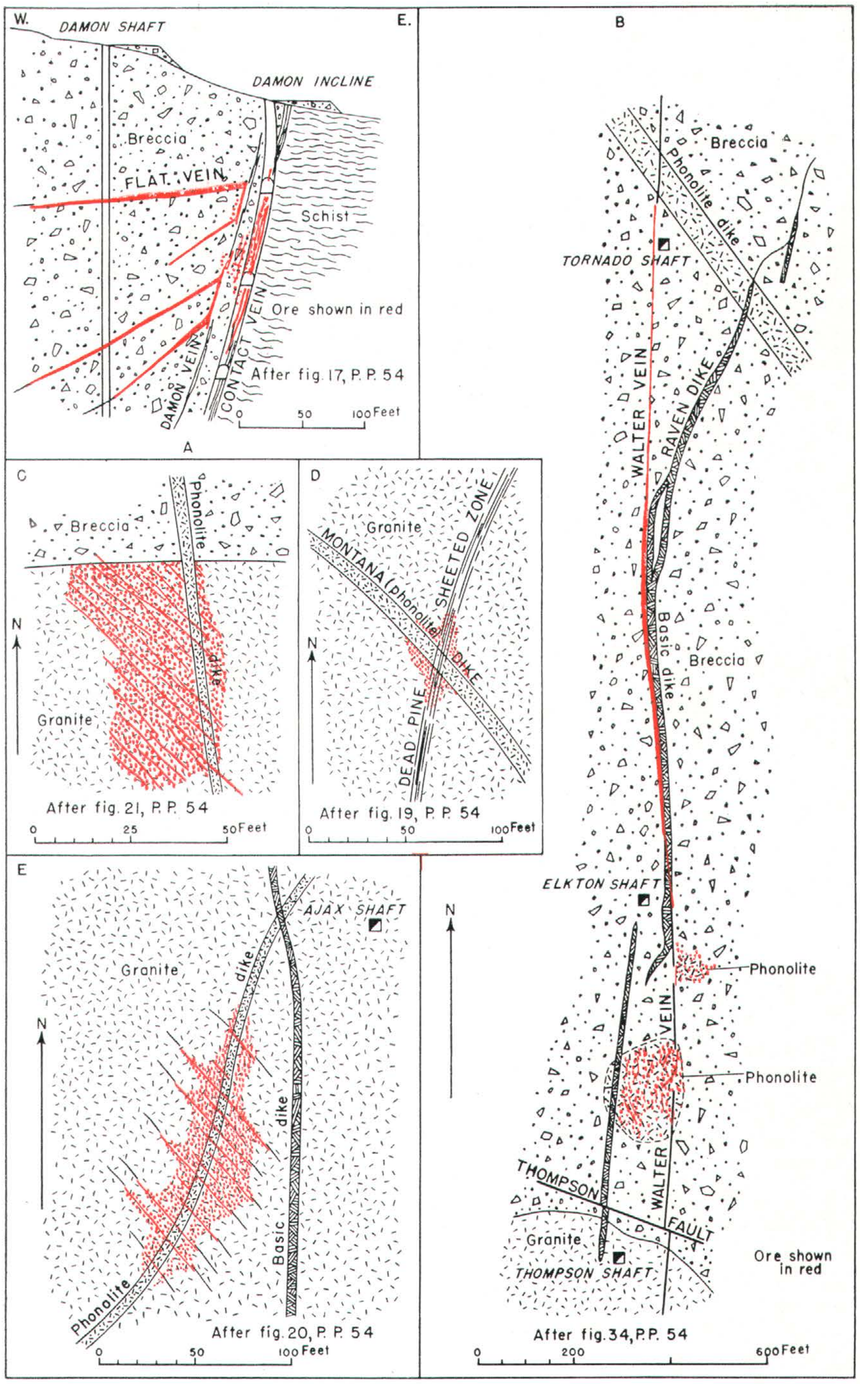

FIGURE 88.—Structural control of ore bodies in the Cripple Creek district.

A, Section of the Damon mine, showing relationship of ore to intersections of flat veins and steeply dipping fissures.

B, Map showing the principal dikes and fissures on level 7 of the Elkton mine. Illustrates the localization of ore along a basic dike and the restriction of ore in a flat fissure to the part between phonolite walls instead of between breccia walls.

C, Plan of an ore body in granite, level 4 of the Ajax mine, showing restriction of ore to fissured zone in granite adjacent to the breccia-filled crater, near a phonolite dike cutting both granite and breccia.

D, Plan showing the occurrence of ore at the intersection of a sheeted zone with a phonolite dike in the Dead Pine mine.

E, Diagrammatic plan showing the localization of an ore body in fissured granite adjacent to a phonolite dike on level 5 of the Ajax mine.

