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GEOLOGY AND ORE DEPOSITS

OF THE

LEADVILLE MINING DISTRICT, COLORADO

BY

S. F. EMMONS, J. D. IRVING, AND G. F. LOUGHLIN

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SUMMARY

Adequate treatment of so large and so extensively developed a district as that of Leadville necessitates a voluminous report, in which the practical questions of prime interest to the commercial world can not be systematically answered until the data on which they depend are discussed. Many readers will no doubt wish to turn at once to the chapter on ore reserves, which will give them an appraisal of the district, without bothering with geologic detail. For those who wish a brief general account, a summary of the principal chapters of the report is presented below.

Chapter 2. Quaternary geology.—The glacial deposits are of economic interest because they form so thick a covering over much of the district that the bedrock surface could be mapped only by the upward projection of boundaries, faults, and other features exposed in mine workings. In upper Evans Gulch glacial erosion has removed much oxidized and placer material, and sulphide ores are found comparatively near the surface; but in the western part of the district a great thickness of glacial deposits has buried thoroughly oxidized ore bodies to surprising depths. These deposits have also buried old channels, some of which have been found in mining operations, particularly in the Rock Hill area. Displacement of the older of the glacial deposits by renewed movement along faults has also affected mining operations in the Downtown area.

There is distinct evidence of two glacial stages separated by a long interglacial stage. The "lake beds" found in mine workings in the Downtown and Graham Park areas may belong to a still earlier glacial stage, the evidence of which is very obscure. They lie upon a thoroughly oxidized preglacial surface and are covered by high terrace gravel or outwash deposits that belong to the earlier of the well-recognized stages. These deposits are cut by gulches into a series of mesalike areas, on one of which the city of Leadville is situated. Moraines of this early stage in the vicinity of Leadville are nearly all eroded or are covered by moraines of the late stage, which are well developed in Evans, Iowa, and other gulches. During the long interglacial stage the high terrace gravel and older moraines were much oxidized, but the underlying ore bodies, already oxidized, were protected from further oxidation by a rise of the ground-water table.

California Gulch, which was famous for placer mining in the very early days, is not glaciated. It was cut during and since the last glacial stage along the boundary between high terrace gravel and the southern bedrock slopes of Iron and Carbonate hills.

The postglacial deposits include, besides the alluvium of California Gulch, a few landslides, the most conspicuous of which are rock streams, and broken rock that has been derived from the immediately underlying bedrock or has crept down the slopes.

Chapter 3. Pre-Cambrian and sedimentary rock.—The oldest rocks in the Leadville district are gneisses and schists cut by a granite batholith of pre-Cambrian age.

Upon this basement complex lies a succession of Paleozoic rocks ranging from Upper Cambrian to Pennsylvanian in age. Although this succession is apparently conformable throughout, with a local exception at the top of the "Parting" quartzite, the evidence obtained from fossils in central Colorado indicates a stratigraphic break at the top of each formation.

The Sawatch quartzite, commonly known in Leadville as the "Lower" or Cambrian quartzite, is for the most part a typical light-gray to white quartzite, 50 to 140 feet thick, with local relatively soft beds that have matrices of sericite or calcite. These softer and more readiy weathered beds are more numerous near the contact of the quartzite with the overlying "transition shales." The "transition shales," which are about 40 feet thick, were regarded by Emmons as a member of the Lower quartzite and have been so regarded by other authors who have described the Sawatch quartzite elsewhere in central Colorado, but as they can not be sharply separated from the overlying "White" limestone, the more clearly defined contact between the shales and the typical quartzite is regarded by local mining companies as the top of the Cambrian quartzite, and the shales are regarded by them as part of the "White" limestone.

The Yule limestone, of Ordovician age, includes the rocks originally described by Emmons as "White" limestone and "Parting" quartzite. The "White" limestone comprises thin beds of light-gray siliceous dolomitic limestone separated by thinner beds of greenish-gray shale. Nodules and seams of light-gray chert or "flint" are characteristic of it. The shale is most abundant in the lower and upper parts of the limestone.

The "Parting" quartzite consists of typical quartzite beds separated by shale beds, which in places are so numerous that the quartzite escapes recognition.

The Leadville limestone, locally called the "Blue" limestone, is a dark-blue fine-grained thick-bedded dolomite 200 feet thick with very little calcite or insoluble matter. It is mostly of Mississippian age, but its lower part may be Devonian. It is rarely interrupted by shale beds, although locally it becomes shaly at the top and at the base. In the western part of the district there is a sandstone in the lower part of the Blue limestone, which is the only lithologic suggestion of a boundary between possible Devonian and Mississippian strata.

The Weber (?) formation, which overlies the "Blue" limestone and crops out only in the eastern part of the district, includes a lower division called by Emmons the "Weber shales" and an upper division called by him the "Weber grits." The shales are prevailingly black and contain some impure coal seams but are calcareous and sandy in places and are interrupted by numerous layers of arkosic sandstone. Their maximum thickness in the surrounding region is 300 feet, but within the Leadville district they are rarely more than 100 feet thick and are usually much less. The overlying grits are gray and rather coarse grained and consist mainly of quartz, feldspar, and white mica derived from pre-Cambrian rocks. They include several fine-grained and shaly beds and a few nonpersistent beds of impure dolomitic limestone. Their greatest thickness within the district is 940 feet.

Evidence from the surrounding country indicates that the late Carboniferous Maroon and "Wyoming" formations, 3,000 feet thick, and the Dakota sandstone and later Cretaceous strata, 5,500 feet thick, were once present here. Their total thickness can not be closely estimated because erosion may have removed part or all of the Maroon and "Wyoming" formations from the Leadville district before the Cretaceous rocks were deposited. The total thickness of strata within the district at the end of Cretaceous time, however, probably ranged from 8,000 to 12,000 feet. Intrusive sheets of porphyry, of late Cretaceous or early Tertiary age, increased the thickness by 2,500 feet or more. These figures agree closely with Emmons's original estimate of 10,000 to 12,000 feet.

The ore deposits, which were formed subsequent to the porphyry intrusions, have a vertical range, so far as revealed by mining, from the pre-Cambrian granite to a horizon well within he "Weber grits," a distance of at least 900 feet. The bulk of them, however, lie in the "Blue" and "White" limestones and must have been formed beneath a cover of 9,800 to 12,000 feet or more of rock.

Chapter 4. Post-Cambrian igneous rocks.—The intrusive igneous rocks include a widespread group of porphyries and a few rocks or pipes of rhyolitic agglomerate. There are two main varieties of porphyry, known since the early days of the district as "White" porphyry and "Gray" porphyry. The "White" porphyry is cut by the "Gray" porphyry at a few places, but both are believed to have been intruded in late Cretaceous or early Tertiary time. These porphyries commonly form sills in all the Paleozoic rocks and dikes in the pre-Cambrian rocks but the sills are by far the more abundant. Two small stocks of the "Gray" porphyry beneath Breece Hill and Printer Boy Hill are imperfectly outlined by mine workings. There is reason to believe that an intrusion distinctly later than the sills of Gray porphyry and closely related to ore deposition has taken place in the stock beneath Breece Hill.

The "White" porphyry is most conspicuous in the western part of the district and also south and southeast of it. It is too much altered for its original character to be exactly determined, but it corresponds to a muscovite granite porphyry or to a granodiorite porphyry with an unusually small content of biotite.

The term "Gray" porphyry, applied in the Leadville monograph to rock typically developed in Johnson Gulch, has since become a general term to include a variety of porphyries that are generally similar and in contrast to the "White" porphyry. They are medium gray to greenish gray and contain prominent phenocrysts of white plagioclase, colorless to smoky quartz, chloritized biotite, and in the darker, less salic varieties hornblende.

The two subdivisions of the "Gray" porphyry group in and about the Leadville district are the Lincoln porphyry and the Johnson Gulch porphyry. Large crystals of pink orthoclase are prominent in the Lincoln porphyry and to a less degree in the Johnson Gulch porphyry. The Johnson Gulch porphyry is, next to the "White" porphyry, the most widespread intrusive rock within the Leadville district but is not definitely recognized elsewhere. Both the Lincoln and the Johnson Gulch porphyries are too much altered to be definitely classified, but the original rocks were either quartz monzonites or closely related granodiorites. The "Gray" porphyry at Breece Hill is so changed in appearance and composition that it was called "pyritiferous porphyry" in the Leadville monograph.

A third variety of "Gray" porphyry, called the Mount Zion porphyry by Emmons, is developed at Mount Zion, north of the district. Cross, who first studied this rock, remarked that specimens bleached by alteration could not be distinguished from "White" porphyry, and Emmons also stated that the two rocks apparently graded into each other. The type rock at Mount Zion is a siliceous quartz monzonite.

A fourth variety of the "Gray" porphyry, herein designated the Evans Gulch porphyry, differs from the other members of the group in having a fine, almost even-grained texture, resembling at first glance a fine-grained granite. This rock occupies a triangular area on the north slope of Evans Gulch.

The main sheet of "White" porphyry, intruded between the "Blue" limestone and the local shaly member of the Weber (?) formation, is fairly conformable with the bedding over a considerable distance, but in the vicinity of Stray Horse Gulch it splits, and the mine workings to the north cut two horizons of "White" porphyry. The "Gray" porphyry sills, on the other hand, are irregular in outline, especially in the Iron Hill area. They cross the bedding abruptly for short distances and send out short branches, some of which form interlocking bodies. The crosscutting of the sills of both porphyries appears to be upward, or away from the conduit at Breece Hill.

The characteristic irregularity of the "Gray" porphyry sills may be attributed in part to structural conditions and in part to their degree of viscosity at the time of intrusion. The pressure exerted by the intrusion near the conduit produced some local thrusting aside of limestone blocks which also resulted in marked variations in thickness of both limestone and porphyry.

The only volcanic rock within the Leadville district is a rhyolitic agglomerate erupted subsequent to ore deposition and prior to glaciation. This rock occurs as the filling of four irregular volcanic vents or pipes, which decrease somewhat in diameter with increasing depth, and also as dikelike masses along some of the major faults and fissures. The agglomerate disintegrates rapidly when exposed on mine dumps, and this tendency explains the occurrence of the pipes in depressions of the bedrock surface and their almost total concealment beneath glacial débris and "wash." The approximate outlines of the pipes have been determined by mine workings.

The best exposed, called the Ollie Reed pipe, underlies South Evans Gulch on the west side of the Ball Mountain fault. A small irregular pipe lies just northwest of the Ollie Reed pipe. The Josie pipe is exposed in the Josie, Midnight, and Silver Spoon mines. The Eureka pipe, at the northwest base of Breece Hill, is very imperfectly outlined by mine workings. The only other agglomerate body that can be mapped is a dikelike mass of southwesterly trend at the head of California Gulch.

The agglomerate consists of fragments of pre-Cambrian and Paleozoic rocks, the intrusive porphyries, rhyolite, and ore bodies in a matrix of rhyolite. The marginal portions of the pipes, where exposed, consist of glassy to dense rhyolite with well-developed flow structure and free from inclusions, but only a few feet from the contacts the typical agglomerate is present. Ore bodies terminate abruptly against the agglomerate.

Chapter 5. Structure.—Folding is not so pronounced within the Leadville district as in the surrounding region, where the principal folds trend N. 30° W. and are associated with reverse faults. These folds and reverse faults were developed subsequent to the intrusion of the porphyry sills, but prior to the intrusion of stocks and batholithic masses of monzonitic rock in central Colorado. Folding and reverse faulting were followed by normal block faulting on a comparatively small scale. The block faults are particularly conspicuous in the eastern part of the Leadville district, where they are mineralized. Subsequent to mineralization block faulting on a larger scale took place.

The reverse faults are of considerable interest because of their influence upon the localization of certain ore bodies. This influence was not appreciated until a comparatively small reverse fault, here called the Tucson-Maid fault, was discovered in the Tucson mine in 1908 and developed during the next few years. It is offset by the Iron fault, and its westward continuation has been found in the Mahala, Wolftone, and Maid mines, and a further offset continuation may extend through the eastern and northern parts of the Downtown area. The fault itself contains ore at a few places, but for the most part it is sealed by gouge, whereas auxiliary faults and fissures along it are mineralized and have served as feeders to replacement ore bodies in limestone. In the Cord mine, where the reverse fault is crossed by the Cord vein, the shattered ground contains both replacement deposits in limestone and stockworks ("brecciated ore") in "Gray" porphyry and quartzite.

The Colorado Prince reverse fault contains ore where it is crossed by the Colorado Prince vein, which fills a younger fissure. Throughout much of its course this reverse fault is filled with agglomerate, which may have obliterated small showings of ore. The upturned limestones on the southwest side of the fault have yielded some rich ore, and study of the distribution of recorded mine workings suggests that considerable productive ground remains to be prospected, particularly in the "White" limestone.

Ore in the London mine, on the east slope of the Mosquito Range, has evidently been introduced along auxiliary faults and fissures on the footwall side of the London fault. In the Clear Grit mine, on the south slope of Iowa Gluch, ore has been found both within the Weston reverse fault and in auxiliary fissures on its footwall side. The general conclusion regarding the influence of the reverse faults on ore deposition is that although they are not the trunk channels through which ore was introduced, where they or the broken ground along them are intersected or joined by the younger fissures that did serve as channels the conditions have been favorable for ore deposition.

The Mosquito, Weston, and Mike faults, as mapped by Emmons, are composites of earlier reverse faults and later normal faults.

Faults and fissures formed subsequent to reverse faulting and prior to ore deposition are most prominent in the eastern part of the district, but a few have been found in Iron and Carbonate hills. The faults and fissures that can be definitely assigned to this class are mineralized. Some, like the Ibex, Winnie-Luema, Garbutt, and Sunday veins, have been mined extensively; others, like the Cord vein in Iron Hill, minor veins in the Ibex group, and those in the Resurrection mine, have been stoped at a few places but are chiefly important as feeders of blanket ore bodies in limestone.

These faults and fissures trend in several directions and may comprise two subclasses—one trending at right angles to associated reverse faults and one trending north or north-northeast. So far as observed, those at right angles to the reverse faults are marked by comparatively little or no displacement. The others include some faults of considerable size, though small compared to the major postmineral faults. The larger of these faults, notably the Winnie-Luema, have transverse branches or auxiliary faults which are also mineralized.

The Ibex group of premineral faults is complex and numbers more than 70. Its largest members, the Ibex No. 4, Garbutt, and Modoc faults, form the irregular northern boundary of a large down-faulted block between the Weston and Ball Mountain faults, which is one of the least known parts of the district. Many of the minor members of the group are only a few inches thick but serve as leads to connected replacement ore bodies in limestone.

The origin of the reverse and later mineralized faults must be deduced from evidence from the surrounding region rather than the Leadville district itself. The folds and accompanying reverse faults were developed by a thrust acting in a west-southwest to west direction.

The fissures and minor faults at right angles to the reverse faults are attributed in part to a minor recoil movement following the period of folding and reverse faulting and in part to disturbances accompanying or closely following the late stock-like intrusion at Breece Hill.

With the exception of the Mike, Weston, and London faults and the northern part of the Mosquito fault, the largest and most conspicuous faults of the reigons are of postmineral age. Some of the older faults, notably the Mike, underwent renewed movement at this time. Postmineral faults have been more thoroughly explored in the western part of the district than elsewhere. They occur singly and in groups.

The two conspicuous groups of postmineral faults are the Pendery, in the Downtown area, and the Dome-Iron-Mikado, along the west slope of Iron Hill. The faults vary considerably in strike and dip, but their prevailing trend is N. 12° E. and their dip westward. Movement along them has been almost entirely in the direction of dip, as proved by the positions of faulted ore bodies. Auxiliary faults that branch from the major faults mostly strike northeastward, but the Adelaide fault, which is auxiliary to the Iron fault, is unusual in having a southeastward to southward trend.