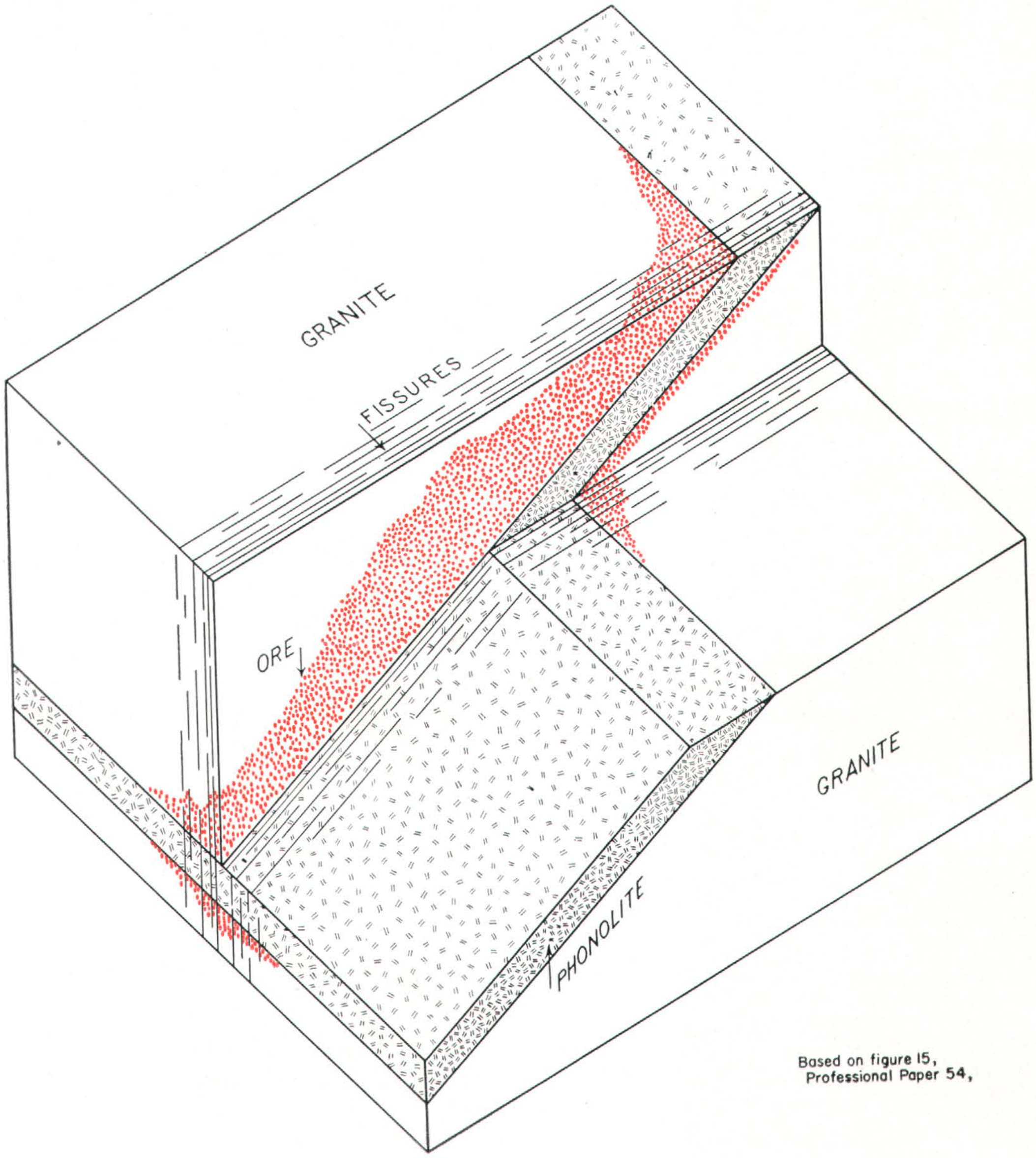

FIGURE 89.—Block diagram of ore shoot in the Prince Albert mine, showing its relation to a phonolite dike.

and intervening dike-filled fissures, and spread upward where openings permitted, within and around the blowout. Localization of the larger ore bodies was controlled mainly by junctions of the rim of the blowout with mineralized fissures in the surrounding rock, especially those along and intersecting certain dikes. Some ore bodies within the blowout were controlled mainly by fissures bordering large included masses of latite-phonolite but were also related to fissures along the rim. According to this structural control the ore bodies of the mine may be placed in five groups: (1) The south side, where the rim cuts off the two nearly parallel dikes known as the Funeral and the Sliver dikes, (2) the main south ore shoots along the rim east of group 1, (3) the eastern part of the rim and the adjacent interior part of the blowout, (4) the northern part of the rim and the adjacent interior part of the blowout, and (5) the western part of the rim, where it encroaches on a dike of latite-phonolite.

In group 1 the ground along or near the junction of the rim with the Funeral and Sliver dikes has been productive on all levels of the mine, though the stopes have been mostly of small to moderate size. The two dikes, also exposed on all the levels, trend south-southeast and are intersected by veins of southwesterly trend. The most productive ore shoots occur at the intersections, especially in the southward and downward tapering wedge of ground between the Funeral and Sliver dikes and between levels 13 and 15. Smaller shoots were mined along both veins and dikes away from the intersections, but they decreased with increasing distance from the blowout. On level 18, the two dikes practically coincide for a considerable distance from the rim, and the productive wedge of ground therefore pinches out. The dikes may diverge again below level 18 to form another wedge, but this lower wedge does not appear to be as favorable ground as the wedge above the level.

In group 2 the main south ore shoot was discovered on level 6 where the rim is close to a local abundance of intersecting fissures of east-northeast and north-northwest trend. Below the shoot the fissures are fewer and tighter and dip farther from the rim. The shoot coincided with group 1 on level 6, and the two were continuous down to level 8. From there the main shoot pitched northeastward down to level 12, where it attained its maximum size and connected with group 3 near the stope called the Vug. Below level 12 it contracted and was bottomed a short distance below level 13, but a long stope on that level extends southwestward toward group 1. No ore related to this shoot has been found along the rim at lower levels, and apparently the shoot was formed by the coalescence of solutions spreading from groups 1 and 3.

Group 3 consists of three connecting zones. Along the easternmost part of the rim down to level 10 the stopes are of small to moderate size; on levels 9 and 10 they extend westward within the blowout. Below level 10 the blowout extends farther to the east and northeast and is overlapped by collapse breccia, but the stopes continue almost vertically downward and are close to the irregular margin of the collapse breccia, though well within the blowout. On levels 11 and 12 large stopes that contained extremely rich ore are closely associated with a large nearly horizontal mass of basalt. From the Vug, a large cavity thickly lined with calaverite, ore with a net mill settlement of $1,200,000 was mined. Below the basalt, on levels 13 and 15, the stopes again become small but lead to another very large shoot from which the principal output from levels 16 and 17 has come. This shoot lies above a large mass of basalt exposed on level 18 and is also above the junction of the two roots of the blowout along a considerable part of the north rim. The localization of the shoot was evidently due to the junction of the shattered ground of the blowout with two converging veins of southerly trend in the outside rock. The main shoot, which furnished the bulk of ore produced on levels 16 and 17, was mined on levels 18, 19, and 20, but was much smaller and of lower grade. Stopes on level 19 averaged 0.50 ounce of gold to the ton, and those on level 20 averaged 0.35 ounce. Ore on the floor of level 20 is reported to be of higher grade than that of the stopes above the level, and, in accordance with the views of Loughlin and Koschmann,[8] "if mining were to continue downward this part of the mine would undoubtedly be a principal prospect."

The ore bodies along the large pillarlike inclusion of latite-phonolite east of the shaft are between levels 7 and 13. The largest lie along the southeast, overhanging side of the pillar, and smaller bodies lie on its west side. As Loughlin and Koschmann [9] state: "This localization of ore justifies further exploration of mineralized fissures along or near the sides of the pillar."

In group 4, along the north rim, ore shoots of small to moderate size were mined, though not continuously, down to level 16, where they proved to be upward branches of the large shoot already mentioned that was mined mainly on levels 16 and 17.

In group 5, along the westernmost part of the rim, no ore has been found above level 6, but this fact may be due in part to incomplete development. On levels 8, 10, 12, and 13 the ore occurred where the rim encroached on a dike of latite-phonolite of north-northwest trend and a branch of more northerly trend. The dike is followed southwestward by a low-grade vein. The opening of the fractures by adjustment along the rim of the blowout was evidently the factor that determined the localization of ore. Ore in a similar position was found on levels 14 to 17. The dike and the rim appear to diverge with depth, and on the whole the outlook is less favorable at greater depth than on the higher levels.

Loughlin and Koschmann [10] state: "To summarize, two favorable places for the continuation of ore shoots below level 20 can be clearly recognized—one at the junction of the Funeral and Sliver dikes with the west root of the blowout and one along the east end of the same root."

PORTLAND MINE

The Portland mine, at the south border of the crater, just north of Victor, was opened in 1893 and was for many years the largest producer in the district. Its total output of shipping ore and mill dirt from April 1, 1894, to December 31, 1931, amounted to 6,230,785 tons having a gross value of $62,255,484. It is developed by three shafts, the Portland Nos. 1, 2, and 3. Shaft 2, about 3,250 feet deep, was the deepest in the district in 1945. It connects with the Carlton drainage tunnel by means of a short crosscut. The drainage tunnel, completed in 1941, reaches the mine at an altitude of about 6,990 feet.

The Portland mine lies at the south rim of the crater, along the eastern border of a granite prong (pl. 29). In the following description of its workings most of the

[8] Loughlin, G. F., and Koschmann, A. H., op. cit., p. 324.
[9] Idem, p. 325.
[10] Idem, p. 326.

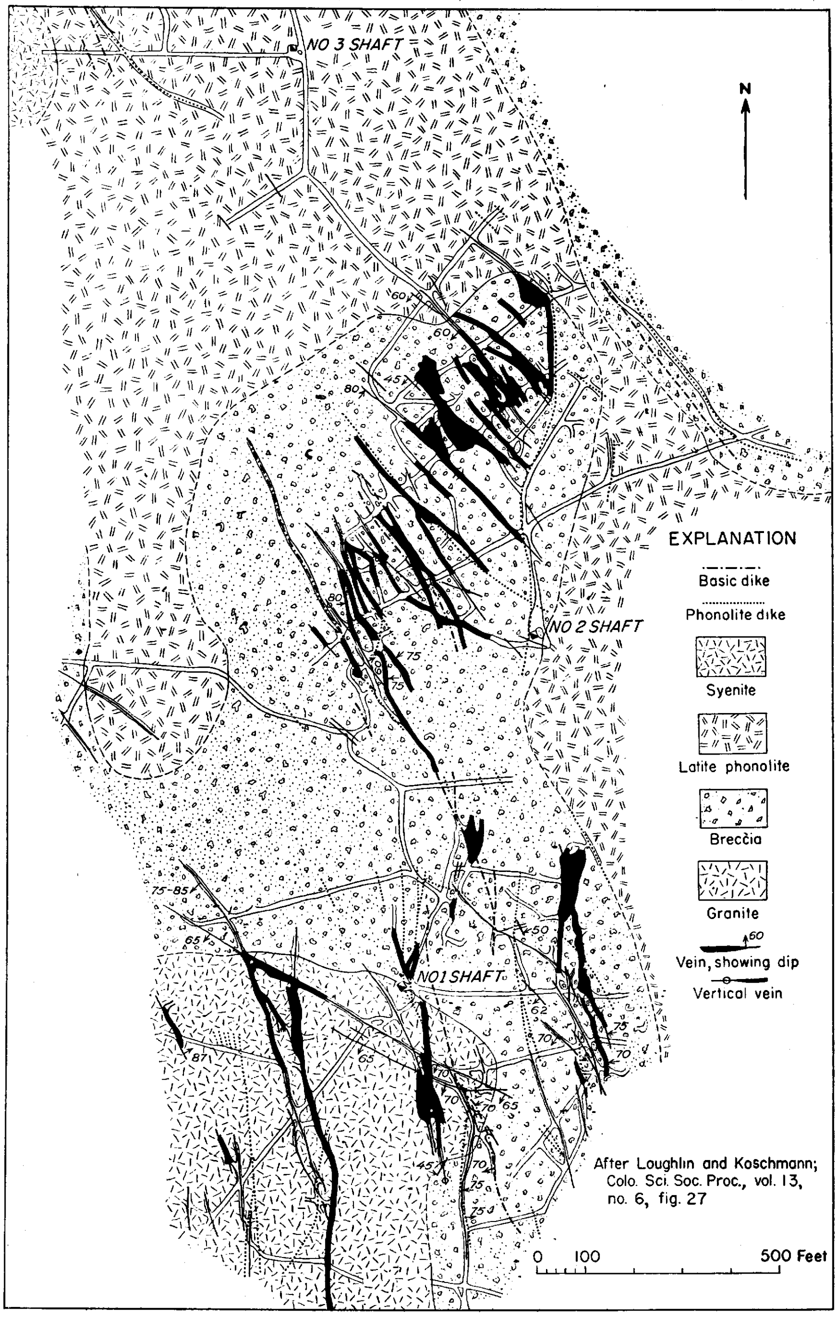

FIGURE 90.—Level 5 of the Portland mine, showing network of veins in the main zone near the breccia-granite contact and the Hidden Treasure and Captain group of veins in a mass of breccia that is surrounded by latite-phonolite.

data are from the report by Loughlin and Koschmann.[11] The upper workings are partly in granite and partly in breccia and large masses of latite-phonolite. The workings below level 15 are mainly in breccia and syenite close to the granite contact, but some exploration has been conducted a considerable distance from it on levels 17 and 21. The contact as a whole dips steeply eastward and northeastward, but its upper part is undulating, with local benches, or terraces of gentle dip. It was formed along master fissure zones of northwesterly and southerly trend (fig. 90). The northwesterly zone dominated in the northern and deeper part; the southerly zone dominated in the southern and upper part of the mine and continued southward in granite, forming the main fissure zone of the Independence mine.

These fissure zones are among the most pronounced in the district and connect with a third master zone that extends north-northeastward from a point near the Portland No. 2 shaft to the Wisconsin claim, where it curves through a north to north-northwest course and passes through the Last Dollar, Lucky Guss, and Orpha May mines. They have been repeatedly reopened and

[11] Loughlin, G. F., and Koschmann, A. H., op. cit., pp. 327–342.

contain dikes of all the intrusive rocks, as well as vein material of all three stages. The zones of north and northwest trend are upward extensions of prevolcanic fissures, and the zone of north-northeast trend must have been opened early in the volcano's history.

The local arrangements of fissures were determined by differences in resistance of the different rocks to shearing. On level 5 the weak breccia between two parts of a latite-phonolite body was severely stretched northeastward and developed a closely spaced set of tension fractures in which the rich Captain and Hidden Treasure ore bodies were formed.

The veins of southeasterly trend in and beyond the southeast corner of the area, well shown on level 5 of the Portland mine, evidently fill tension fissures roughly parallel to those of the Captain ore body but east of the local shear zone. The Bobtail vein, which trends in the same direction (strike N. 62° W. and dip 65°–70° SW.) but is west of the shear zone, is evidently an old fissure reopened by tension and filled with ore, especially near its intersection with local northward-trending veins.

Veins are limited to the main fissure zones close to the granite contact. A large number of shallow veins occur in the granite southwest of the Portland No. 1 shaft and in the breccia east of it. Below level 8, however, the contact is steep, the Bobtail and parallel fissures dip away from the main fissure zones, and the northward-trending zone steepens and tightens. Thus the main zone has not been productive in the granite south of the contact below level 14 of the Independence mine. As the line of the junction of the northward-trending and northwestward-trending zones pitches to the north, the south limit of productive ground also pitches to the north. Northwest of the point where the granite contact turns west, the continuous fissures of the northwest system pass into a steplike series of short fissures, some of which contained small ore shoots.

The main zone of fissures has been continuously productive from level 24 to level 30, but the shoots pinch southward where the zone turns to a southerly course and approaches the east turn in the breccia-granite contact. They pinch northwestward just beyond the junction with the north-northeast or east vein zone, which becomes the most productive zone in the lowest levels; in fact the main zone may be feathering and dying out beyond the westward turn of the granite contact.