Movement along the postmineral faults has taken place continuously or at repeated intervals until the present time, but the principal movement occurred during the main uplift of the Mosquito Range, in middle Tertiary time. Minor subsequent movements are indicated by the faulting of "lake beds," "wash," and mine workings.

The force that produced the postmineral faults acted vertically. The blocks between faults were tilted to the east but underwent very little horizontal movement along the strike of the faults and no compression transverse to the faults. The greatest amount of uplift was along the Mosquito fault, northeast of the Leadville district, and the next greatest along the Dome-Iron-Mikado and Pendery fault groups. The Mosquito fault diminishes southward, the Dome-Iron-Mikado group is at a maximum just north of Iron Hill and diminishes both to the north and south, and the Pendery group increases southward as far as it can be traced (to the south edge of the Leadville district). The shift of the main zone of uplift took place, therefore, in the vicinity of Leadville, and adjustments within this area of change are expressed by movements along faults between the Dome-Mikado-Iron and Mosquito faults. These movements were mostly uplifts on the east side of the faults but include the depression of the block between the northern Mike and Pilot-White Prince faults and perhaps the block between the Weston and Ball Mountain faults south of the Ibex mine. This last block, however, was depressed to some extent before the period of ore deposition.

The local depression of these blocks during a period of general uplift indicates some expansion of the earth's crust during the uplift. East of the Mosquito fault the uplift is marked by eastward tilting without conspicuous faulting unless renewed movement took place along the London fault zone. West of the Mosquito fault eastward tilting took place but was subordinate to faulting. The amount of uplift at the Mosquito fault compared with the strata in South Platte Valley, to the east, is about 7,000 feet, and as compared with the strata beneath Leadville, about 8,000 feet. Although this uplift is best indicated in the Mosquito Range, it has been much more extensive, but the limits of the area characterized by postmineral normal faults are not known.

Chapter 7. Production, history, and mine development.—Leadville now ranks fifth among the mining districts of the country in total value of its mineral output. Its history may be divided into three periods according to the dominant metals produced—gold, silver-lead, and zinc.

Chapter 8. Classification and mineralogy.—The ore bodies may be classified according to form into veins, stockworks closely related to veins, replacement deposits or "blankets," and placers. The first two classes are found principally in siliceous rocks and the third in carbonate rocks. The placers are of only historic interest and are only incidentally considered in connection with the supergene concentration of gold. Classification may also be based upon the genetic relations of the ores and their constituent minerals, and a subclassification on the metals and gangue present. A combination of these classifications is necessary for an adequate understanding of the ores.

The important hypogene minerals are comparatively few and of simple chemical composition, but supergene minerals, derived wholly or in part from them, include more than 50 species, some of which are of complex composition. The hypogene minerals are divided, according to the temperature at which they were formed, into two groups—high-temperature minerals, in replacement bodies near the Breece Hill stock, and moderate-temperature minerals, in veins and replacement bodies away from the main center of intrusion. The mineral composition of a few deposits indicates a gradation between the two groups.

The minerals diagnostic of high temperature are wollastonite (uncommon), pyroxene or olivine (now altered to serpentine), magnetite, and specularite. The last two minerals are also present in small quantity in deposits that belong more to the moderate-temperature group. Manganosiderite is in minor degree closely associated with massive magnetite, but for the most part it forms casings around the mixed sulphide ore bodies. Quartz also is associated to a minor extent with the high-temperature minerals but is mostly present in moderate-temperature deposits. In siliceous rocks it is accompanied by large quantities of sericite and minor quantities of chlorite, epidote, and calcite. It is also present together with chalcedony and opal in the supergene ores.

The principal sulphide minerals, in order of abundance, are pyrite, zinc blende (marmatite), and galena. The pyrite, like the manganosiderite, is intimately associated with magnetite to a small extent and is also present in veins that distinctly cut the massive magnetite. It is the principal ore mineral in the veins and stockworks and also in many of the replacement bodies in limestone. Zinc blende and galena are more limited to deposits of moderate temperature. They are mostly present in the blanket bodies, either in mixed sulphide ore or in nearly pure zinc or lead ores, but are also locally present in the veins. Zinc blende is much more abundant than galena.

Among the minor hypogene sulphide minerals chalcopyrite is most prominent. It is locally interstitial among pyrite and zinc blende in the veins and is present as microscopic inclusions in the blende. The ores commercially classified as copper ores (copper 2½ per cent or more) have been enriched by supergene chalcocite, which coats chalcopyrite and pyrite and to a minor extent zinc blende. The chalcocite is commonly accompanied by considerable silver and also gold.

Argentite is present, usually as microscopic grains accompanying the other sulphides, and is occasionally found intergrown with bismuthinite. This intergrowth is the principal constituent of the rich silver sulphide ore found here and there.

Gold is present in commercial quantity in this rich silver ore, also in certain shoots in the lodes and stockworks, and in rather closely associated blanket bodies. Visible gold is practically confined to oxidized parts of these ore bodies, where it is locally present in flakes and wires, and to certain enriched parts of the associated sulphide zones. Gold presents one striking mode of occurrence in the sulphides as veinlets, coatings, and interstitial filling, particularly in zinc blende. It is also closely but not constantly associated with chalcocite.

Chapter 9. Primary (hypogene) ores and ore bodies.—The original hypogene ores include (1) iron oxides with silicate and carbonate gangue formed at high temperature by replacement of limestone near the Breece Hill stock; (2) veins and stockworks of sulphide ore, mainly in siliceous rocks; (3) replacement bodies or "blankets" of sulphide ore in limestone.

The first group belongs to the class generally called "contact metamorphic," but this term is not very apt for some of this group at Leadville, as the ore is in contact with sills of porphyry which were consolidated and fractured before the deposition of the ore. This group is the least important commercially Magnetite-specularite ore, affected to some extent by weathering, has been shipped for fluxing from the Breece iron or Penn mine since the early days, but other shipments have been limited to ore that has been cut and enriched by pyritic gold of the second group. The high-temperature ores can not be sharply distinguished from the sulphide ores of the third group.

The mineral composition of the ores of the second and third groups is characteristic of ores formed at moderate temperatures. The veins of the second group have been worked since 1868, but with the exception of the Ibex group of veins on Breece Hill, they have been overshadowed by the sulphide replacement bodies of the third group. Only a few stockworks have been found and they may be regarded as variations of the veins.

The veins lie mostly east of the Weston fault, but several minor veins have been worked or prospected on the west slope of Breece Hill, and productive veins in close association with "blanket" ore bodies have been mined in the Cord and Tucson mines, in the Iron Hill area, and the Wolftone and Greenback mines, in the Carbonate Hill area. Those east of the Weston fault are in part isolated but mostly occur in groups of closely spaced veins.

Most of the important veins of the district have been discovered by underground development. The scarcity of outcrops is due to relatively rapid erosion of vein materal; extensive coverings of glacial débris and disintegrated rock; and the failure of most veins to reach the surface of bedrock. Shale beds, particularly the lower part of the Weber (?) formation, or the so-called "Weber shales," have acted as barriers against which many veins terminate upward and spread as blanket replacement deposits in the underlying limestone; but intense mineralization at Breece Hill and on the western slope of Ball Mountain reached well into the so-called "Weber grits," or upper part of the Weber (?) formation. The greatest production has come from veins of approximate northward trends.

The veins are divided into three classes based on dominant mineral composition—(1) pyrite-chalcopyrite with subordinate zinc blende, (2) highly siliceous, (3) mixed siliceous sulphides, locally with prominent galena. These classes grade into one another.

Although mineralization extends from veins along certain beds in quartzite and shale, workable ore is almost wholly confined to the replaced shattered rock within the fissure zones between siliceous wall rocks. The exceptions are small blanket replacement deposits that branch from veins in the "Weber grits." Where the veins cut limestone, however, most of them spread into blanket deposits, whose longest dimensions are generally parallel to the strike of the veins, though some trend away from the main vein along branch fissures. The ores that have been mined from these connected replacement deposits are mostly similar to those within the veins and different from the ores of the large replacement bodies in the western part of the district, but gradations between the two kinds of replacement deposits have been established at a few places. Where gradations have been exposed the siliceous pyritic gold or gold-copper ore extends a short distance from the vein fissure and grades rather abruptly into massive zinc blende-galena ore.

The large blanket ore bodies occur mostly in groups that have a roughly radial arrangement with respect to the intrusive stock of Gray porphyry at Breece Hill, but their location and arrangement are more closely controlled by other structural features, notably the reverse faults and the transverse normal faults and fissures.

These "blankets" have been found in all the sedimentary formations but mostly in the two limestones. In shaly formations more limy beds have been replaced by ore in areas of intense mineralization, but the principal function of the shales, and particularly of the porphyry sills, has been to serve as an impervious cover beneath which the ore-forming solutions spread and replaced limestone.

The Blue limestone has contained the greatest number and the largest of the ore bodies mined. The White limestone has been the more productive for several years in certain places, particularly in the Iron Hill and Carbonate Hill areas, but its ore bodies have not been so large as those mined in the Blue limestone in the earlier years. The White limestone is well worth prospecting in certain undeveloped places, particularly in the Iron Hill area, but its ores on the whole are less widely distributed and of lower grade than those in Blue limestone.

The replacement bodies commonly occur at certain horizons, locally called "contacts," where structural conditions have controlled the concentration of ore. The number of "contacts" varies on the whole with the number of porphyry sills and shale beds that serve as impervious covers to ore bodies. In some places ore has been mined at as many as ten or eleven "contacts." The uppermost, usually the contact of White porphyry or "Weber shales" with Blue limestone, is called the "first contact," and others are numbered in consecutive descending order, regardless of their stratigraphic positions. The original ores of the blankets are classified below according to the ratio of sulphides and gangue minerals, and the classes may be subdivided according to the relative abundance of the different metallic sulphides. The different varieties grade into one another.

1. Massive sulphide ores (sulphides with inconspicuous gangue):
   - *a.* Pyritic or iron ores.
   - *b.* Galena or lead ores.
   - *c.* Sphalerite or zinc ores.
   - *d.* Chalcopyrite-bearing mixed sulphides or copper ores.
   - *e.* Mixed sulphide ores.
   - *f.* Argentite-bismuthinite or silver-bismuth ores.
2. Carbonate-sulphide ores (mixtures of sulphides and large quantities of manganosiderite).
3. Siliceous sulphide ores (mixtures of sulphides and large quantities of quartz or jasperoid):
   - *a.* Pyritic gold ores.
   - *b.* Chalcopyritic gold ores.

Concentric banding characterizes much of the mixed sulphide ore.

Chapter 10. Genesis of the hypogene ores.—The ores are believed to have been deposited by magmatic waters. The evidence for this belief is similar to that presented in several reports on mining districts during the last 20 years. The magmatic waters were not directly associated with the sills of Gray porphyry but with a later intrusion, which is not certainly exposed in the Leadville district but may be represented in pyritized rock of the Breece Hill stock, where mineralization was intense and took place at higher temperatures than elsewhere.

The high-temperature deposits were formed by waters escaping from the upper part of the stock soon after its consolidation. At a later stage, after a much larger quantity of ore-forming solution had accumulated in the magma reservoir, fissuring and minor faulting allowed this solution to rise to and above the level of the high-temperature deposits; but by the time this level had been reached the solutions had cooled to moderate temperature and formed sulphide veins crosscutting the high-temperature deposits. Differences in mineral composition of the deposits were determined largely by the kinds of rock through which the solutions passed and by the temperature at which reaction with the rocks took place.

Pyrite was deposited through a considerable range of temperature, and only after its deposition was nearly completed were other sulphides deposited, either in the interstices among pyrite grains or in local shoots. Deposition of zinc blende as a whole preceded that of chalcopyrite and galena, but chalcopyrite is most closely associated with pyrite, which evidently was its most efficient precipitating agent. These briefly stated relations were necessarily complicated by variations in local conditions.

Manganosiderite evidently began to replace limestone at a temperature too high for the deposition of sulphides, but at lower temperature the sulphides were more stable and replaced manganosiderite. The manganosiderite was transferred in solution to localities where it could again replace limestone around the margins of the sulphide bodies. Silica had a similar relation, which accounts for the deposition of siliceous pyritic ore in or close by trunk channels, followed by sulphides low in silica, and for margins of jasperoid around some ore bodies, as well as masses of jasperoid more remote from the trunk channels. Barite, found principally in the marginal parts of productive ground, was formed mainly during the later part of the sulphide stage of deposition, and the minor carbonates, dolomite, ankerite, and calcite, were the last minerals deposited.

Primary gold, argentite, and bismuthinite, so far as scanty data show, were only exceptionally deposited in visible quantity. They followed the more common sulphide minerals and, where the solutions were held back by impervious barriers, filled interstices among the sulphides.

Chapter 11. The oxidized ores.—Oxidized ores, formerly dominant but now subordinate to sulphide ores, include iron-manganese and manganese oxide ores derived from manganosiderite, iron oxide ore derived from pyrite ore low in silica, oxidized siliceous gold and silver ore derived from siliceous pyrite ore, lead carbonate ore derived from massive galena and mixed sulphides, lead-iron sulphate (plumbojarosite) ore derived from mixed sulphides, oxidized siliceous lead ore derived from siliceous mixed sulphides, zinc carbonate and silicate ore derived from massive zinc blende and mixed sulphides, oxidized siliceous copper ore and copper sulphate ore derived from siliceous pyrite-chalcopyrite ore, and oxidized bismuth ore derived from bismuth sulphide ore.

Chapter 12. Alteration and enrichment of the ores.—The bottom of the oxidized zone is in general sharply defined in the blanket bodies, where circulation was mainly parallel to the dip of the country rock; it is less distinct in the steeply dipping veins, and some effects of oxidation are found considerably below the zone of thorough oxidation. The zone of sulphide enrichment, principally indicated by chalcocite, is very poorly defined and in several places absent. It is far more common in the veins than in the blanket bodies but can rarely be separated from the oxidized zone above and the zone of primary ore below.

The depth of the oxidized zone below the bedrock surface ranges from 75 to 940 feet, but in most parts of the district it is between 400 and 600 feet. The depths of complete oxidation approach uniformity within any area bounded by major faults but are very different in adjacent areas separated by the faults. Although a rough correspondence exists between the eastward rise of the top of the sulphide zone and that of the ground surface, many striking variations from such a correspondence are due to the effect of geologic structure, the effect of lithologic character of country rock, the form and position of the ore body, and the effects of glacial erosion and deposition and of the changes in ground-water level.

Chapter 14. Ore reserves.—Leadville has been a large producer for about half a century, and there has been considerable opportunity to determine the limits of productive territory. Most of the favorable ground within those limits has been thoroughly explored, but there are reasons for hoping that the productive area of the district may still be enlarged and that some good ground hitherto overlooked may be found within the developed area. It is also reported that large quantities of low grade and complex ores stand ready to be mined when higher prices or improvements in metallurgy shall make them profitable.

Good ground within the productive area may include a few undiscovered masses of replaced Blue limestone within the main sheet of White porphyry, but the most promising ground in the western part of the district includes the insufficiently explored Blue and White limestones along reverse faults in the Iron Hill and Carbonate Hill areas. The northern part of Breece Hill and the area northeast of the Colorado Prince fault contain promising ground that has not been adequately explored. The down-faulted block south of the Modoc lode and east of the Garbutt lode is also promising, especially in its northwestern part.

The territory north of Evans Gulch has not been studied in detail but has not much to commend it so far as available evidence is concerned.

Beyond the east and south limits of the area studied some good ore bodies at the Blue limestone horizon have been mined. No appraisal of this outlying territory is attempted, but it is hoped that the information presented in this report will serve as a basis for more extended studies.