On levels 27, 30, and 31 a compression fissure of westerly trend and steep south dip is exposed about 300 feet north of the granite contact. In the wedge-shaped mass of ground between the fissure and the granite contact there are numerous northward-trending tension fissures parallel to the east vein and therefore included in the east vein group. The most open fissures of this group contain dikes of phonolite, trachydolerite (?), and basalt. The whole group was mineralized. Upward, the east vein decreases in dip, and east of its main course it passes into a local conjugate system of fissures of northward and northwestward trend, in which small discontinuous ore shoots have been mined. The east vein is interrupted below level 30, and the rich shoots die out.

If the syenite mass extends downward to the granite contact, as is very possible, there is little likelihood that there is another large shoot on level 31, but if considerable masses of breccia are enclosed between dikelike masses or even in a single mass of syenite they may contain ore-bearing fissures either close to the granite contact or a considerable distance north of it.

The local source of ore-forming solutions was evidently below the large syenite mass. The north-northeast and main or contact fissure zones afforded the principal channels along which they rose and mineralized not only the Portland ground but that of the Last Dollar, Modoc, and other small mines along the upper part of the north-northeast zone and the Independence and, in part at least, the Strong and adjacent mines along the southward continuation of the contact zone.

STRATTON'S INDEPENDENCE MINE

Stratton's Independence mine [12] is immediately south of the Portland mine and just northeast of Victor. It is one of the oldest and probably the most famous of the Cripple Creek mines. Up to 1905 it had produced more than $15,000,000 worth of ore. It 1904 the workings consisted of the Independence shaft, about 1,430 feet deep, and the No. 2 shaft, about 600 feet deep. All the ore with the exception of a little above level 2 and the ore bodies of the old Washington mine are north of the shaft.

The mine lies at the contact of the volcanic breccia with the granite at the south border of the crater and is partly in granite and partly in breccia. The contact forms a curved embayment on the east side of the granite prong that juts into the Portland ground. It dips about 30° NE. toward the crater as far as level 5 and then steepens to about 85°, showing the same benched form as in the Portland mine (pl. 29). Thus the productive northern part of the mine is in breccia above level 5 and in granite below that level. The Independence shaft is sunk in granite close to the contact. In detail the contact is exceedingly irregular, with minor salients and reentrants. Both granite and breccia are cut by dikes, sills, and irregular masses of phonolite. In general, the Independence lode follows a phonolite dike, but the dike is much more irregular than the vein,

[12] Lindgren, Waldemar, and Ransome, F. L., Geology and ore deposits of the Cripple Creek district, Colo.: U. S. Geol. Survey Prof. Paper 54, pp. 449–465, 1906.

especially in the breccia. Several other lodes follow dikes for part of their length, particularly the West Independence lode on level 2. The No. 1, Bobtail, and East Bobtail lodes accompany phonolite dikes for parts of their courses on level 5. The main phonolite and "basalt" dikes of the Strong mine are exposed in several drifts in the extreme western parts of the Independence mine.

The most prominent lodes of the mine are the Independence, Emerson, Bobtail, No. 6, and Flat veins. The Bobtail, Diamond, and No. 2 veins of the Portland, converge from the north, and the Emerson, Bobtail, West Bobtail, Independence, West Independence, and other veins of Stratton's Independence converge from the south and come together in a plexus of fissures near the boundary between the two mines. None of the veins appear to preserve distinct individuality across this complex zone. The rocks of the Independence mine, particularly above level 5, are cut by a complex network of fissures, few of which can be identified from one level to another. The Independence lode has a general trend of N. 15° W., but is far from straight, and dips 70°–90° E. The Emerson lode, which lies mostly northeast of the Independence, strikes N. 58° W. and dips 50°–68° SW. The Bobtail lode lies southwest of the Emerson. It strikes in general northwest and dips 50°–68° SW. On levels 2 and 3, the Independence, Emerson, and Bobtail lodes all meet close to the Portland line. The Grant lode lies east of the Independence. It strikes about N. 23° W. and dips 55°–70° W. It crosses the Bobtail and Emerson and joins the Independence at the north end of the claim. There are also numerous minor lodes of no great persistence, some parallel to the more important sheeted zones and other branch lodes, and they add greatly to the complexity of fissuring. The Flat vein lies between levels 2 and 4 and dips about 18° W. It is crossed without any apparent faulting by the Independence and several minor lodes. A very significant fact is the much greater abundance and more open character of the fissures in the breccia above level 5 than in the granite below.

By far the greater part of the ore from the mine came from the part of the breccia-filled embayment that lies above the benchlike contact above level 5. Some good ore, however, occurred in granite in the Independence lode and in the No. 6 vein. Some ore shoots attained considerable width, and stopes on the Bobtail were in places 50 to 60 feet wide. The main ore shoot of the Independence lode extended on the surface from about 250 feet south of the breccia-granite contact northward practically to the Portland line. Its southern limit pitches about 52° N., and below level 3 the ore rarely extended from the breccia into the granite but ended abruptly at the contact. Below the 950-foot level the ore was narrower; on the 1,150-foot level the Independence vein is a single narrow fissure containing fluorite and pyrite but no ore, and on the 1,400-foot level the lode is so indistinct as to be hardly recognizable. On level 6 the ore occurred in an irregular expansion of the Independence phonolite dike at the breccia-granite contact and extended northward partly in breccia and partly in phonolite. On level 5 the ore shoot attained its greatest width at the crossing of the Emerson lode, and another wide body of ore was found at the crossing of the Bobtail. At the Portland line the convergence of the Independence, Grant, and East lodes localized a large body of ore worked in the Independence stope on the No. 2 vein of the Portland. The ore shoots on the Emerson and Bobtail veins are generally rather narrow, but at junctions or crossings with other veins they expand to unusual widths. One shoot on the Bobtail on level 4, where several fissures of nearly parallel strike join, had a width of 40 to 50 feet for a distance of 200 feet. The Emerson ore shoot attained its maximum length of 600 feet on level 5. The Bobtail ore shoot reached its greatest length, 1,000 feet, just above level 2. Just below this level the ore shoot narrows against these breccia-granite contacts. The Grant, Drury, East, and London lodes are for the most part narrow sheeted zones in breccia and are not known below level 5, but they contained several important pay shoots, which were not as persistent as those of the Independence, Emerson, and Bobtail. The only important lodes in granite besides the Independence load is No. 6, which had fairly continuous bodies of ore from the breccia-granite contact above level 5 to level 6 and isolated bodies between levels 6 and 9. One of the most interesting ore bodies in the mine was that stoped from the Flat vein above and below level 3. It had a length of 400 feet from southeast to northwest and a maximum width of 200 feet. The ore had an average thickness of 6 or 7 feet and dipped about 18° NW. It was crossed by many vertical fissures that contained ore only at their intersection with the Flat vein; excellent ore occurred where the Independence lode and dike crossed it, and extended for some distance above and below the Flat vein.

The average yearly tenor of the ore mined ranged from a maximum of $132 in 1895 to $20 in 1903. Some of the ore from the Flat vein is said to have been unusually rich. Calaverite and perhaps sylvanite associated with fluorite occur in very narrow fractures in the sheeted zones in the breccia. Some very rich ore consisting of small irregular stringers of nearly solid calaverite in dark sheeted breccia has come from the Emerson vein near level 4. Calaverite is intimately associated with pyrite, molybdenite, and a little quartz and fluorite. Galena is rarely visible in the Independence vein but is said to have been abundant in the Bobtail vein above level 2.

GRANITE (AJAX) MINE

The Granite mine,[13] which includes the formerly independent Granite, Gold Coin, Dillon, Monument, Dead Pine, and Ajax mines, is in and just north of the town of Victor and is bounded on the east by the Portland and Strong mines. It is operated mainly through the Ajax and Gold Coin shafts. The Ajax shaft at the surface is within the breccia close to the granite contact at an altitude of 10,108 feet, but it passes through the contact near the 200-foot level. Until 1941 it was 1,952 feet deep, with 20 levels, and a winze extended 250 feet below level 20, but after completion of the Carlton drainage tunnel in that year the shaft was extended to a depth of about 2,700 feet and probably will be connected with the tunnel, which at this point has an altitude of about 6,985 feet.

The workings cross the breccia-granite contact, which trends west and dips north in the upper part of the mine but changes to a northwesterly trend and steeply overhanging dip in the lower part. In the eastern part, the breccia fills a wedgelike embayment with overhanging walls and southerly pitch. The fissure zones belong to three main sets of trends—west-northwest, north-south, and north-northwest—and fall within the master shear zone that was developed by compression from the south and was locally controlled by the breccia-filled embayment and the prevolcanic fissures beneath it.

The west-northwest set of fissures dips southwest and includes the Bobtail and closely parallel fissures that extend into the property from the Portland mine. This set curves to a more northwesterly course near the Granite shaft and continues to a point about 1,400 feet north of the Ajax shaft. The Apex fissure, which parallels the system on the southwest, is the most persistent in the northern part of the mine and has been followed almost continuously for a distance of 1,600 feet. Another fissure zone that appears closely related to the west-northwest set trends nearly east and dips 60°–70° N.; it contains the Hamlin phonolite dike, which marks the approximate north limit of ore shoots on the lowest level. The north-south set is best represented by the Coin vein, which dips east. On the upper levels the Granite and Monument fissures and on the lower levels the Dorothy and Newmarket veins, which dip steeply west, also belong to this set. The only important fissure of the north-northwest set is the Mohican or B vein, which dips steeply west-southwest and crosses obliquely from the Dorothy to the Newmarket vein. A barren premineral fault called the Cashen fault is exposed on some of the upper levels east of the Gold Coin shaft. It strikes N. 20° E. and dips 51° NW. It marks the southern limit of productive ground in that part of the mine.

[13] Loughlin, G. F., and Koschmann, A. H., op. cit., pp. 343–356. Lindgren, Waldemar, and Ransome, F. L., op. cit., pp. 471–475.

The Coin fissure was especially well situated for the formation of openings, and it contained an ore shoot about 850 feet in stope length and about equal vertical extent, which ended at its intersection with the Cashen fault. Below level 9, the Coin vein contained only small isolated ore shoots, and its downward continuation coincided with the northern part of the Montana vein. On the Montana vein the stope lengths ranged from about 300 to 400 feet. From April 1928 to April 1929, 773 tons of ore from the Montana winze had an average gold content of 1.713 ounces to the ton, and ore assaying 1.25 ounces to the ton was said to lie in the bottom of the stope when it became flooded. Just north of the stope the Montana vein on level 17 intersects the Bobtail group of dikes and fissures, which dip south. The intersection pitches 34° SE. and may mark the north limit of productive ground in that locality.

The principal ore shoot mined at shallow levels in the northwestern part of the mine extended along the Apex dike for a distance of 500 feet and was widest at junctions with transverse fissures of northeast trend. The dike is not accompanied by ore below the breccia-granite contact. The largest ore bodies in the upper levels are in honeycombed granite at the intersection of groups of fissures of northwest, northeast, and north trends between levels 3 and 8. Some of the fissures follow phonolite dikes. Below level 7 they grade into pyrite veinlets. On levels 9 and 10 the B and C veins of the northwestward-trending group were productive, but the ground between levels 11 and 13 was practically barren. The B vein, which is essentially continuous with the Mohican vein, was stoped between levels 18 and 14 of the Ajax, a vertical distance of 500 feet. The ore shoot pitched north-northwest, and its north limit was approximately the Hamlin dike.

The Newmarket vein has been by far the most productive in the lowest part of the mine. It has been stoped continuously from level 9 (Gold Coin) to a sublevel 160 feet below level 20, a vertical distance of more than 800 feet. Its maximum stope length, about 1,050 feet, is on level 16, and the aggregate length on level 20 is about 700 feet. Production by lessees between the sublevel and ground 100 feet above level 20 during the period 1927–32 amounted to 15,145 tons of ore with an average gold content of 0.93 ounce to the ton. The Newmarket fissure is very narrow but cuts squarely across the Hamlin dike. It is filled or lined with quartz, minute to microscopic telluride crystals, and little or no flourite.

The most likely source of the solutions that deposited ore in the Newmarket and adjacent veins was beneath the Queen–Ajax subcrater. There were at least two local centers from which the solutions rose—one close to the junction of the Montana and Bobtail fissure zones and near the south end of the breccia embayment and the other along a northerly continuation of the Newmarket fissure, which roughly parallels the northwestward-trending boundary of the embayment.

EL PASO MINE

The El Paso mine, which includes the C. K. and N., Ajax, and Nichols workings, is on the west side of Beacon Hill, about half a mile southwest of the main breccia area. The original El Paso Co. was organized in 1894. The mine produced to the end of 1903 a total of 82,176 ounces of gold having a value of $1,698,576. The output in 1904 was 65,550.26 ounces with a gross value of $1,354,923.87. The total output from 1904 to 1932 was about 489,000 ounces of gold with a gross value of $10,108,000. The main shaft is 1,332 feet deep with nine levels. Much of the following data is taken from the description by Loughlin and Koschmann.[14]

The El Paso and adjacent mines are along the El Paso master shear zone, which is continuous with the prevolcanic fissure of north-northeastward trend along which the southwest corner of the main crater was developed. The workings are in granite on the west side of the Beacon Hill phonolite plug. The granite in this area is rather gneissic and contains several lenticular inclusions of schist, which also trend north-northeastward. Thoroughly sheared zones of granite of similar trend have also been locally called schist. A local explosive eruption opened the way for the intrusion of the Beacon Hill plug, which forms a knob above the surrounding granite. This knob at the surface is about 2,200 feet long in a north-northeasterly direction and 1,200 feet wide, but it tapers downward until in the Roosevelt drainage tunnel it appears as a dike 100 feet wide striking north-northwest and dipping 30° W. The thicker part of the plug exerted sufficient pressure on the adjacent granite to form a conjugate system of "flat" fissures that dip at low angles to the northwest or southeast. Dikes and sills or flats branch from the plug along these as well as the steeply dipping fissures and locally influence the fissuring that preceded ore deposition. The largest of these dikes extends southwestward from the northwestern part of the plug and dips 45°–50° NW., away from the plug.