PANORAMIC VIEW OF LEADVILLE IN 1912, LOOKING WEST

Behind the town and across the intervening valley of Arkansas River are the lofty summits of the Sawatch Range

GEOLOGY AND ORE DEPOSITS OF THE LEADVILLE MINING DISTRICT, COLORADO

By S. F. Emmons, J. D. Irving, and G. F. Loughlin

INTRODUCTION

By G. F. Loughlin

The publication in 1886, by the United States Geological Survey, of S. F. Emmons's monograph entitled "The geology and mining industry of Leadville" marked the beginning of an epoch in the investigation of mineral deposits in America. Before that report was written comparatively little had been done in this country to further our scientific knowledge of the deposition of the metalliferous ores. During the years that have elapsed since 1886 economic geology has seen a greater advance than that which had been accomplished in the preceding century—an advance to which American geologists have abundantly contributed. Certainly the time was ripe, in the early eighties, for a great acceleration of progress in economic geology, but it is equally certain that this acceleration derived its most powerful impulse from the enthusiasm inspired, in geologists and mine operators alike, by the varied excellences of the Leadville monograph.

The dominant position of the original Leadville monograph and the unfortunate death of its author before its revision render appropriate a brief account both of Emmons's life and of the conditions that led to the writing of the present volume.[1] The infinitely painstaking effort, the then unprecedented elaboration of detail, the remarkable accuracy of the data presented, and the masterly skill with which the mass of facts and conclusions were marshaled before the reader afforded an example of geologic insight and a model of literary excellence to which American geology offers few parallels. It is not surprising that such a volume should have had so far-reaching an influence nor that the stimulating effect which it produced should have extended over three decades and still be potently felt.

When Samuel Franklin Emmons died at his home in Washington, March 28, 1911, he lacked only one day of completing his seventieth year. He was born in Boston, March 29, 1841, entered Harvard College in his seventeenth year, and was graduated in the class of 1861 with the degree of A. B. The outbreak of the Civil War drew several of his class into the Army. Emmons desired to go to the war but reluctantly yielded to the expressed wish of his parents, who were averse to his enlistment. A long-cherished ambition of the elder Emmons was that at least one of his sons should pursue a professional career. Frank, as he was called, had always shown the habits of a student and was then completing a collegiate course; the choice therefore naturally fell on him; and as his own taste led him to prefer an outdoor life, he began early to look forward to some form of engineering as a profession.

When his invalid mother, in 1861, was advised, in the hope of bettering her health, to take a summer trip abroad, he was selected as the most available member of the family to accompany her, and they sailed in June for England and the continent of Europe. His mother returned in the fall, but he remained for a time in England and went to Paris in December, bent upon some line of scientific work but still undetermined in his own mind just where and what he should study.

Shortly after reaching Paris he made the acquaintance of Eckley B. Coxe, of Philadephia, then a student at the École Impériale des Mines. Emmons always regarded this meeting with Coxe as the turning point in his own life. Acting upon his friend's advice he entered the École des Mines after nine months of preparation, during which he became well grounded in chemistry and physics under Prof. Adolf Wurtz. Foreign students were admitted to the École des Mines only upon application of the representatives of other friendly governments, and Emmons owed his privilege to the Hon. William L. Dayton, American minister to France. He worked there industriously for two academic years, to the summer of 1864, and was particularly inspired by the famous French geologists Élie de Beaumont and Daubrée.

The next year he spent in the Bergakademie at Freiberg, Germany, where the practical side of engineering was taught in more detail and where he became familiar with the German school of geology and with Bernhard von Cotta, one of the pioneers in economic geology. He left Freiberg in the summer of 1865, visited many

[1] The paragraphs that follow are abstracted by G. F. Loughlin from memorials by Arnold Hague (Geol. Soc. America Bull., vol. 23, pp. 12–28, 1912) and George F. Becker (Am. Inst. Min. Eng. Bull. 57, pp. 673–692, 1911) and from annual reports of the U. S. Geological Survey from 1887 to 1919.

important mining centers in different parts of Europe, spent the winter in Italy, and returned to Boston in June, 1866.

Early in 1867 the Geological Exploration of the Fortieth Parallel under the direction of Clarence King was authorized by Congress. Shortly afterward Arnold Hague, a mutual friend, brought King and Emmons together, with the result that Emmons was accepted as volunteer assistant, and in the following winter he received an official appointment as assistant geologist.

On May 1, 1867, several members of the scientific corps, including Emmons, left New York for San Francisco by way of the Isthmus of Panama, a trip occupying three weeks. After several days in San Francisco a camp for assembling equipment was established at Sacramento, and a ride of a few days across the high Sierra brought the party, early in August, to its first working camp on Truckee River, not far from the present city of Reno, Nev. The party was accompanied by a cavalry escort of 25 men to guard life and property, and frequently a mounted soldier accompanied a geologist when it was deemed unwise for anyone to be quite alone in the mountains. Two well-equipped organizations were constantly in the field—one known as the Emmons party, the other as the Hague party. The parties worked eastward and ended at the Great Plains of Wyoming and Colorado in 1872.

The first winter of the work was spent at Virginia City, Nev., in a study of the Comstock lode and the geology of Mount Davidson. The subsequent winter quarters were in San Francisco, Washington, and New Haven. After completion of the field work the final report was prepared in New York. This report contained Emmons's first scientific publications, the most noteworthy of which was his part in volume 2, "Descriptive geology." The manuscript of this volume, by Emmons and Hague, was presented to King in January, 1877, and the book was issued early in 1878. It contains 890 pages. The companion volume of atlas maps and cross sections was printed in 1876. Upon completion of the report Emmons resigned to attend to personal matters. It was that 10 years of training in descriptive geology, as he practiced it, which enabled him to deal subsequently with the complexities of Leadville.

The United States Geological Survey was created by act of Congress on March 3, 1879, and three weeks later the President nominated Clarence King as its first Director. This nomination was confirmed by the Senate, and on May 24 King took the prescribed oath. One of his first official acts (August 4) was to appoint Emmons geologist in charge of the Rocky Mountain division, with headquarters in Denver. The first two lines of his instructions read as follows: "You will devote the first years of your administration of your division exclusively to a study of the mineral wealth of the Rocky Mountains." In accordance with these instructions, he was requested to prepare, without delay, a monograph on the Leadville region.

In the fall of 1879 the newly organized Geological Survey undertook an examination of the precious-metal industries under the Tenth Census, as a matter of courtesy to the Census Bureau, and Emmons and George F. Becker were placed in charge of the work. During the period of preparation for this work King completed his plans for the investigation of ore deposits, which he also placed in charge of Emmons and Becker. They had to select and instruct a staff of young mining engineers in the collection of statistics and technologic data for the Census and at the same time organize and begin their geologic field work. Emmons began on the geology of Leadville just before the end of 1879.

In spite of this double duty, Emmons pushed the examination of the geology of Leadville so energetically that he was able to close his office at the camp April 1, 1881, and to transmit his "Abstract of a report on the geology and mining industry of Leadville" on October 20 of that year.[2] Publication of the full report (Monograph 12), which involved a great amount of chemical and other detailed study, was delayed by various causes until 1886.

The monograph of nearly 800 pages and its accompanying atlas containing 35 sheets of maps and sections attracted immediate attention, not only of geologists and practical mine workers, but of all classes of scientific men. It won for its author an international reputation, being received both in Europe and America as a work of the highest order. No single publication of the United States Geological Survey since its organization has exerted a more beneficial influence and stimulated more discussion. It everywhere aroused investigation of the origin of ore deposits, and similar studies were prosecuted in other areas throughout the northern Cordillera.

Emmons's views on the Leadville ore deposits, as stated in the monograph, were briefly as follows: Prior to oxidation the ores consisted of sulphides of lead, silver, zinc, and iron, which were deposited by substitution for country rock, mostly limestone or dolomite but in some places rock of siliceous character. The ore reached the deposits from above as hot aqueous solutions at high pressure. The temperature was due to the depth (about 10,000 feet) and the magmatic heat of the intrusive porphyries. The water was of meteoric origin and derived its metallic content, perhaps wholly but demonstrably in part, from masses of porphyry, which were not necessarily in juxtaposition with the ore. The principal deposition took place at the upper surface of the blue Carboniferous limestone.

Emmons revisited Leadville in 1887, and during the next three years he studied the geology of the Tenmile, Silver Cliff, Crested Butte, and Denver Basin

[2] U. S. Geol. Survey Second Ann. Rept., pp. 201-290, 1882.

regions. In 1890 he again visited Leadville, where underground explorations, conducted with a rapidity then unknown in any other part of the world, had exposed since his early study, a vast amount of significant data. He began the compilation of a large map of the underground workings of the whole region, a task in which he had the cordial cooperation of the various mine owners, especially of A. A. Blow and Charles J. Moore, mining engineers, who had been closely studying the geologic structure as development work progressed. He also profited by the assistance of Whitman Cross, who made a petrographic study of the igneous rocks of Breece Hill.

It was evidently Emmons's intention to issue a supplementary report on the district, but as detailed studies progressed he began to speak of a resurvey of Leadville and a revision of the monograph. He continued his studies in the district, assisted by Cross, in 1892 and 1893 and devoted much of 1894 and 1895 to preparation of the new report, but the scope of the work was too great for completion by him alone, along with his supervisory duties. No mention of work by him in Leadville is made in the Director's annual reports for 1896 to 1900. In 1901 he resumed the systematic study of the mine workings, assisted by J. D. Irving, and the two devoted part of their time during the next three years to the work. No mention of any progress is made in the annual reports for 1905 and 1906, but the report for 1907 stated that information based on field studies had been brought up to date and announced the publication of Bulletin 320, on the Downtown district, for which the data were most readily compiled and were likely to be most immediately useful to those engaged in mining. Emmons concluded this report by a discussion of views that had been expressed since 1886 regarding the genesis of the Leadville ores and that differed with the conclusions stated in the monograph. He modified those conclusions by laying more emphasis on the ultimate deep-seated source of the ores and ended by stating that three questions still at issue were (1) whether the sulphide ores were originally deposited by meteoric or magmatic waters or in part by both; (2) if by magmatic waters, whether they reached the site of the deposits directly from below, or indirectly as implied in the monograph; (3) whether some or all of the deposits were formed by contact metamorphism.

This statement of the problem doubtless represented a transitionary state of mind, experienced by many geologists who got their early training prior to 1900, when the efficiency of magmatic waters as depositors of sulphide ores began rapidly to gain recognition. His original interpretation of the stratigraphy and geologic structure remained unchanged, however, except in such details as the somewhat more accurate location of faults and more accurate delineation of intrusive bodies as revealed by underground workings, and the original atlas has to this day held the admiration of all who have consulted it as a guide to the local geology.

Progress on the new report continued until March, 1911, when Emmons died. His manuscript had been little more than outlined, and the maps and sections still required much correlation. They reflected, however, the results of his extensive studies of ore deposition and enrichment in several of the most productive mining camps of the country.

After Emmons's death completion of the new report fell to Irving, who cheerfully accepted the task, although already overwhelmed with university work and the editing of the journal Economic Geology. Irving's progress, though interrupted by illness, was rapid in 1912 and even more so in 1913, when his entire summer was devoted to the work and a short visit was made to Leadville in the fall. Most of his manuscript and illustrations were prepared in that year. During the same year G. F. Loughlin studied the newly developed oxidized zinc ores, and early in 1914 he transmitted a paper on them as a chapter for the new report. In 1913 and 1914 F. B. Laney made careful studies of the microstructure of the sulphide ores by means of the metallographic microscope. Some of his results have been available to the present authors, but no complete report of his work has been transmitted.

Little further progress on the report was made by Irving after 1914, and just before his departure for France in 1917, as a captain in the Engineers' regiment in the American Expeditionary Force, he transmitted a rough draft of it, which lacked certain important data that had been made available since his last visit to the district. Owing to the diversion of the Geological Survey's activities to war work and to the length of time that would necessarily elapse before the report could be completed and published, the chapter on the oxidized zinc ores was issued separately in 1918 as Bulletin 681.

Irving's untimely death in France in 1918 left the completion of the report to Loughlin, whose field work in Leadville and whose general review of the work with Irving in 1913 made him the most available to inherit the task. Loughlin visited the district to study new developments in 1919 and 1922, but his administrative duties prevented devotion of consecutive time and thought to the report, and it was not transmitted for publication until 1925. There has been some compensation for the delay in that certain structural data of critical importance in the interpretation of economic problems were not brought to light until after the resurvey was well advanced.

Some readers will regret that the resurvey has not extended beyond the limits of the area represented by the topographic map of the Leadville mining district. This regret is justified, but such an extension would have taken considerable time, and after the long delay in completion of the new report, it seems better to make the report available in its present form, with the hope that it will serve as a basis for detailed studies in the surrounding area.

The text as it stands has been written almost wholly by Irving and Loughlin, but the fundamental nature of the work done by Emmons in preparation for this report is recognized by recording him as the senior author.

Besides the field work done especially for this report, a study of the Pleistocene geology of a region including the Leadville mining district was made by S. R. Capps and published as Bulletin 386. Capps's descriptions and conclusions are incorporated in chapter 2. In 1918 J. B. Umpleby made a brief visit to the manganese deposits of Leadville in connection with investigations of war minerals, and some of his observations are referred to in chapter 11.

C. W. Henderson, in charge of the United States Geological Survey's Denver office since 1908, has been gathering statistical, historical, and other information on the Leadville district and has been of much help in the preparation of the report. The chapter on production, history, and development is largely his work.

A work of this kind is possible only through the cordial cooperation of the mining companies interested and of public and private individuals in possession of valuable information. To name those to whom the United States Geological Survey is indebted in connection with this report would require the listing of practically all the mining companies that have been active in the district since 1886 and many of their officials, who spared no effort in rendering all possible service. The maps and other illustrations, nearly all based on data furnished by these men, constitute testimony of the general whole-hearted support given to the work. To all who have shared in the work acknowledgment is gratefully made. Irving's incomplete manuscript contained a memorandum to add personal acknowledgments, but he had recorded no names. Loughlin has also benefited from some whom Irving had in mind, but his acquaintance and the scope of his work have been so small compared to those of Emmons and Irving that no adequate acknowledgment to those who have been the most helpful in the preparation of this report can be made. Specific assistance is acknowledged in text or footnotes. The many who have helped Loughlin in his study of the oxidized zinc ores are mentioned in Bulletin 681. His visit to Leadville in 1919 was made at the suggestion of Philip Argall, whose geologic observations had brought to light some interesting facts regarding the structure and ore bodies exposed in the Graham Park area and in the Tucson mine, in Iron Hill. His recent work was also particularly aided by George O. Argall and Frank Aicher, of the Iron-Silver Co., John Cortellini, W. F. Page, George Cramer, J. M. Kleff, and Russell Paul and A. H. Buck, of the Empire Zinc Co.

The authors are indebted to F. C. Calkins, of the United States Geological Survey, for his very helpful detailed criticism of the manuscript.

PART I. SUPERFICIAL FEATURES

CHAPTER 1. GEOGRAPHY

LOCATION

The city of Leadville is in Lake County, Colo., on the western flank of the Mosquito Range, at the head of the Arkansas Valley, in longitude 106° 17′ 30″ and latitude 39° 15′ north. The courthouse, in the center of the city, is 10,150 feet above sea level.

The exact location of the Leadville mining district is indicated on the accompanying outline map of Colorado (pl. 2). The shaded area surrounding the city indicates that covered by the special map of the mining district (pl. 13). This area is hereinafter referred to simply as the Leadville district. The larger shaded area indicates that covered by the Mosquito Range map of the Leadville monograph and the Tenmile folio, which are reproduced in Plate 11.