First-stage fluorspar and quartz were deposited as relatively continuous narrow veins, but minerals of the second stage were more restricted to the intersections with phonolite. Undulations in the courses of the principal veins and intersections with minor veins also controlled the position of the ore shoots in some degree, but the passage of a vein from granite into schist commonly marked the end or at least an interruption of an ore shoot.

The veins trend about N. 35° E., with the exception of the C. K. and N. vein, which trends from northeast to east-northeast. The prevailing dip is steep to the northwest except along two minor veins that follow and closely parallel the southeastward-dipping margin of the phonolite plug on the upper three levels. The most productive veins have been the El Paso, Tillery, and C. K. and N. The El Paso and Tillery veins are roughly parallel for the most part but locally converge and unite and are also connected by minor cross veins. The El Paso vein has been very productive in the upper three levels in the southern part of the mine, where it approached or followed the main phonolite dike, but at lower levels, where it diverges from the dike, it has not been productive. The Tillery vein has been very productive from level 3 down to level 7, also in the southern part of the mine. On level 7 its stoped portion terminates downward just below its intersection with dikes and flats of phonolite.

The C. K. and N. vein has been productive between its intersection with the El Paso and Tillery veins, where its dip is about vertical, and also farther north, where it follows and gradually crosses the main phonolite dike and also crosses two phonolite flats on the footwall side of the dike. Its average dip there is 60°–70° NW. down to level 6, and its ore shoots have been found mainly where its undulating strike locally turns northward in the vicinity of the phonolite. On level 9, where its dip is 82°–90° E., it has been stoped in two places—one near the supposed intersection of the Tillery and one farther to the northeast, where it splits into several small branches.

Where the C. K. and N. vein turns east-northeastward away from the phonolite dike, on level 3 just north of the phonolite plug, a branch vein continues north-northeastward along the dike and is continuous, except for a small steplike interval, with the Ajax vein, which was productive in the vicinity of the Ajax and Nichols shafts down to level 5.

As the veins of the El Paso mine are in a zone that trends toward the Mary McKinney mine, they may have been derived from the same local deep source. Such a derivation would encourage deep prospecting above and below the present Roosevelt tunnel drainage level in this intervening area, but, because of the general restriction of ore shoots to the intersections of veins with dikes, it is equally possible that the ore-forming solutions moved southward until they finally reached the favorable open fissures controlled by the phonolite plug and its branches.

C. O. D., GOLD KING, AND MOLLIE KATHLEEN MINES

The C. O. D. group, which includes the C. O. D., Gold King, and Mollie Kathleen mines, is close to the southwest corner of the northern crater, in Poverty Gulch, just east of Cripple Creek. In 1905 the C. O. D. shaft

[14] Loughlin, G. F., and Koschmann, A. H., op. cit., pp. 387–402. Lindgren, Waldemar, and Ransome, F. L., op. cit., pp. 349–354.

was 800 feet deep with 10 levels, and the output had a value of about $594,000.[15]

The following data are taken from the report by Loughlin and Koschmann.[16] The breccia-schist contact where cut on level 7 of the C. O. D. has a very steep dip, but on level 8 of the Gold King, only 350 feet to the west, the contact has an irregular north-northeast trend, at nearly right angles to the outcrop, and even indicates a small overhanging embayment. If this irregular exposure is a fair indication of the trend of the western wall of the crater, it implies an average easterly slope of 50° or more above level 8. The breccia in the vicinity is cut by dikes and irregular masses of latite-phonolite, syenite, phonolite, and basalt. The presence of all these intrusive rocks suggests that one of the roots of the Globe Hill crater is beneath this southwest corner, and the steepness of the crater wall and its overhanging embayment accord with such an interpretation.

The dikes and the more persistent veins trend north-northeastward in the C. O. D. and Gold King mines but turn more to the northeast in the Mollie Kathleen mine. The most persistent dike, the Gold King (basalt), dips northwest and is followed in the Gold King mine by a vein of minor importance. The main vein of the Gold King is said to follow a phonolite dike 300 feet east of and parallel to the basalt dike. The two veins are practically connected by a barren north-northwest vein. The C. O. D. vein zone is in breccia and is roughly parallel to the productive Gold King veins, although it curves northward and has a steplike interruption to the northwest. Similar interruptions would bring the C. O. D. vein zone nearer to the main Gold King vein with increasing depth.

Neither of the Gold King veins continues northward into the Mollie Kathleen mine, although the basalt dike does. Only the 200-foot and 700-foot levels have been developed in this mine, and the lower level exposes an irregular mass of pyritized syenite west of the shaft. The fissure zones in this mine trend northeast and northwest and are not persistent. The ground was apparently warped somewhat but was protected from the fissuring that characterized the C. O. D. and Gold King mines. The only noteworthy ore shoots in the Mollie Kathleen were two along the basalt dike—one a wide shoot extending from the surface to a depth of 75 feet and the other at the intersection of a northeastward-trending fissure zone with the dike on the 200-foot level.

The main Gold King vein is apparently the strongest and most persistently productive of the group and is the most entitled to further downward exploration. The other veins may have been supplied with material that escaped from the Gold King fissure along minor oblique fractures at moderate depth, but the steplike structure of the C. O. D. veins, as already noted, is encouraging for further exploration to the northwest and southeast, especially on the upper levels.

[15] Lindgren, Waldemar, and Ransome, F. L., op. cit., pp. 272–275.

[16] Loughlin, G. F., and Koschmann, A. H., op. cit., pp. 407–408.

OTHER REPRESENTATIVE MINES

Data on other mines are given briefly below. Detailed descriptions have been given by Lindgren and Ransome [17] and by Loughlin and Koschmann.[18]

ANACONDA

Development.—Adit connects with drifts, and crosscuts connect with two shafts; 3 levels above adit level and 6 below.

Production.—To 1904, $1,500,000.

Veins.—Anaconda: Strike, N.–N. 5° E.; dip, 70° E.; tends to split up to south; trends northeastward at junction with Excelsior vein. Colorado Boss: Strike, north-south; dip, 80° E. Excelsior: Strike, N. 80° E. to S. 80° E.; dip, 60° N.; loses identity at junction with Anaconda. Howard Flat: Contains no ore in the Anaconda mine, but productive in Mary McKinney. Kitty M. or Matoa: Strike, N. 83° E.; dip, vertical. Virginia M. or Lincoln: Strike, N. 65° E.; intersects Anaconda. Work or Black: Strike, N. 80° W.; dip, steeply southeast.

Wall rock.—Breccia with irregular bodies of latite-phonolite and dikes of phonolite and basalt. Schist in north part of adit level.

Ore and sulfide minerals.—Free gold, calaverite, and sylvanite.

Gangue minerals.—Chiefly quartz, some fluorite and kaolinite.

Changes with depth.—Large ore body in oxidized zone.

Ore shoots.—Shoot from surface to between 100 and 200 feet above adit level, stope length 700 to 800 feet. Shoot 80 feet long pitched west.

Tenor.—High grade, 16 ounces gold per ton.

ANCHORIA-LELAND

Development.—Shaft 1,100 feet deep; workings connected with Cripple Creek, Gold Hill, and Good Will tunnels.

Production.—1895–1905, more than $1,000,000.

Veins.—Chance lode: Strike, N. 80° E.; dip, vertical to 80°; explored 1,200 feet along strike; intersects Maloney. City View: Strike, northeast; dip, north. Fault "vein": Barren; strike, northwest; dip, 50°–70° SW.; crosses City View, Chance, and Matoa; intersects Potter and breaks up into complicated fissure system. Matoa: Strike, N. 25° E.; dip, varies; explored 500 feet along strike. Maloney: Strike, N. 30° W.; dip, 80° NE.; intersects Chance and Potter. Potter and Wordell: Strike N. 60° E.; dip, 85° NW.; Potter explored 200 feet along strike; intersects Maloney and Matoa, breaking up into complicated fissure system after intersection with Matoa. Maximum width of ore in veins is 5 feet.

Wall rock.—Breccia cut by phonolite dikes and City View basic dike (2 feet wide).

Ore and sulfide minerals.—Gold and calaverite.

Gangue minerals.—Quartz and some fluorite.

Changes with depth.—Nearly all ore from oxidized zone within 300 feet of surface.

Ore Shoots.—Ore in narrow sheeted zones in breccia. Pay shoot on Chance lode 600 feet long. Ore body on Matoa lode northeast of fault vein. Pay shoot on Maloney lode pitched south at low angle.

[17] Lindgren, Waldemar, and Ransome, F. L., Geology and gold deposits of the Cripple Creek district, Colo.: U. S. Geol. Survey Prof. Paper 54, pp. 271–496, 1906.

[18] Loughlin, G. F., and Koschmann, A. H., Geology and ore deposits of the Cripple Creek district, Colo.: Colorado Sci. Soc. Proc., vol. 13, no. 6, pp. 310–407, 1935.

DOCTOR-JACK POT AND MORNING GLORY

Development.—Morning Glory shaft 700 feet deep. Smaller scattered shafts. Doctor incline extends to 700-foot level of Morning Glory shaft. Two shafts on Jack Pot claim.

Production.—To 1904, $4,500,000.

Veins.—Two groups of lodes, northeast system and north system. Doctor-Jack Pot: Strike, northeast; dip, 50° NW. Galeta: Strike, northeast; dip, 50° NW.; consists of two fissures 3 to 6 feet apart with sheeted zone between. Ingham: Strike, N.–N. 10° E.; dip, steeply northwest. Mattie D: Strike, N. 30° E.; dip, 70° NW. North Star: Mineralized basalt dike; strike, N. 10° E.; dip, vertical. Smith Riley: Strike, N.–N. 10° E.; dip, 70° W. Walter: Strike, N. 15° W.

Wall rock.—Breccia with fragments of phonolite cut by dikes and sills of phonolite; small bunches and veins of bituminous coal.

Ore and sulfide minerals.—Calaverite, sylvanite, tetrahedrite, and some pyrite.

Gangue minerals.—Fluorite, dolomite, and some quartz.

Ore shoots.—Doctor shoot east of North Star dike. Jack Pot shoot extended from surface at Jack Pot shaft to level 12 at Doctor shaft; pitched 30° NE.; maximum length on any level 400 to 500 feet; 5 to 10 feet wide.

Tenor.—Tetrahedrite ore contained 6 to 27 ounces of silver per ton. High-grade ore contained 200 ounces of silver and 20 ounces of gold per ton.

ELKTON

Development.—Elkton, Thompson, Tornado, and Raven shafts. Elkton, 1,700 feet deep; others 500 to 850 feet deep.

Production.—1893–1916, $13,931,580.

Veins.—Henley: Strike, north. Raven: Strike, N. 20° E.; dip, steeply west. Walter: Strike, due north; dip, steeply east to vertical. Granite prong juts northeast into breccia; shattered near contact. Steep dikes trend north to northwest in northern part. Postmineral Thompson fault, strikes N. 72° W., dips 83° S. and follows granite-breccia contact. Cross fissure in south part trends east and dips 50° N.

Wall rock.—Breccia, granite, and phonolite.

Ore and sulfide minerals.—Calaverite, sylvanite, pyrite, and some molybdenite.

Gangue minerals.—Chiefly quartz, some fluorite, adularia, and celestite.

Ore shoots.—Phonolite flats mined as ore on levels 6 and 7. Ore in vicinity of cross fissure between levels 6 and 17. Ore extended 1,200 feet north along Walter vein between levels 6 and 17.

HULL CITY

Development.—Vertical shaft 1,265 feet deep, 11 levels. King or Vaughn shaft 860 feet deep, smaller shafts to depths of 400 feet.

Veins.—A, B, C: Strike N. 40° W.; dip, vertical. D: Strike, northwest.

Wall rock.—Breccia with latite-phonolite dike.

Ore and sulfide minerals.—Chiefly calaverite and tetrahedrite, some galena, sphalerite, pyrite, and molybdenite.

Gangue minerals.—Chiefly quartz, fluorite, some carbonates.

Changes with depth.—Partial oxidation to depth of 850 feet.

Ore shoots.—Stopes from surface to level 4, maximum length of 600 feet. Good ore on lower levels east of dike.

Tenor.—0.4 ounce of gold and 8.5 ounces of silver per ton and 0.27 percent of copper.

ISABELLA

Development.—Lee shaft 1,128 feet deep; 14 levels. Buena Vista incline to level 7. Several miles of drifts and crosscuts. Buena Vista and Cheyenne veins opened for 3,400 feet.

Production.—Total to 1905, about $4,000,000.

Veins.—Buena Vista: All values are in narrow sheeted zones with central fissure. Campbell and Cheyenne: Strike, N. 40° E. Empire No. 2: Strike, northeast. Klondike: Strike, N. 10° E.; dip, vertical; displaces Buena Vista 20 to 50 feet west on south side. Pharmacist and Victor: three branches.

Wall rock.—Breccia, latite-phonolite, phonolite, and trachydolerite.

Ore and sulfide minerals.—Rusty gold, calaverite, and tetrahedrite.

Gangue minerals.—Kaolin, quartz, and some fluorite.

Changes with depth.—Oxidation to 1,100 feet below collar of shaft.

Ore shoots.—Three shoots on Buena Vista vein (2 vertical); small bunches of ore where Klondike and Campbell cross Buena Vista. Big Cheyenne shoot from level 3 to level 10 pitched 45° NW. Six ore shoots on Victor vein extend 250 to 350 feet below surface.

Tenor.—27½ tons of ore yielded $219,000.

LAST DOLLAR

Development.—Main shaft 1,268 feet deep; 12 levels aggregating 10,000 feet; 3 inclines; deepest reaches level 6.

Production—1896–1906, $2,090,396.

Veins.—Last Dollar: Strike, N. 10°–25° W.; dip, vertical to steeply northwest. Also Modoc vein. Short cross veins trending N. 50°–60° E. and dipping steeply northwest intersect Last Dollar. All veins are sheeted zones having a central fissure.