TOPOGRAPHY

The most striking feature in the topography of the Rocky Mountains in Colorado is the fact that they consist of two approximately parallel ranges, separated by a series of broad mountain valleys or parks. The eastern range, the Colorado or Front Range, rises abruptly from the Great Plains, which lie along its base at an altitude of 5,000 to 6,000 feet above sea level, to its crest at 13,000 to 14,000 feet. It is deeply scored by narrow, tortuous gorges, worn by mountain streams, whose clear waters flow out upon the plains and are absorbed in the turbid currents of Platte and Arkansas rivers. The trend of the range is due north, and its highest portions are mostly included within the boundaries of the State, beyond which at each end it becomes gradually lower and disappears as a topographic feature beneath the plains. West of this range lie the mountain valleys of North, Middle, South, and San Luis parks, in Colorado, and the Laramie Plains, in Wyoming, each of which is almost completely encircled by mountain ridges, though each has distinct topographic features of its own.

Beyond the parks on the west, and separating them from the basin of Colorado River, is the Park Range. It has by no means the regular structure of the Colorado Range, but is made up of a series of short ranges en échelon, from which offshoots connect with the Colorado Range and separate the park basins. In the latitude of Leadville this western uplift consists of two distinct ranges, the Mosquito Range—called the Park Range in the Hayden atlas of 1877, probably because it forms the boundary of South Park—and the Sawatch Range, which forms the watershed between the Atlantic and Pacific waters.

The Mosquito Range is a narrow, straight ridge about 80 miles long, trending a little west of north, and has an exceedingly sharp crest due to the development of glacial cirques.

The Sawatch Range, on the other hand, is a broader series of massive oval mountains and lacks the continuous ridge structure of the Mosquito Range. In this respect, as in its component formations, which have determined its topographic form, it resembles the Colorado Range. The culminating points of each range have a remarkably uniform altitude of about 14,000 feet above sea level.

Between the two ranges lies the valley of the upper Arkansas, which extends southward for 60 miles and is about 16 miles in width, measured from the crests of its bounding ridges. From the south end of this valley Arkansas River, after receiving the waters of the South Arkansas, bends sharply to the east and cuts through the southern continuations of the Mosquito and Colorado ranges in deep canyons, the eastern one well known to tourists as the Royal Gorge.

About midway in the upper Arkansas Valley the present bed of the stream is confined within a narrow rocky canyon, called Granite Canyon from the prevailing rock of the surrounding hills. Both above and below this canyon the foothills of the bordering ranges recede, leaving a valley bottom from 6 to 10 miles in width. But little of this area is occupied by alluvial soil, its surface consisting mostly of gently sloping, gravel-covered terraces. Above Granite Canyon the valley for a distance of 20 miles is remarkable for its breadth and straightness and for the beauty of its landscape. In the center of this basinlike portion is a relatively wide stretch of meadow land immediately adjoining the river, on each side of which mesalike benches slope gently up to the foothills, 3 or 4 miles distant.

On the upper edge of one of these terraces, on the east side of the valley, is the city of Leadville. From the north bank of California Gulch it extends along the west base of Carbonate Hill to the valley of the east fork of the Arkansas, covering with its rectangular system of streets an area of about 1¼ square miles. On the hill slopes immediately above and thence eastward to Ball Mountain are the mines that constitute its wealth.

Two views of the city of Leadville accompany this report. One taken from the west in 1880 is shown as Plate 4. It constituted Plate 2 of the Leadville monograph. The second, taken from the east in 1912 by B. C. Gray, forms Plate 1 of the present report. These views not only serve to show the growth of the city as outlined in chapter 7 but give to the reader an idea of the north-south mountain ranges that border the two sides of the Arkansas Valley. Plates 3 and 4 show the peaks of the Mosquito Range, toward which the hills and valleys of the Leadville district gradually rise. In Plate 1 the lofty summits of the Sawatch Range are seen behind the town and across the valley of the Arkansas. On the left appears the sharp summit of Mount Elbert; and next on the right, immediately above the smoke of the Arkansas Valley smelter, rises the great bulk of Mount Massive. Farther north are the top of Homestake Peak and the distant summit of the Mount of the Holy Cross. On the extreme right and relatively near the observer is Mount Zion, on the ridge that intervenes between the East Fork of the Arkansas River and Tennessee Pass.

As Emmons remarked, the Mosquito Range is in an alpine region where scarcely a point is less than 10,000 feet above sea level. Its most prominent and striking features, shown on Plate 8, have resulted in large measure from alpine glaciation. Its sharp crest runs nearly north and south, separating the broad valley of the Arkansas on the west from that of the South Platte on the east. The ridges that extend outward from this divide have sharp, narrow summits, which gradually become more rounded both eastward and westward from the crest of the range.

Between the ridges on both sides of the range are gulches that head in broad cirques, bordered by steep or even precipitous rock walls, which rise from 1,000 to 1,500 feet above the floors, the change from floor to wall in some being very gradual and in others rather abrupt. These cirques are due to the gradual crestward erosion of the gathering fields of the glaciers that once occupied most of the gulches. Several small lakes occupying the bottoms of cirques are shown in Plate 8. The cirques on the west side of the range are smaller than those on the east side, where the erosive action of the individual glaciers was more intense. No cirques are seen within the Leadville district (pl. 7).

Where the range connects with the lateral ridges that form the sides of the cirques, roughly triangular masses of rock, called "dreikanter" (three-cornered) by the Swiss, have been left between the cirques. These triangular masses form the sharp prominent peaks of the range at altitudes of 13,300 to more than 14,000 feet. One of the more perfect of them is Mount Sheridan. Some of the others are Weston Peak, Mount Sherman, Gemini Peaks, Dyer Mountain, Mount Buckskin, and Bartlett Mountain. At a few points the ridge between the triangular peaks nears other peaks of the first order, notably Ptarmegan Peak, Horse Shoe Mountain, Mount Evans, Peerless Mountain, Mosquito Peak, and Mount Arkansas.

Most of the principal gulches of the range have in their upper portions the broad U-shaped cross sections characteristic of glaciated valleys. One of these, Empire Gulch, which is south of the Leadville mining district, is shown in Plate 5, *A*. There are also a few unglaciated gulches of V-shaped cross section, of which California Gulch is an example. (See pl. 6.)

Westward away from the range and beyond the gathering grounds of the glaciers the wide-floored cirques and sharp ridges give way gradually to the narrow valleys and rounded hills characteristic of subaerial erosion. The lower slopes are flanked by morainal ridges deposited along the borders of the glacial valleys. These moraines increase in size toward the west until they become high ridges which form conspicuous features of the topography. Such are the north lateral moraines of Evans and Iowa gulches, which are shown on Plate 7. These ridges, being composed of loose débris, are nowhere precipitous, but their linear form is striking, and they rise in places 300 feet or more above the bottoms of the glacial valleys which they border. They are described more at length in chapter 2 (pp. 13–15).

Still farther west, toward the Arkansas Valley, the hills subside, the moraines terminate, and the surface consists of broad flat-topped mesas or terraces with gentle westerly slope. These terraces are floored with gravel, the outwash from the glaciers that once occupied the valleys of the western slope of the range.

The area represented by the map of the Leadville district (pl. 7) contains parts of each of these three topographic zones. In its eastern part the gulches are U shaped and strongly glaciated; in its middle part they are narrowing and partly flanked by moraines; and its western part shows a beginning of a gently sloping terrace of outwash gravel. On the north is Little Evans Gulch, an intermittent stream course which runs between the north moraine of the Evans Gulch glacier and the bedrock surface of Prospect Hill. South of this moraine is Evans Gulch, which extends westward nearly parallel and close to the northern edge of the area. On the southern border of the area is the north wall of Iowa Gulch. Between these two is a broad divide of undulating character topped by knoll-like hills. It is interrupted by the deep unglaciated, V-shaped California Gulch and by the small east-west depression of Stray Horse Gulch.

Locations in the Leadville district are commonly referred by those familiar with the ground to certain famous "hills," the chief of which are Fryer Hill, Yankee Hill, Little Ellen Hill, Carbonate Hill, Iron Hill, Breece Hill, Rock or Dome Hill, and Printer Boy Hill. Others, such as Canterbury Hill and Long & Derry Hill, are beyond the limits of the Leadville district and are little more than rounded knolls that cap the divides between the several gulches mentioned.

The summit of Fryer Hill is only 40 feet above the bed of Little Stray Horse Gulch. Yankee Hill is relatively well defined, its southwest slope rising 100 to 200 feet above the bed of Stray Horse Gulch and its northern slope rising 340 feet above the bottom of Evans Gulch. Carbonate, Iron, and Breece hills rise successively eastward as elliptical knolls with north-south major axes, capping the broad ridge between Stray Horse and California gulches. They are separated from one another by northward and southward sloping gulches which head in flat saddles, locally called "parks."

Carbonate Hill has a low, rounded summit 2,600 feet long in a north-south direction and about 800 feet wide. It rises steeply 430 feet above the city of Leadville and slopes gradually on the east to the saddle of Graham Park, 60 feet below its summit, which separates it from Iron Hill. On the north it merges with the morainal topography of the Stray Horse Ridge, but on the south it slopes steeply to California Gulch. It may be seen in the distance in Plate 6 on the extreme left.

Iron Hill is very similar to Carbonate Hill in shape and size but slopes even more abruptly to California Gulch. It is separated from Yankee Hill by Stray Horse Gulch and from Breece Hill by the saddle known as Adelaide Park. An idea of the beehive shape of Iron Hill may be gained from Plate 6, which shows likewise the mine dumps, railroad cuts, and roads that extend around its steeper slopes.

Breece Hill (pl. 6) is the name given to the very broad shoulder of Ball Mountain, the highest point in the Leadville district. It lies east of Iron Hill and separates Evans Gulch on the north from California Gulch on the south. Its summit may be considered to be at the flat area around the Ibex No. 5 shaft. On the northeast Breece Hill slopes abruptly to the broad bottom of South Evans Gulch, which once held a lobe of the Evans glacier. On the south it is bordered by the steep slopes of California Gulch and its branches.

Little Ellen Hill is a sharp, well-defined, roughly triangular hill lying northwest of West Dyer Mountain, between the Evans and South Evans cirques. Only its westerly spur is shown on the map of the Leadville district.

The term Rock Hill is applied to that portion of the ridge between Iowa and California gulches lying south of Carbonate and Iron hills. As there is no knoll or eminence to mark the exact position, it must remain a vague term. A knoll that lies farther east on the same ridge is known as Printer Boy Hill.

The extreme vertical range of the topographic features shown on the map of the Leadville district is 3,560 feet. The lowest point is at Bucktown, on the southwest, and the highest at the crest of Ball Mountain, on the east. As the extreme difference in altitude between the Mosquito Range on the east (not shown) and the Arkansas Valley on the west is 4,408 feet, nearly two-thirds of the rise from valley to mountain is included in the general upward slope of the range within the area mapped.

DATUM FOR ALTITUDE

During the first survey of the Leadville district, according to Emmons,[1] the datum point from which the levels of the map of Leadville were reckoned was the threshold of the First National Bank, at the southeast corner of Harrison Avenue and Chestnut Street.

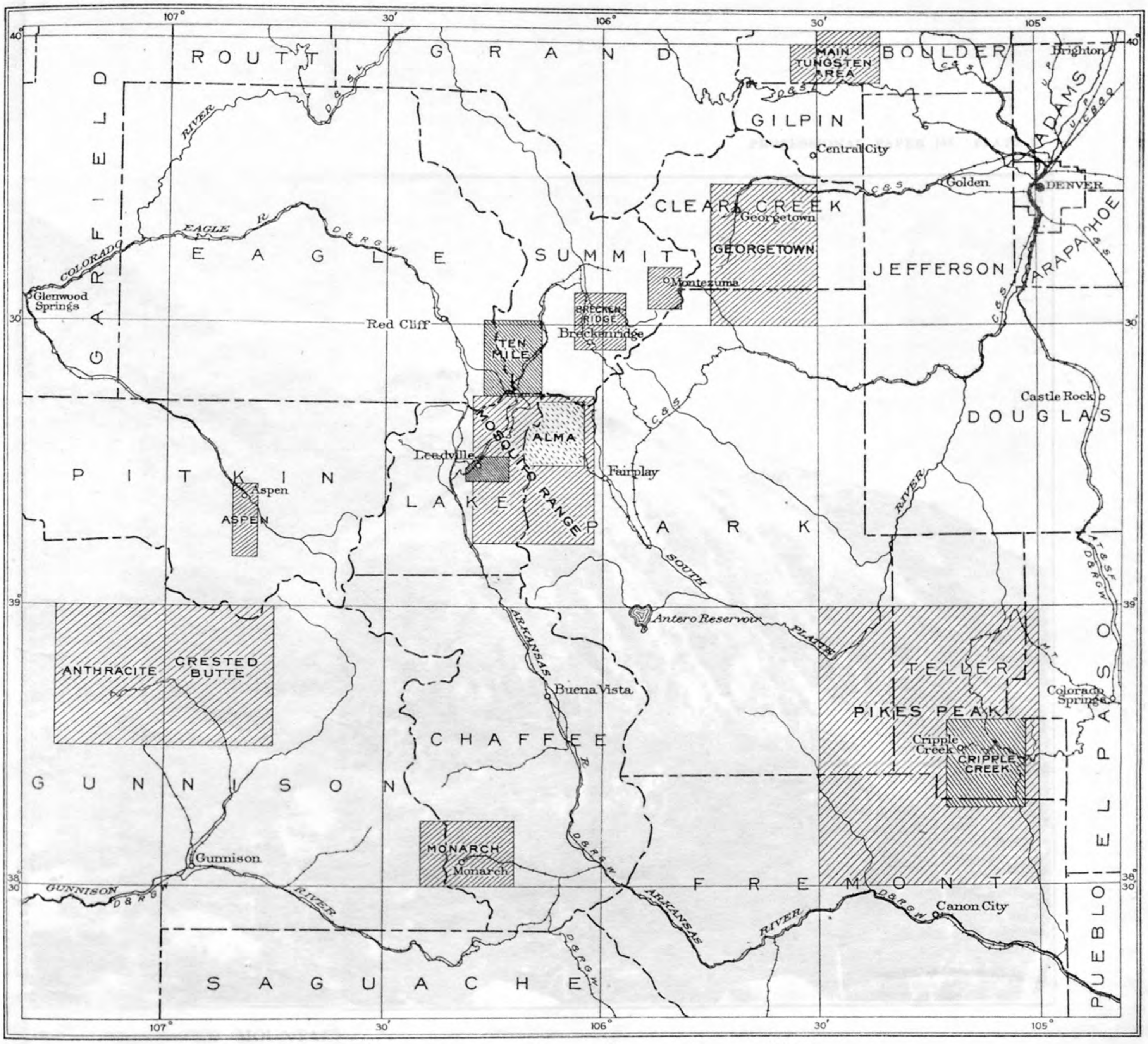
The altitude of this point, as determined by connection by levels with the bench marks of the Denver & Rio Grande Railroad, is 10,135.55 feet; by levels with the bench marks of the Colorado Central Railroad, 10,113 feet; by depression angles from the top of Mount Lincoln, 10,112 feet. As a mean, the contour passing through it is assumed to be 10,125 feet, greater weight being given to the first figure, since the leveling by which it was arrived at was probably more carefully done than in the case of the other two. A level line had been run from Fairplay to the top of Mount Lincoln by the members of the Hayden Survey in 1872.

The survey for the new topographic map (the base of pls. 7 and 13), made in 1911, established two bench marks on Harrison Avenue—one at the southwest corner of the post office with a recorded altitude of 10,153 feet, and the other at the south end of the courthouse, nearly three blocks to the south, with a recorded altitude of 10,141 feet, 9 feet lower than the corresponding contour line on atlas sheet 12 of the Leadville monograph. The datum for these bench marks is mean sea level. According to Platt & Kleff, civil and mining engineers, of Leadville,[2] the altitude of

[1] U. S. Geol. Survey Mon. 12, p. 3 (footnote), 1886.
[2] Letter to G. F. Loughlin, dated Aug. 13, 1921.

the threshold of the First National Bank, referred to the bench mark at the courthouse, is 10,115.285 feet, or 9.715 feet lower than the average assumed by Emmons. As correlation of levels in different mines with one another and with the geology requires constant use of the surveyors' data, recognition of the difference between the old and new datum planes is essential to accuracy.

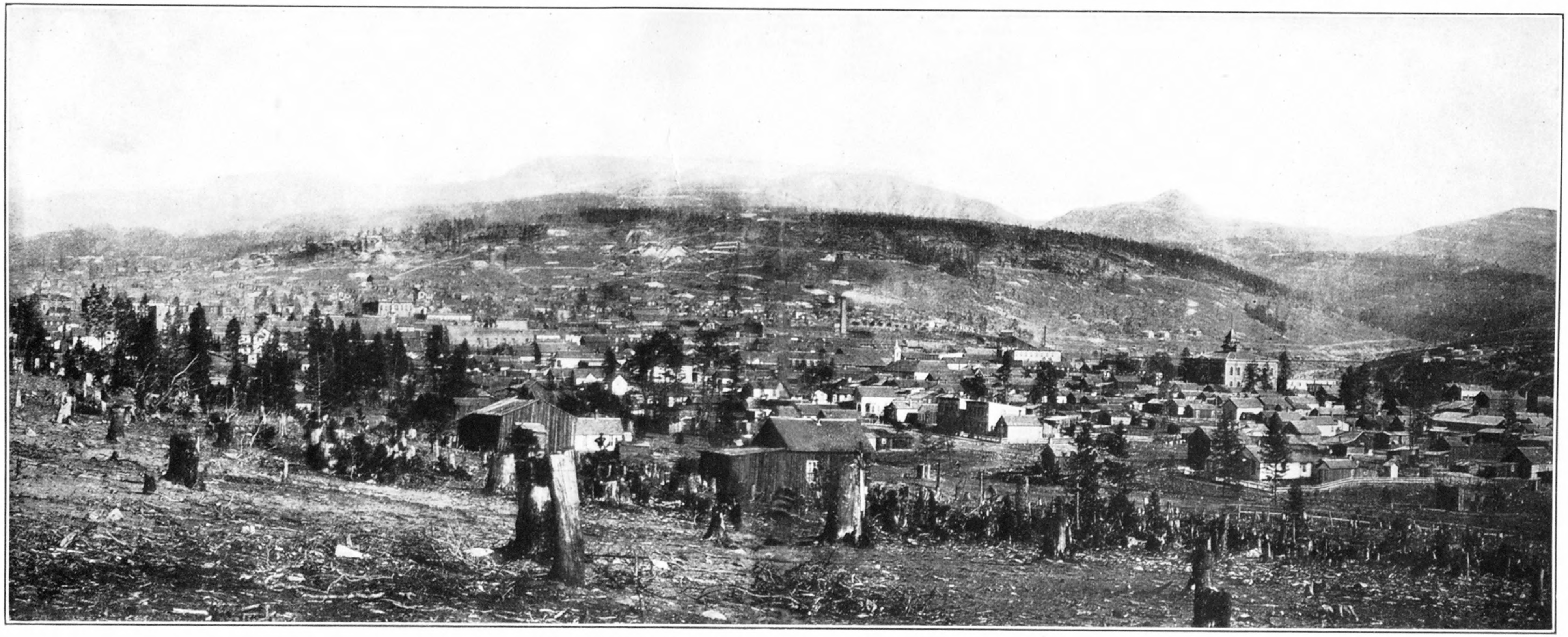
In order to adjust the local mine surveys as exactly as possible to the new topographic map and accompanying sections, photographic copies of field sheets showing the altitude at hundreds of places in the area were supplied by the topographic branch of the United States Geological Survey and were used. Of the larger maps the Downtown map (pl. 18) is figured on the old datum and the Iron Hill map (pl. 22) on the new datum. The Graham Park and Ibex special maps (pls. 19 and 27) have been adjusted irregularly, owing to lack of adequate information, and those who use them should bear this fact in mind.



10 0 10 20 30 40 MILES

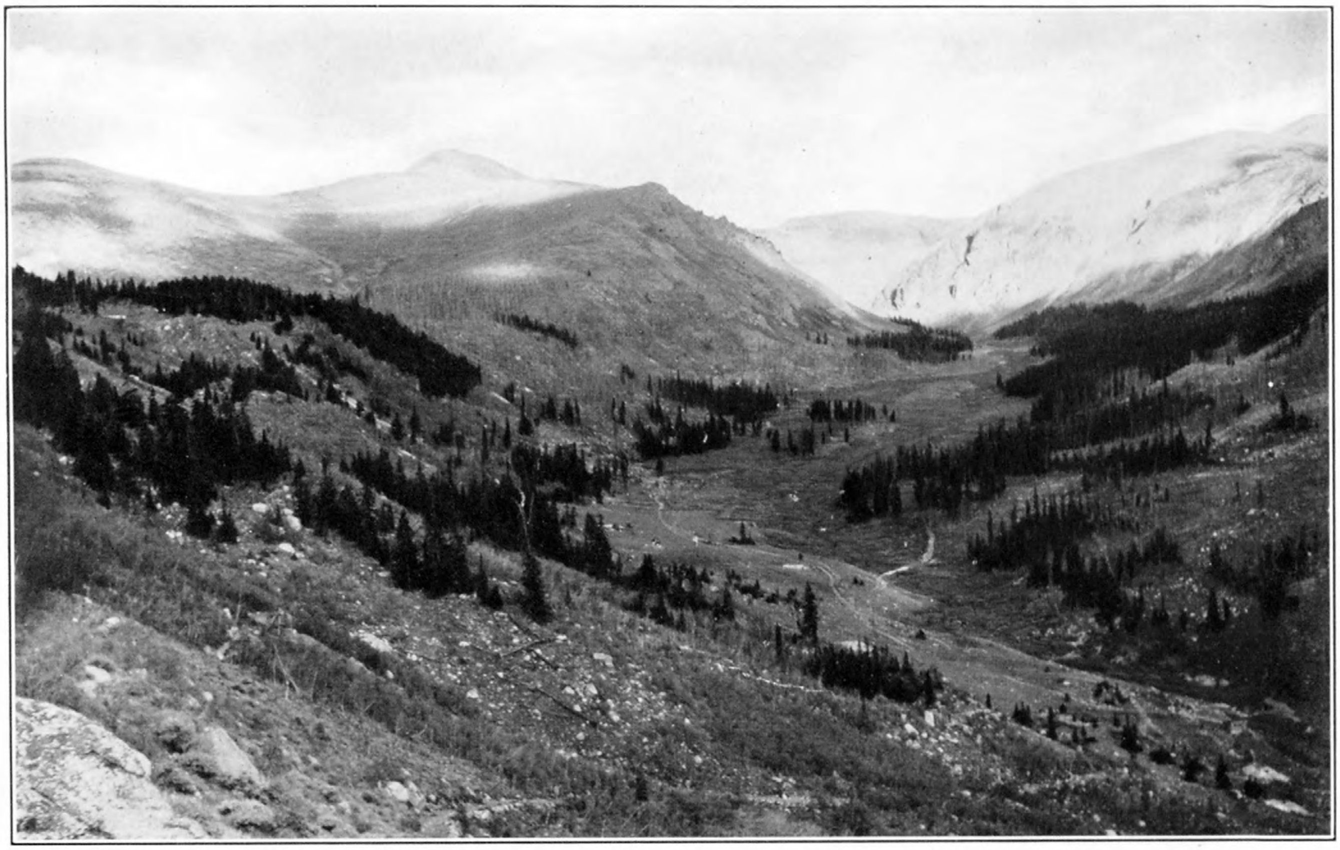
MAP OF CENTRAL COLORADO, SHOWING LOCATION OF LEADVILLE-ALMA-TENMILE REGION AND OTHER IMPORTANT MINING DISTRICTS

PANORAMIC VIEW OF HEAD OF IOWA GULCH, SHOWING GLACIATED MOUNTAINS OF MOSQUITO RANGE, CIRQUES, AND TALUS "GLACIERS"



PANORAMIC VIEW OF LEADVILLE IN 1880, LOOKING EAST

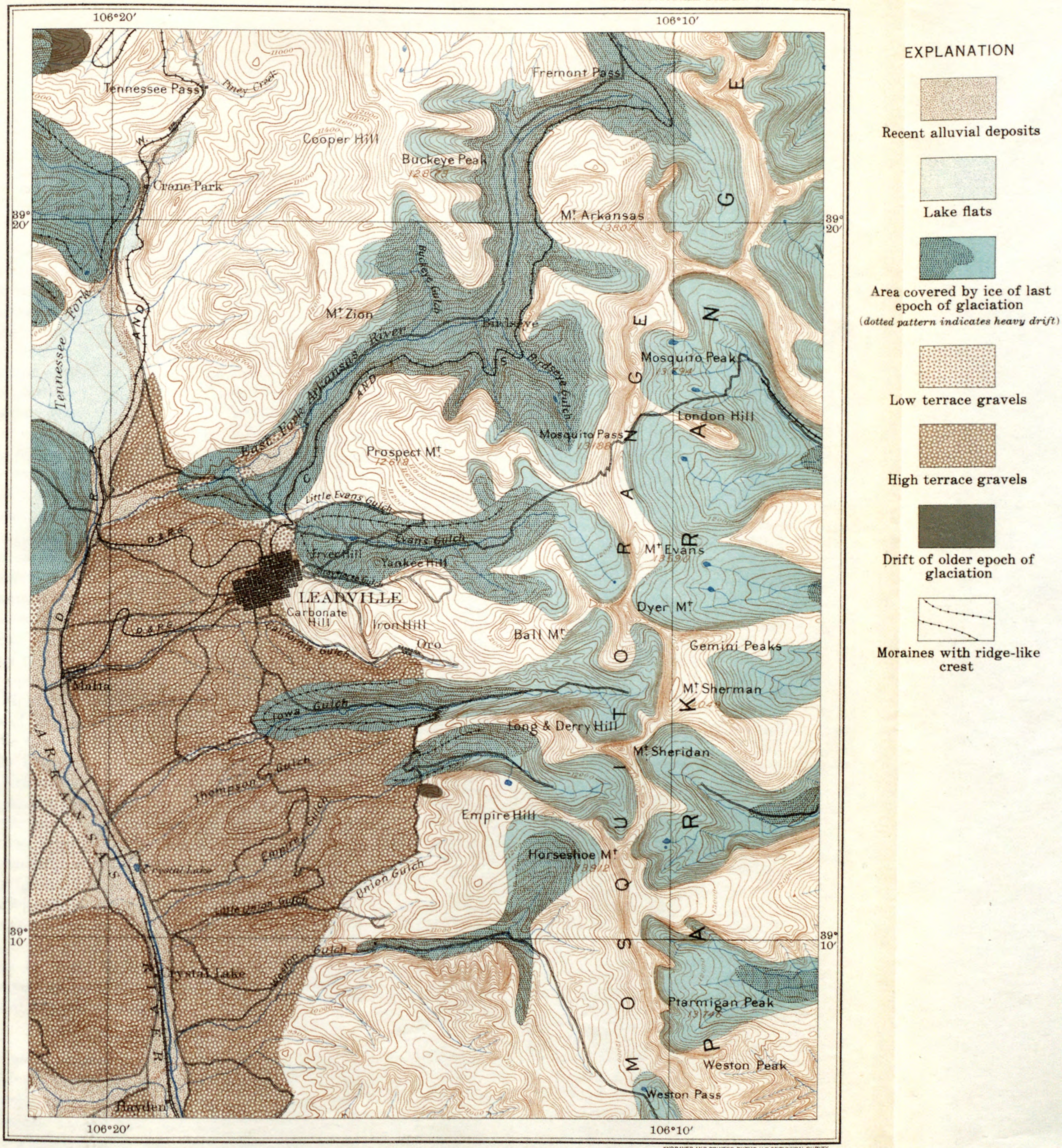
Mosquito Range in background



A. VIEW LOOKING EAST UP EMPIRE GULCH, SHOWING A TYPICAL U-SHAPED VALLEY DUE TO GLACIAL EROSION

B. VIEW UP CALIFORNIA GULCH, SHOWING AN UNGLACIATED V-SHAPED VALLEY CUT IN BEDROCK

PANORAMIC VIEW UP CALIFORNIA GULCH



MAP OF A PORTION OF THE LEADVILLE QUADRANGLE, SHOWING GLACIERS OF LATEST GLACIAL STAGE AND GLACIAL DEPOSITS OF LAST TWO GLACIAL STAGES

Base from U. S. Geological Survey map of Leadville, quadrangle

Scale $\frac{1}{125,000}$

0 1 2 3 4 5 6 Miles

Contour interval 25, 50 and 100 feet.

1927

CHAPTER 2. QUATERNARY GEOLOGY

PLEISTOCENE DEPOSITS

The Pleistocene or glacial deposits (see pl. 7) are of more than passing economic interest, because they form so thick a covering over much of the district that the bedrock surface could be mapped only by the upward projection of boundaries, faults, and other features exposed in mine workings. The need of appreciating this fact in exploration work based on the geologic map is obvious. The character and significance of the glacial deposits have evidently been misunderstood by some who have sunk shafts and driven tunnels in them. In upper Evans Gulch, where glacial erosion has been marked, much oxidized and placer material has been removed and sulphide ores are found comparatively near the surface, but in the western part of the district a great thickness of glacial deposits has accumulated and buried thoroughly oxidized ore bodies to surprising depths. These deposits have also buried old channels, some of which have been unexpectedly found in mining operations, particularly in the Rock Hill area. Displacement of the older of the glacial deposits by renewed movement along faults has affected mining operations slightly in the Downtown area.

The Pleistocene geology of the Leadville quadrangle, an area of about 950 square miles, which includes the Leadville district, has been described in considerable detail by Capps.[1]

The writers have made free use of Capps's report in describing the glacial features of the Leadville district and its surroundings. Some brief quotations are made, but for the most part this chapter must be regarded as a summary of Capps's work, with an elaboration of detail for certain places. No special investigation of the Pleistocene geology of the Leadville quadrangle was made by the writers, the data collected on this subject being obtained incidentally to other work. Evidence for some modification of certain of Capps's conclusions has been derived chiefly from observations conducted in mine workings.

GLACIAL STAGES

The principal events of the Pleistocene history of the Leadville region are glacial erosion and deposition and interglacial erosion and deposition. The Sawatch and Mosquito ranges have certainly been twice subjected to glacial erosion and deposition, and there is evidence of a possible third period of glaciation which preceded these two. Very little, however, can be learned of this earliest stage, as later erosion and glaciation have almost entirely removed or concealed all traces of it. The "lake beds" exposed in mines of the Downtown and Graham Park areas are tentatively correlated with it. In the Leadville monograph, and later in the Downtown bulletin, Emmons stated it as his belief that there had been two stages of glaciation.