Wall rock.—Syenite grading into latite-phonolite.

Ore and sulfide minerals.—Calaverite, tetrahedrite, pyrite, sphalerite, some molybdenite and galena.

Gangue minerals.—Chiefly quartz, some dolomitic minerals and fluorite.

Changes with depth.—Ores oxidized to level 8. Calaverite chief ore mineral below this.

Ore shoots.—Most important shoots at intersection of cross veins with Last Dollar; pitch 75° N. Most of production between levels 4 and 8; maximum length of shoots 250 feet. Modoc shoot stoped from surface to level 6.

MARY McKINNEY

Development.—Original discovery, 1893. Main shaft 1,382 feet deep, 13 levels.

Production.—1901–32, $5,777,096.25.

Veins.—Le Clair: Strike, N. 6° E.; dip, vertical. Mary McKinney: Strike, N. 9°–25° E.; dip, 65°–75° W.; splits downward, becomes poorly defined, intersects Le Clair at acute angle. El Paso shear zone extends half a mile southwest in granite. Breccia-granite contact nearly vertical. Minor cross lodes trend due west to northwest; also flat veins in north part of mine.

Wall rock.—Breccia and phonolite.

Ore and sulfide minerals.—Calaverite and some tetrahedrite.

Gangue minerals.—Chiefly quartz and dolomite, some fluorite and roscoelite.

Changes with depth.—Good ore on level 10; ore gives out downward.

Ore shoots.—On Mary McKinney vein, shoot stoped from surface to level 5 for length of 2,000 feet. Small shoot on Le Clair vein extends 500 feet from junction with Mary McKinney.

Tenor.—Average 1.277 ounces of gold per ton.

ORPHA MAY GROUP

(Orpha May, Mineral Rock, Shurtloff No. 1, Logan, Los Angeles, Lucky Guss, Sacramento, Specimen, Zenobia, and Favorite)

Development.—Total workings comprise 60,000 feet. John A. Logan shaft 1,400 feet deep, Orpha May 1,264 feet deep, and American Eagle 1,500 feet deep; connected by crosscuts and drifts.

Production.—Orpha May to 1900, $1,000,000.

Veins.—Nearly all veins trend north-northwest to north and dip vertically to steeply west. Basalt: Strike, N. 32° W.; dip, vertical. Logan: Strike, north-northwest. Mineral Rock: Strike, N.–N. 22° W. Orpha May: Strike, N.–N. 15° W.; dip, vertical, intersects Basalt vein. Shurtloff No. 1: Strike, N. 36° W. Zenobia: Strike, northeast.

Wall rock.—Volcanic breccia with much latite-phonolite, many dikes.

Ore and sulfide minerals.—Calaverite, tetrahedrite, pyrite, and some sphalerite.

Gangue minerals.—Chiefly quartz, some fluorite and carbonate.

Changes with depth.—Good ore on Basalt vein gives out below level 11. Good ore on the Logan gives out 200 feet below surface. Little ore below 600 feet on Orpha May.

Ore Shoots.—Ore shoots on Orpha May at intersection with cross fissures.

PINTO

Development.—575-foot shaft; 5,500 feet of drifting and crosscutting.

Production.—To 1904, $1,500,000.

Veins.—Harrington: Mineralized basalt dike; strike, N. 10° W.; dip, steeply east. Pharmacist: Strike, N. 60° E.; dip, 62° NE.; few inches to 3 feet wide; cuts Pinto dike and Harrington vein. Wilson: Strike, N. 36° E.; dip, steeply northwest.

Wall rock.—Chiefly latite-phonolite with some breccia on lower levels. Cut by 3 basaltic dikes—Isabella, Pinto, Harrington. Isabella dike trends east to northeast and dips vertically; 10 to 20 feet wide. Pinto dike strikes N. 25° W. and dips vertically; 4 to 7 feet wide. The two intersect without displacement.

Ore and sulfide minerals.—Rusty gold and gold tellurides.

Gangue minerals.—Quartz.

Ore shoots.—Intersection of veins with dikes improved the ore. Pharmacist vein stoped from 250-foot level to 550-foot level. Irregular shoot at intersection of Harrington and Pharmacist veins; 5 to 20 feet in thickness; stoped from 100-foot level to 350-foot level. Rich ore at intersection of Pharmacist vein and Pinto dike; 6 to 15 feet in thickness; extended from surface to 550 foot level.

Tenor.—Ore from intersection of Harrington and Pharmacist veins averaged 4 ounces of gold per ton. Ore at intersection of Pharmacist vein and Pinto dike averaged 7 to 8 ounces of gold per ton.

VICTOR

Development.—Vertical shaft 1,000 feet deep with 14 levels; total workings 2 to 3 miles.

Production.—To 1900, $2,216,671.

Veins.—Main vein: Strike, northwest; dip, 70° SW. Branch of Main vein: Strike, northwest; dip, gently southwest. East vein: Strike, N. 52° W.; dip, 68° SW. Main vein branches into East and West veins northwest of shaft. Northwest branch diverges close to shaft. Veins form narrow sheeted zone with central fissure.

Wall rock.—Volcanic breccia with flat mass of phonolite on lower levels.

Ore and sulfide minerals.—Gold tellurides.

Gangue minerals.—Quartz, fluorite, kaolin, and manganese oxides.

Ore shoots.—Shoot where East and West branches diverge. Rich shoot on East vein 20 feet wide in places; extended 280 feet below surface.

VINDICATOR-GOLDEN CYCLE

Development.—Main shaft 2,193 feet deep.

Production.—1894–1914, $38,274,933 from 2,040,722 tons of ore.

Veins.—Vein systems near east margin of large syenite mass. Latite-phonolite and breccia contact slopes north at a low angle. In shearing, east part moved north. Fracturing developed most readily along northwestward-trending boundaries of syenite mass.

Wall rock.—Syenite, latite-phonolite, and breccia.

Ore and sulfide minerals.—Calaverite and native gold, some galena, sphalerite, and pyrite.

Gangue minerals.—Quartz and some dolomite, fluorite, and celestite.

Changes with depth.—Mine most productive on level 11.

Ore shoots.—Ore commonly associated with syenite contacts.

WILD HORSE

Development.—Original discovery, 1887. Wild Horse and Gleason shafts, 10 levels aggregating 2,400 feet.

Production.—To 1903, more than $1,000,000.

Vein.—Wild Horse: Strike, north-northwest to north-northeast; dip, 60° W. to vertical, vein curves.

Wall rock.—Breccia with granite detritus.

Ore and sulfide minerals.—Gold tellurides and pyrite.

Gangue minerals.—Kaolin, limonite, quartz, and fluorite.

Changes with depth.—Richest ore near bottom above level 9.

Ore shoots.—Shoot at surface south of shaft pitched 45° N.; pitch length, 1,200 feet; stope length, 200 to 600 feet. Richest stope 40 feet long and 27 feet wide; yielded $200,000.

Tenor.—Best ore yielded $300 per ton at old price of $20.67 per ounce of gold.

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