The evidence cited for these two stages is the presence of older and younger morainal material or drift. All the boulders in the drift of the earlier stage, except those of quartzite, show evidences of long exposure to weathering and readily crumble when struck with a hammer. The later drift, on the contrary, is generally composed of bluish unoxidized material, and all its boulders, both resistant quartzite and less resistant porphyry, are fresh and sound. The earlier glaciers occupied essentially the same positions as those of the late stage—the valleys or gulches formed by previous stream erosion—and extended from the gathering grounds near the crests of the Mosquito and Sawatch ranges down into the broad valleys of Arkansas, South Platte, and Blue rivers. The older drift, therefore, is almost completely covered by the later moraines where it was not removed by erosion in the interglacial stage. In some places the earlier drift appears beside the newer covering and affords definite evidence of difference in age; in others it is exposed immediately beneath the later drift, and there the contrast between the two is very marked. Capps mentions no traces of the older drift in the Leadville district, although he indicates one area of it 2 miles to the south, on the southern slope of Empire Gulch. (See pl. 8.)

INTERGLACIAL STAGE

There was a very long interglacial stage. Capps believes that the time which elapsed between the two stages of glaciation was very much longer than that which has occurred since the last stage. There is abundant evidence to support this belief in the Leadville district. During this interglacial stage deep decomposition of rock surface and extensive oxidation of morainal deposits took place. Though oxidizing climatic conditions prevailed during this long interglacial stage, little oxidation of ore bodies took place, as the oxidation of ore bodies had been largely completed before any glaciation occurred, and the ores were protected from subsequent oxidation by a rise in the water level. (See chapter 12, pp. 249–256.)

[1] Capps, S. R., jr., Pleistocene geology of the Leadville quadrangle, Colo.: U. S. Geol. Survey Bull. 386, 1909. This report was preceded by a short paper (Jour. Geology, vol. 12, pp. 698–706, 1904).

GLACIERS OF THE LAST STAGE

All the larger valleys of the Mosquito and Sawatch ranges were occupied by glaciers of the last stage of glaciation, and probably also by those of the earlier stage. These glaciers are indicated on Plate 8.

Five glaciers of the west slope of the Mosquito Range lay within the immediate vicinity of Leadville. These are listed below in geographic order from north to south; the figures indicating length and area are taken from Capps.

Glaciers on west slope of Mosquito Range

	Length (miles)	Area (square miles)	Range of altitude (feet)
East Arkansas glacier	15	20	13,000–9,900
Evans Gulch glacier	6	6	13,000–10,300
Iowa Gulch glacier	7	6	13,300–9,900
Empire Gulch glacier	4	3	13,200–10,100
Weston Gulch glacier	4	4	13,100–9,000

All except the East Arkansas glacier were much smaller and shorter than those on the east slopes of the Mosquito and Sawatch ranges. The Evans Gulch glacier is the only one whose larger portion was included within the Leadville district. Two others, the East Arkansas glacier, near the northwest corner of the district, and the Iowa Gulch glacier, along the extreme southern border, encroached slightly on the district. Only the Iowa Gulch and Evans Gulch glaciers are described here.

IOWA GULCH GLACIER

The main features of the Iowa Gulch glacier are described by Capps, from whom the following paragraphs are quoted, [2] but certain additional interesting features that occur along the north edge of the gulch are described on page 15.

Iowa Gulch contained a glacier more than 7 miles long, which extended down to an altitude of 9,850 feet. The head of this gulch is roughly divided into three cirques, which received the ice from the west slopes of Dyer Mountain, Mount Sheridan, and the Gemini Peaks. The head southwest of Dyer Mountain has its walls in the Paleozoic beds, but the valley bottom is in the pre-Cambrian rocks. The valley has a well-developed U shape, and the bottom is fairly free from talus, except at the base of the steep walls. The ice in this cirque extended almost to the col at the valley head.

The head southeast of Dyer Mountain is in the crystalline rocks and is deeply eroded, though not of a very broad U shape. The bedrock is exposed over much of the valley floor, but it is concealed by talus at the foot of the cliffs.

The south head is only a slight reentrant into the south valley wall. The entire south wall of the valley, above the lateral-moraine deposits, is composed of fractured and broken outcrops of rock above and of deep talus below, so that the limit to which the ice reached could be determined only approximately

The south lateral moraine begins about 3 miles above the terminus and at its upper end takes on a ridge form above the high terrace gravels which form the walls of the valley at this place.

On the north side of the valley the drift first appears as a covering of the rock wall but becomes thicker to the west and locally shows a ridge form. A little below the 10,000-foot level the laterals converge to form a terminal moraine, consisting of a large body of drift lying across the valley, which is here cut into the high terraces. To avoid the highest part of this moraine the stream makes a bend to the south and flows around the obstruction. This drift has a strong, irregular topography, and at its highest point it stands about 100 feet above the stream to the south of it.

[2] U. S. Geol. Survey Bull. 386, pp. 92–93, 1909.

EVANS GULCH GLACIER

The description of the Evans Gulch glacier given by Capps [3] is quoted below in part:

Evans Gulch was occupied by a glacier from its head down to Leadville, a distance of 6½ miles. Two large cirques and one small one contributed ice to this glacier, which had a total area of 6½ square miles.

The head of this system took its ice from the slopes of Mount Evans and Dyer Mountain. This cirque is large and broadly U-shaped and is cut down into the pre-Cambrian gneiss. At its upper end the east wall of this valley rises in an almost perpendicular cliff below Dyer Mountain. Between Dyer Mountain and Mount Evans the divide shows serrate peaks where the Sacramento and Evans glaciers have worked their head walls back to the crest of the ridge. The lower and more gentle slopes of the cirque walls are deeply buried in talus.

For the upper 2 miles of its course Evans Creek flows to the northwest; then it turns sharply to the southwest. North of this bend there is a small valley running back to the north which was occupied by ice, but the erosion in it was never strong enough to excavate it into a cirque.

South Evans Gulch had an ice lobe of some size, but the ice here was never very deep or of very great erosive power. Some drift covers the lower valley floor, and the talus-covered slopes above the ice limit are in contrast with the steeper glaciated slopes below.

The area occupied by the part of this ice sheet which lay within the Leadville district, as indicated by the limits of glacial drift, is shown on Plate 7. The ice in all stages of glaciation undoubtedly covered Yankee Hill. Its depth in the main valley during the third stage is shown by sections H–H′ to O–O′, Figure 1. Near the lakes north of Little Ellen it exceeded 500 feet. From that point down the valley it decreased slightly in thickness, but opposite Yankee Hill it was perhaps 400 feet thick. The ice over the top of Yankee Hill was very thin, so that the main mass of the glacier was divided into a northern thick portion and a southern thin portion, as is shown by the distribution of morainal material (section M–M′, fig. 8).

EFFECTS OF GLACIATION ON TOPOGRAPHY

It is certain that the large features of the topography of the Leadville district and the adjacent territory included in the Leadville quadrangle were established in preglacial time, but they were considerably modified by glacial erosion and deposition. This has been well shown by Capps in the cross section here reproduced as Figure 2, which depicts the development of knife-edge divides between cirques at the heads of the valley of the East Fork of the Arkansas and Mosquito Gulch from a less sharply accentuated topography.

Of the two forms of glacial action, erosion has dominated in the uplands and deposition in the lowlands. Glacial erosion has produced the most striking features of the topography of the Mosquito Range, and its effects are seen in the gulches that extend down toward

[3] Idem, p. 95.

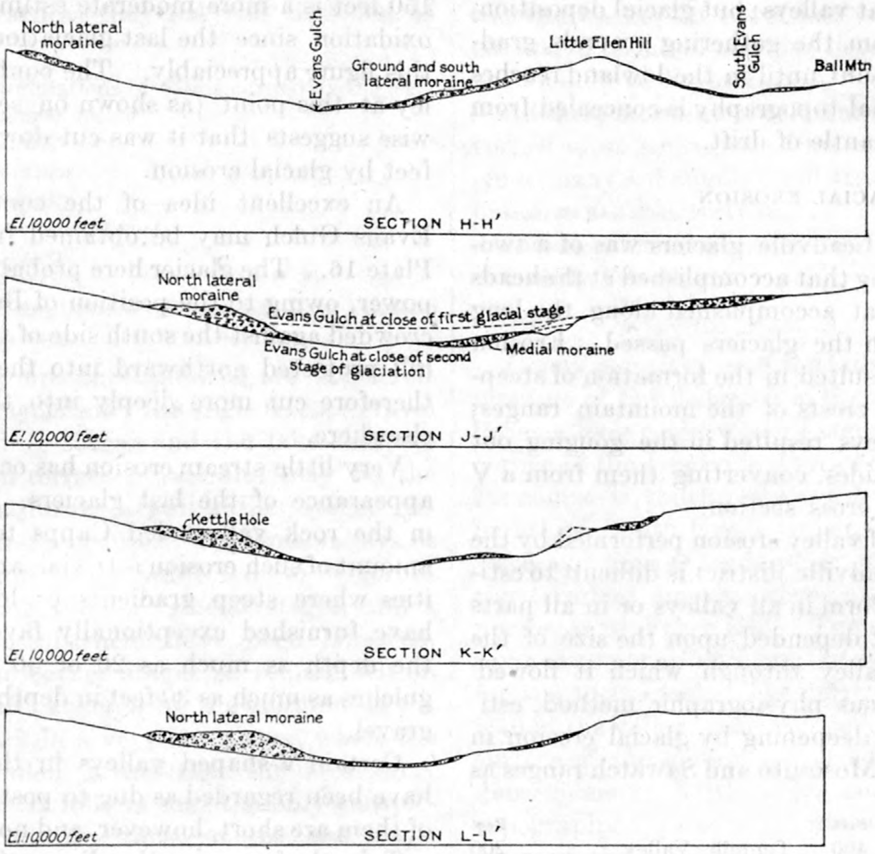


FIGURE 1.—North-south sections across Evans Gulch, showing position and character of lateral and terminal moraines and shape of valley. Vertical lines in section N-N' indicate shafts from which data were obtained

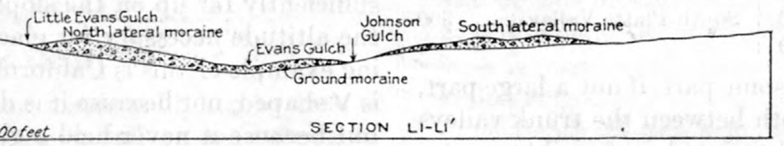


FIGURE 2.—Diagrammatic cross section of divide between head of East Fork of the Arkansas and Mosquito Gulch. *c, a, b*, The divide at the present time. On either side of *a* peaks rise to 13,700 feet, or to point *d*. *d, a*, Probable amount which this divide was lowered by glacial erosion; *g, d, g'*, probable preglacial cross section of this divide; *f, e, e', f'*, an intermediate stage in the glacial lowering of the divide; *h', h, h'*, height to which the last glacier filled the present valleys. Horizontal scale, 1 inch = 1 mile; vertical scale, 1 inch = one-half mile. (After S. R. Capps, U. S. Geol. Survey Bull. 386, fig. 10.)

the bottoms of the great valleys; but glacial deposition, beginning not far from the gathering grounds, gradually increased in amount until in the lowland reaches nearly all of the original topography is concealed from view under a heavy mantle of drift.

GLACIAL EROSION

The erosion by the Leadville glaciers was of a twofold character, including that accomplished at the heads of the glaciers and that accomplished along the long valleys through which the glaciers passed. Erosion at the glacier heads resulted in the formation of steep-walled cirques at the crests of the mountain ranges; erosion along the valleys resulted in the gouging out of their bottoms and sides, converting them from a V shape to a U shape in cross section.

The exact amount of valley erosion performed by the glaciers within the Leadville district is difficult to estimate. It was not uniform in all valleys or in all parts of the same valley but depended upon the size of the glacier and of the valley through which it flowed Capps,[4] by an ingenious physiographic method, estimated the amount of deepening by glacial erosion in certain valleys of the Mosquito and Sawatch ranges as follows:

	Feet		Feet
Homestake Valley	400	Tenmile Valley	200
Lake Creek Valley	800	South Platte Valley	300
Empire Gulch Valley	400		

It seems probable that some part, if not a large part, of the discordance in depth between the trunk valleys and hanging tributary valleys is to be referred to greater deepening on the former by interglacial stream erosion than on the latter. The valleys were also widened by glacial erosion, so that in many valleys the quantity of material removed was very great.

The Evans Gulch and Iowa Gulch glaciers, within the Leadville district, are believed by Capps to have eroded less deeply than those in the valleys above listed. There are no tributary hanging preglacial valleys whose height above the glaciated floors of the main valleys affords an estimate of the amount of glacial erosion, but some light is thrown on the problem by a consideration of the depths of oxidation of the sulphide ores. At the foot of the quartzite escarpment that forms the south wall of South Evans Gulch above the St. Louis mine unoxidized sulphides have been found in the Little Bob, Louise, and Gold Basin shafts at depths as slight as 40 feet from the bedrock surface, and the average for these shafts (about 200 feet) is less than one-half of the usual depth (450 to 500 feet) in the Leadville district. Comparison of these figures suggests that as much as 250 to 300 feet of oxidized material may have been removed by glacial erosion; but, as oxidation may not have proceeded so rapidly in South Evans Gulch as to the south and west, 150 feet is a more moderate estimate. Allowance for oxidation since the last glaciation would not reduce this figure appreciably. The configuration of the valley at this point (as shown on section 2, fig. 1) likewise suggests that it was cut down about 100 to 150 feet by glacial erosion.

An excellent idea of the configuration of South Evans Gulch may be obtained from section J–J′, of Plate 16. The glacier here probably had great erosive power, owing to the position of Breece Hill. The ice crowded against the south side of the valley, where the hill projected northward into the glacier's path, and therefore cut more deeply into the south wall than elsewhere.

Very little stream erosion has occurred since the disappearance of the last glaciers. Many observations in the rock valleys led Capps to conclude that the amount of such erosion is trivial, and that only in localities where steep gradients or looseness of material have furnished exceptionally favorable conditions is the depth as much as 20 or 30 feet. For example, gulches as much as 30 feet in depth cut the high terrace gravel.

Certain V-shaped valleys in the Leadville district have been regarded as due to postglacial erosion. All of them are short, however, and none of them extended sufficiently far up on the slopes of the range to reach the altitude necessary for glacier formation. A striking example of this is California Gulch (pl. 5, *B*), which is V shaped, not because it is due to postglacial erosion but because it never held a glacier. It is highly probable that there was a minor preglacial valley in bedrock along its course, but the present gulch was cut along the boundary between high terrace gravel and the bedrock of Iron and Carbonate hills. The relations of the depth of erosion to the level of oxidation indicate that much of the cutting was accomplished during the last stage of glaciation. The sulphide ores in California Gulch opposite Iron Hill have been found only 125 feet under the surface, and this relatively slight depth of oxidation appears to indicate that the erosion was accomplished more recently than the interglacial stage prior to last stage of glaciation.

GLACIAL DEPOSITION

Under the head of glacial deposits are included (1) those which have been formed by the accumulation of drift or rock material carried by the ice and deposited along the sides, at the bottoms, and at the lower ends of the glaciers; (2) the outwash material that has been carried down into the Arkansas Valley by water from the melting ice; and (3) accumulations of water-laid clay and sand which may have been formed in glacial lakes but whose origin is obscure. All these classes of material are present in the Leadville district and form conspicuous features of the geology and topography. Their distribution is shown on Plate 7.

[4] U. S. Geol. Survey Bull. 386, pp. 11-12, 1909.

For the sake of clearness they may be classified as follows:

Moraines, or accumulations of débris carried by the ice:
- Lateral moraines.
- Medial moraines.
- Terminal moraines.
- Ground moraines.

Glacial outwash deposits:
- Low terrace gravel.
- High terrace gravel.

"Lake beds" of doubtful origin and age (late Pliocene or early Pleistocene).

Of these seven groups the first five are the result of the last stage of glaciation; the high terrace gravel is due to the preceding stage; and the lake beds are overlain by the high terrace gravel and may be the result of deposition during a still earlier stage. As the glaciers of all stages occupied the same valleys or gulches their deposits were subjected to vigorous stream erosion during the interglacial stages, and a considerable portion of them have been removed. Such deposits of the earlier stages as remain within the gulches are usually covered by the moraines of the latest stage, and only in a very few places, where the earlier glaciers extended farther than the latest, may they be recognized. It follows that the only conspicuous morainal deposits are those of the last stage. They will therefore be described first.

MORAINES

Blocks of rock and finer material broken by frost or removed by marginal erosion fall or are carried by water on to the upper surface of glaciers. Much of this débris accumulates along the sides of the glaciers, forming ridges or lateral moraines, which remain along the sides of the valleys after the ice has melted. Where two branches of a glacier unite, their adjacent lateral moraines coalesce, forming a medial moraine on the main glacier. Fragments are also plucked from the floor of the valley by the overriding ice and carried or pushed along. Where the erosive power of the moving ice is sufficient the removal of this material leaves a bare rock floor; but where it is less, especially in the lower course of the glacier, the débris is dropped and overridden by the ice, forming a thin irregular deposit—a ground moraine—over the bedrock. The larger part of the débris, however, is moved to the lower end of the glacier, where it accumulates as the ice melts, forming irregular heaps of unassorted material, called the terminal moraine.

Four lateral moraines or portions of them appear within the Leadville district. These are the south lateral moraine of the East Arkansas glacier, the north and south moraines of the Evans Gulch glacier, and the north moraine of the Iowa Gulch glacier. There is one medial moraine, on the west spur of Little Ellen Hill, where the tributary glacier of South Evans Gulch joined the main glacier of Evans Gulch. A ground moraine covers the lower half of Evans Gulch, and an extensive terminal moraine lies across Evans Gulch in the vicinity of Fryer Hill. (See pl. 7.)

All these moraines are similar in composition. They consist of an aggregate of material of all sizes and include many subangular and striated boulders. Large boulders are relatively uncommon, though they appear in considerable numbers in some places. Fine material is usually abundant.

MORAINES OF EVANS GULCH GLACIER

Lateral moraines.—Of the lateral moraines the north moraine of Evans Gulch is the most conspicuous. It forms a long ridge which extends from the northeast corner of the Leadville district for more than 3 miles. Its course is southwestward to a point opposite the mouth of South Evans Gulch, where it bulges southward and then extends westward until it merges with the terminal moraine three-quarters of a mile north-northeast of Fryer Hill. The south slope of this moraine rises abruptly from the bottom of Evans Gulch for 100 to 300 feet. The north slope, toward the rock wall of the valley, is neither so high nor so steep. The surface of the moraine is pitted with many irregular depressions or kettle holes and has the hummocky topography typical of moraines. At its east end the crest of the moraine is single and relatively sharp; but it broadens westward, becomes lower, and in some places is made up of a series of irregular but generally parallel ridges.

The depth of the morainal material, as estimated with considerable accuracy by projecting the rock slope of Prospect Hill to the bottom of Evans Gulch, ranges from 120 to 225 feet. Relatively few shafts penetrate the moraine and enter bedrock, as there is comparatively little to encourage extensive exploration along its course. So far as known only two shafts, the Abe Lincoln and Little Hoosier, have been sunk through its thickest portions. In the Little Hoosier shaft the moraine was 120 feet thick. Many tunnels have been driven into it for considerable distances without encountering bedrock, apparently with no clear knowledge as to its morainal nature.

Little Evans Gulch owes its existence entirely to this moraine, marking the boundary between the moraine on the south and the bedrock surface of Prospect Mountain on the north. Near the lower end of the gulch the stream has cut 30 feet into the bedrock in one place where the moraine has forced it northward against the valley wall.

The lateral moraine on the south side of Evans Gulch is much less pronounced, because the relatively steep slope of Breece Hill did not afford a secure resting place for loose material and possibly also because of a smaller local supply of rock fragments. Farther west the moraine, though devoid of a ridgelike crest, shows distinctly on the hill slope north of the President and

Ballard mines. Still farther west it makes a distinct ridge just north of Adelaide Park and has partly blocked the drainage of Stray Horse Gulch, causing the development of the swampy area southeast of the Dolomite shaft. Between Adelaide Park and Yankee Hill the morainal topography is pronounced, and there are many kettle holes, some of them filled with water. Near the east edge of the Leadville district the Evans Gulch glacier was separated from the lobe that occupied the valley of South Evans Gulch by the wedgelike spur of Little Ellen Hill. On the north side of Little Ellen Hill there is lateral-moraine material 20 to 30 feet thick at the Resurrection shaft No. 1 and 60 feet thick at the Fortune and Sedalia shafts; but no prominent crests are developed, as on the moraines farther west. Some morainal material lies on the south side of the hill, but it is insignificant in amount, as the South Evans lobe was too small to build much of a lateral moraine. The crest of Little Ellen Hill is free from drift.

The two lobes united about 200 feet west of the place where there is now a snowshed of the Denver & Rio Grande Western Railroad, and thence northwestward for 2,400 feet the bedrock divide is deeply buried by the medial moraine that was thus built. In the vicinity of the Silent Friend shaft and east of the New Monarch and Winnie shafts the morainal topography is very pronounced. Just west of the Silent Friend a large kettle hole indicates a considerable depth of morainal material. All the shafts sunk on this spur penetrate this moraine, and they show that it has a depth ranging from 20 to nearly 100 feet. Most of the morainal débris probably came from the main Evans Gulch glacier, as the gathering grounds for the South Evans lobe were so much less extensive.

The lateral moraines of Evans Gulch are shown in cross sections H–H′ to M–M′ of Figure 1.

Terminal moraine.—The terminal moraine of the Evans Gulch glacier occupies a broad area whose eastern boundary lies approximately along a north-south line through the Pawnolos shaft and whose western boundary makes a convex curve, with its most westerly point in about the position of Whale shaft. Its northern limit is just north of the Leadville district, and its southern limit is in the neighborhood of the Robert Emmet shaft, in Stray Horse Gulch. The exact limits of the moraine can not be determined with certainty, for the material overlies the high terrace gravel in its western stretches, and the two gravel deposits can not everywhere be readily distinguished. On the northeast and southeast it merges imperceptibly into the two lateral moraines, and in the center it merges into ground moraine on Yankee Hill, so that its eastern limits are purely arbitrary.

The bedrock of Stray Horse Ridge, Little Stray Horse Gulch, Fairview, Fryer, and East Fryer hills, and the area thence northward to Little Evans Gulch is deeply buried beneath this moraine, which from its hummocky surface and the prevalence of boulders may be readily identified over a considerable portion of its area. Sections LI–LI′, N–N′ and O–O′ of Figure 1 and sections M–M′, N–N′, and O–O′ of Plate 17 show the depth of the drift, the location of many shafts that penetrate it, and the configuration of the underlying rock surface. Along the line of section M–M′ the two lateral moraines have nearly converged and left only a small area at the north base of Yankee Hill uncovered.

Yankee Hill itself, although covered by morainal material on its south and lower west slopes, consists for the most part of bedrock. It was so prominent a topographic feature, directly in the path of the glacier, that it has been subjected more to ice erosion than to deposition. Some of the lower portion of the material mapped as drift just west of the hill (fig. 1, section N–N′) may belong to the high terrace gravel, for the two can not be readily differentiated and the gravel may really extend farther east than is indicated. At the right (south) end of section N–N′ the upper material represented is believed to be entirely high terrace gravel, as it bears the usual relation to the underlying "lake beds." This matter is further discussed on page 18. Along the line of section O–O′, Figure 1, the drift is very thin, as it is near the western limit of the terminal moraine.

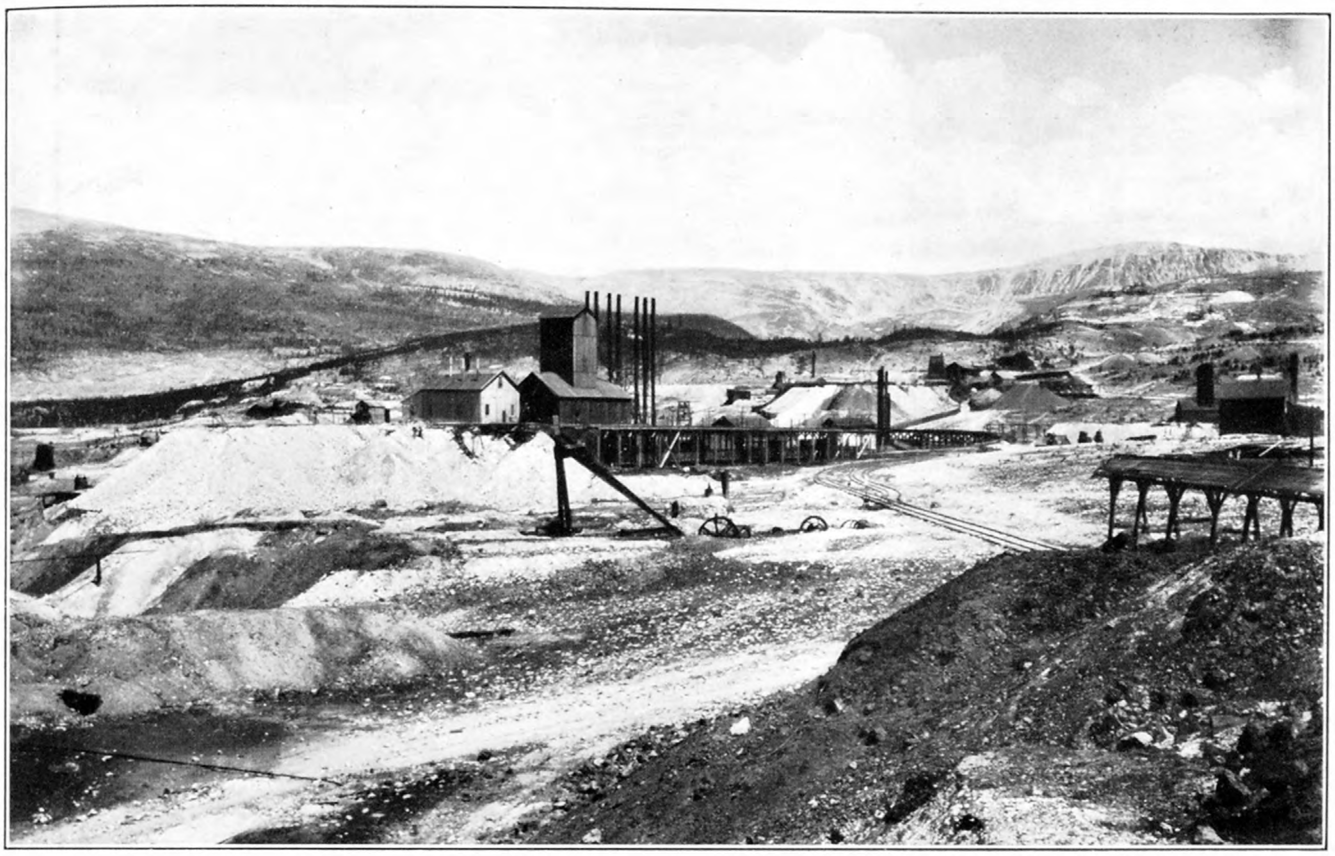
The drainage of Evans Gulch, which formerly passed to the south of Fairview Hill, was considerably displaced by the deposition of the terminal moraine. As the interpretation of the former drainage involves a consideration of recent faulting, however, further discussion of the subject is deferred to the detailed descriptions of local areas or fault blocks (p. 98).

Ground moraines.—As the Evans Gulch glacier melted, the material that lay on its surface was let down in a thin sheet along the bottom of the valley, where it was added to such rock material as had been plucked from the bottom and dragged along beneath or in the bottom of the ice as a ground moraine. The two classes of material are not readily distinguishable and are together included under the term ground moraine.

Erratic boulders, which occur in such areas as that near the White Cloud shaft, where the granite has been bared by glacial erosion, are to be classed as ground moraine. Drift of this kind is illustrated in Plates 9, *B*, and 10, *A*.

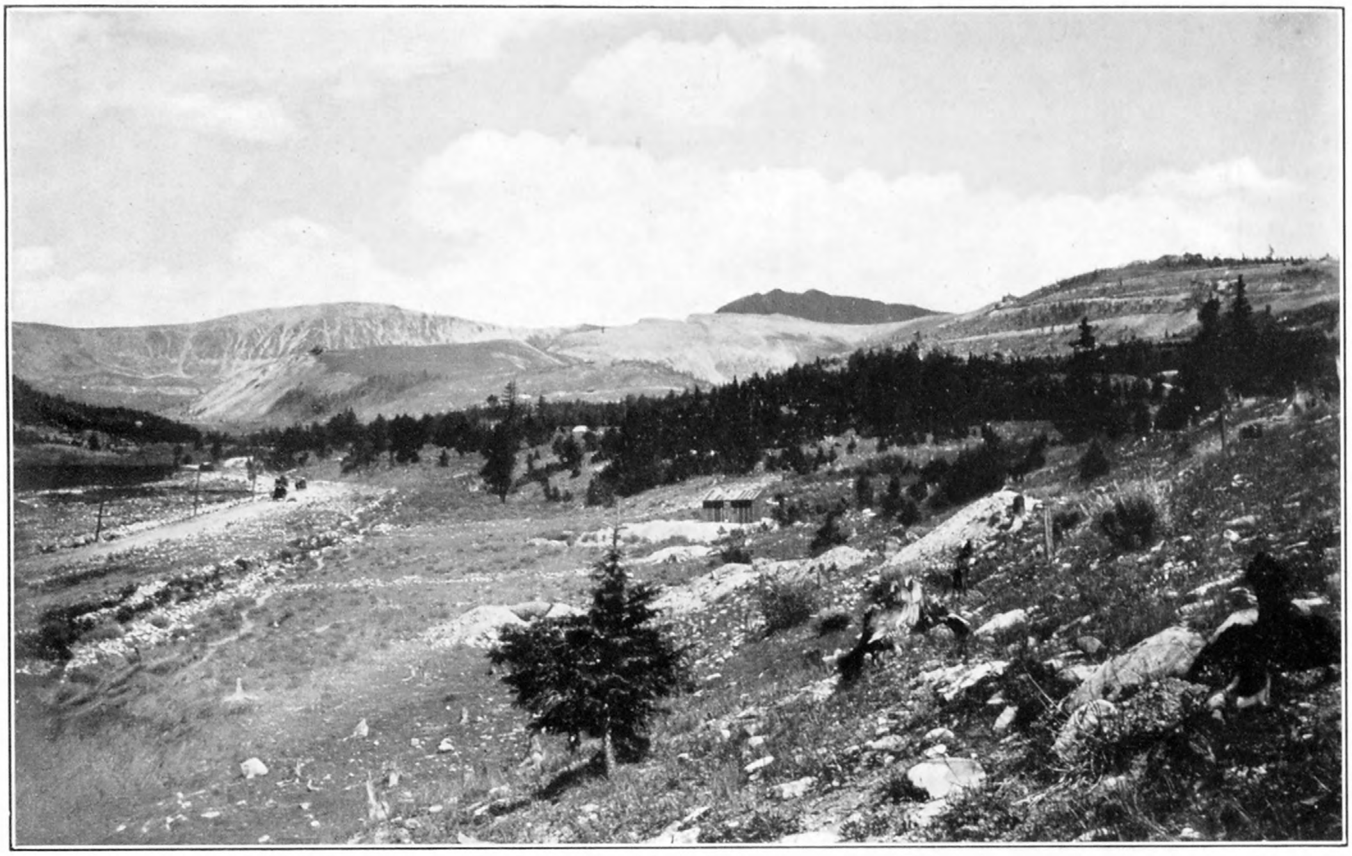
SOUTH LATERAL MORAINE OF EAST ARKANSAS GLACIER

The full extent of the south lateral moraine of the East Fork of the Arkansas was indicated by Capps (see pl. 8), only a small portion of it lying within the northwest corner of the Leadville district. Owing to the great length of the East Arkansas glacier, this moraine is larger and extends farther west into the Arkansas Valley than the moraines of Evans Gulch and has been built upon the underlying high terrace gravel for some



A. SURFACE PLANT OF WOLFTONE MINE, NORTH END OF CARBONATE HILL, LOOKING NORTHEAST

B. VIEW UP EVANS GULCH, SHOWING DITCH IN GROUND MORAINE



A. VIEW UP EVANS GULCH, SHOWING THIN GLACIATED MATERIAL ON NORTH SLOPE OF YANKEE HILL (IN LOWER RIGHT CORNER)

B. TALUS AT HEAD OF EVANS AMPHITHEATER distance beyond the west edge of the Leadville district. The portion shown on the map forms a prominent ridge, sometimes called James Ridge, which has been severed into two portions by the main stream of Evans Gulch. The broad incision made by this stream is about 75 to 100 feet in depth.

NORTH LATERAL MORAINE OF IOWA GULCH GLACIER

The only other lateral moraine within the Leadville district is that along the north wall of Iowa Gulch. This moraine, though less conspicuous than that on the south wall, is prominent along the southern boundary of the area mapped, where it has been built up on the high terrace gravel. Its lower or western extremity is near the head of Pawnee Gulch. Thence the moraine extends eastward for 1¾ miles, forming the south wall of Georgia Gulch. East of this point it is poorly developed, because the steep south slope of Printer Boy Hill did not afford a secure resting place for drift; but enough of the material has been left on the slope to mark its position, and where the top of the ice rose above the crest of the divide morainal matter spilled over into California Gulch. This is very strikingly shown in the saddle between Printer Boy Hill and Green Mountain, where not only is there a little sharp-crested moraine crossing the saddle, but also a V-shaped mass of débris that has been poured through the saddle down the south slope of California Gulch. This mass is marked by a perfect little kettle hole almost on the top of the saddle. This morainal material is not to be confused with the talus and slide rock found at the head of California Gulch. (See pl. 7.)

GLACIO-FLUVIATILE DEPOSITS

HIGH TERRACE GRAVEL

The east side of the Arkansas Valley is fringed by a series of low, flat-topped spurs, which represent a series of high terraces, formerly continuous but now dissected by gulches. When these spurs are viewed from a distance in a north-south direction their tops are seen to be at so uniform a level that the gulches are hardly perceptible. The western part of the Leadville district is occupied by the uppermost parts of some of these terraces. Their eastern margins, which rest on bedrock, are shown on Plate 7 by a different pattern from the remainder, which overlie "lake beds." The city of Leadville is near the upper limits of this terrace area.

There is no question that these deposits of high terrace gravel are the result of outwash from the glaciers of an earlier stage of glaciation. The difference of opinion between Emmons and Capps in regard to their origin has resulted in part at least from a confusion of the gravel with the so-called "lake beds," which are shown on pages 17–20 to be a distinct and separate formation.

Capps's description[5] of the general character, age, and origin of these terraces follows:

A striking topographic feature of this region is the great number of high terraces in the Arkansas Valley. These are seen at their best on the east side of the river, between East Fork [of] Arkansas River and Weston Gulch (fig. 3), but they extend both north and south of these limits, as well as to the base of the Sawatch Mountains.

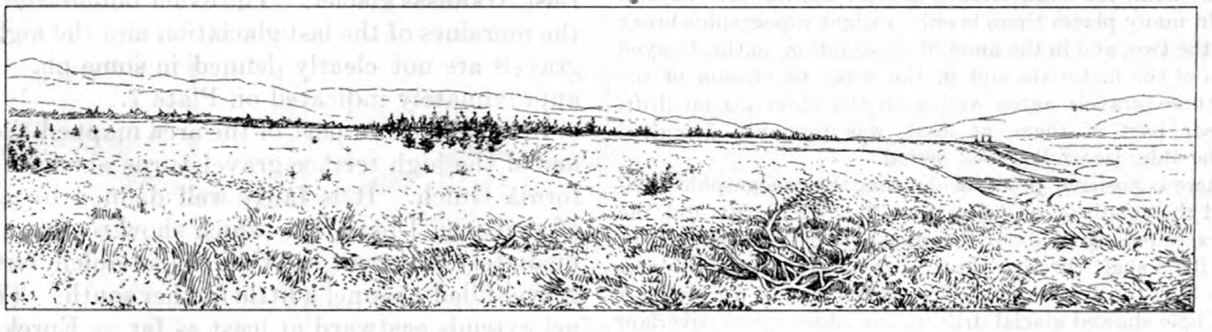


FIGURE 3.—High terraces south of Leadville

Considered as a unit, it appears that these terraces, although now cut into by Arkansas River and its tributaries, are the remnants of two great, gently inclined piedmont plains, which extended continuously along the base of the two great mountain ranges and sloped down to join at the valley bottom. Arkansas River had its course at the junction of the two slopes.

Between the gulches in the terraces there are uneroded, flat-topped ridges, or mesas, which show the original slope of the plain away from the mountains. This slope ranges from 3½° at the mountain base to 1½° at the river edge. Along Arkansas River the flat tops of the terraces slope down the valley toward the south, parallel to the base of the mountains, at a rate of a little more than 1°. There are local variations in this slope, however, which are seen best at the mouths of the gulches from which the gravels came. Here the slope is not that of an inclined plain, but of a flat fan, the apex being at the mouth of the gulch, from which the surface declines toward the periphery of the fan.

The materials that form the high terraces can be seen in numerous cuts and prospect holes, and they have a characteristic appearance wherever exposed. They consist of imperfectly stratified gravels, with an occasional lens of sand. The gravels are uniformly coarser toward the mountains and finer toward the river; but even in the axis of the valley the pebbles composing them average several inches in diameter, and the deposits include no laminated clays such as are laid down in bodies of standing water. In Little Union Gulch, near Arkansas River, the gravels have been cemented into a loose conglomerate by calcium carbonate.

[5] Op. cit., pp. 15–18.

The surface configuration, the topographic relations, and the structure of the terraces seem to show conclusively that their materials were laid down as alluvial-fan and alluvial-plain deposits and that these separate alluvial fans laid down by Arkansas River and its tributaries grew until a great compound alluvial fan was formed along the base of each of the great mountain ranges. The lack of distinct, continuous beds of stratification is characteristic of the deposits of fan-building streams, with their frequent changes of channel, as is also the gradation from coarse materials at the mountain base to finer toward the valley axis, though by no means fine even at the lower edges of the terraces.

The physical condition and the topography of the gravels show them to be of considerable age. Cuts and shafts 60 to 80 feet deep show that the terrace materials are completely oxidized to the bottom. Boulders of rather resistant rock, which must have been hard and firm when they were shaped and deposited, are now deeply decayed. Only the quartzite boulders are still fresh and firm. The gravels also show age by the erosion which they have suffered. Great gulches have been cut into them. Iowa Gulch, the deepest of these, cuts 500 feet into these gravels without reaching bedrock. In almost every place where moraines of the older epoch [stage] of glaciation occur the high terrace gravels appear just beyond them. In many places there is only a slight topographic break between the two, and in the amount of oxidation, in the decayed condition of the materials, and in the stage of erosion of the surface these gravels agree well with the older glacial drift. The upper part of them, at least, was probably deposited during the older [second] glacial period.

But there is positive proof, aside from the topographic relations and the condition of decay, that the older drift and the high terraces belong to about the same period. One mile north of Leadville a shaft through the gravels showed new drift overlying the high terrace gravels. Two miles west of Leadville a prospect hole showed glacial drift of the older epoch overlain by high terrace gravels. Thus we see that the high terrace gravels were deposited before the last glacial epoch, and some of them after the maximum advance of the ice of the older epoch of glaciation. It is probable that these gravels which overlie the older drift were laid down during or soon after the retreat of the older glaciers, for the cutting of the interglacial gorges in the terraces would have soon made impossible the deposition by streams of any considerable amount of materials on their tops.

In addition to the typical development of these gravels in the Arkansas Valley, there are similar gravels on the east side of the Park [Mosquito] Range. These lie beyond the moraines of the Platte system of glaciers and bear the same topographic and structural relations to the older drift of this system as do the Arkansas terraces to the older moraines with which they are associated. The gravels in the Platte Valley, however, did not suffer so much interglacial erosion and do not show the striking terraced appearance exhibited by those in the valley of the Arkansas. The gravels in the Platte Valley were doubtless deposited at the same time and under the same conditions as those in the Arkansas Valley.

The physical and topographic relations of the high terrace gravels indicate that the conditions of their deposition were as follows: The older glaciers advanced down the stream-developed valleys, where the rock was deeply weathered and there was abundant talus. Under these conditions the ice was heavily loaded with débris. To the extraglacial streams, swollen by the melting snow and ice, abundant material was supplied by the glaciers and by accelerated stream cutting in the unglaciated valleys. These streams were normally retarded by the lessened gradient at the mouths of the gorges and consequently dropped their excess load in the order of the size of the material. This tendency of the streams to deposit their loads was stimulated by the partial obstruction of the Arkansas Valley by the glaciers from the Sawatch Mountains. Possibly lakes were formed, but if formed they were shallow and only temporary, for they would have been rapidly filled by the influx of materials from the loaded streams. They could not have been deep enough for the deposition of the terraces, because the glaciers from the Lake and Clear Creek valleys never obstructed the Arkansas Valley to any great height. This aggradation of the Arkansas Valley by the alluvial deposits of the river and its tributaries continued until the end of the older glacial epoch.

The boundary between the high terrace gravel and the uncovered bedrock in the Leadville district extends along the west slope of Carbonate Hill, makes a sharp bend around the north end of the hill and across Graham Park, then makes a sharp bend to the north through the Old Mikado shaft, beyond which it disappears beneath the terminal moraine of the Evans Gulch glacier. The gravel likewise forms Poverty Flat, but its northward continuation is interrupted and concealed by Evans Creek and the south lateral moraine of the East Arkansas glacier. The exact boundaries between the moraines of the last glaciation and the high terrace gravels are not clearly defined in some places but are approximately indicated on Plate 7.

In the southern part of the area mapped the boundary of the high terrace gravel turns sharply up California Gulch. It is fairly well defined by a number of shafts on Dome Hill, which show rock in place immediately adjacent to California Gulch but a deep gravel-filled channel a little farther south. This channel extends eastward at least as far as Eureka Gulch, just west of which an area of gravel extends northward on the spur above the Stephens shaft. The main gravel-filled channel, however, crosses the southern boundary of the Leadville district at Eureka Gulch, 200 to 300 feet south of the Upper Printer Boy shaft, and has been reached by drifts driven southward from this shaft. The gravel filling this channel is cemented at this point by calcium carbonate.

Little opportunity for the study of the material that composes the high terrace gravel is afforded by surface observations in the Leadville district, but in the many shafts that have penetrated the material on the west slope of Carbonate Hill, in Graham Park, and on Rock and Dome hills, it consists of a loose, irregular mass of boulders of all varieties, mingled with sand and some clay. Evidences of stratification are slight, although here and there sandy layers apparently show bedding. There is now little opportunity for observing the character of the material in the workings, as shafts that penetrated it are now lagged. The material is usually termed "wash" by the miners, who make no distinction between the terrace gravel, morainal material of the last glaciation, and the coarsely disintegrated material that overlies bedrock in unglaciated areas.

The thickness of the high terrace gravel is least near the western bases of Carbonate and Fryer hills and beneath the terminal moraine of the Evans Gulch glacier. It increases rapidly westward. (See sections A-A′ to G-G′, pls. 14, 15.) In the Spurr drill hole on Capitol Hill the depth is 500 feet, which may be near the maximum. The depth varies somewhat on account of the concave surface of the bedrock underlying the "lake beds," but it is practically everywhere more than 200 feet and will average possibly 350 to 400 feet. In the easterly tongue that extends up Iowa Gulch the thickness decreases considerably.

Along the south border of the Leadville district the northern edge of this gravel tongue is penetrated by a number of shafts, which show that Iowa Gulch was formerly much wider than now. In these shafts "lake beds" of varying thickness are found, overlain by the high terrace gravel, upon which lies the glacial morainal material of the last stage of glaciation. Figure 4, a section through the Bessie Wilgus shaft, shows the old valley of Iowa Gulch.

"LAKE BEDS"

Character and distribution.—An entirely distinct formation occurs beneath the high terrace gravel of the Arkansas Valley and extends eastward into the Leadville district. To this material Emmons gave the name "lake beds," as he believed it to have accumulated in a broad glacial lake that occupied Arkansas Valley and had been produced by a damming of the river at Granite by glacial moraines. He did not, however, designate them as a separate formation from the high terrace gravel. Capps maintained that no beds of lacustrine origin were exposed in the region, but the beds in question are found only in the shafts of the Leadville district and, so far as the writers know, are exposed nowhere at the surface. It is evident from this fact and from Capps's descriptions that he did not see the formation here designated "lake beds." The absence of similar material beneath high terrace gravel on the east side of the Mosquito Range tends

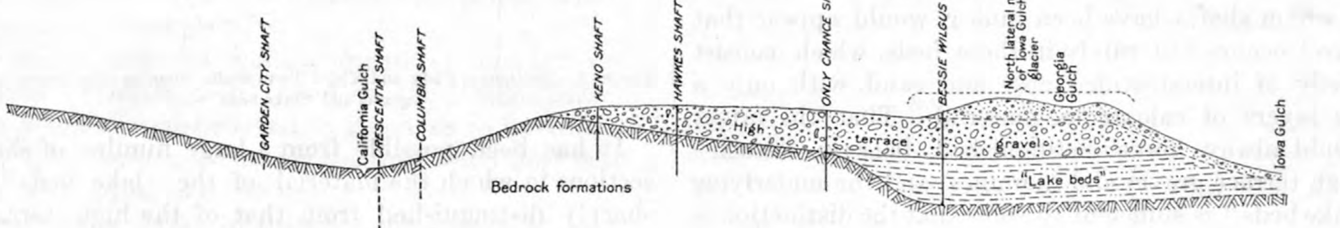


FIGURE 4.—North-south cross section of ridge between Iowa and California gulches, showing that the valley of Iowa Gulch originally extended much farther north. It is now filled with "lake beds" and high terrace gravel, and on the top of these is built the north lateral moraine of the Iowa Gulch glacier

LOW TERRACE GRAVEL

Capps noted in the Leadville region certain low terraces composed of outwash gravel from the latest glaciers. Such material occurs just west of the terminal moraine in Iowa Gulch. An area of low terrace gravel is shown by Capps (pl. 8) just north of Leadville, extending from the south side of Little Evans Gulch just north of Tin Town. This area indicates the principal course followed by water issuing from Evans Gulch glacier but is rather a measure of the quantity of high terrace gravel removed than of new material deposited. The low terrace gravel assumes appreciable thickness only in the extreme western part of this area. Capps described the low terrace gravel as having been formed at the last stage of glaciation in channels that had previously been eroded in the high terrace gravel. After the East Arkansas glacier retreated sufficiently the lower outlet from Evans Gulch into the East Arkansas Valley was established.

There is a small deposit of low terrace gravel in California Gulch at the mouth of Eureka Gulch. Its eastern limit is concealed by an old landslide.

to confirm Emmons's interpretation that the "lake beds" were formed in a local lake.

The material of which these beds consist was not observed at any point by the writers, as they cave very readily, and artificial openings in them are at once timbered. They were, however, observed and examined carefully by Emmons and Jacob in their original survey of the Leadville region, and have always been easily identified and distinguished by the miners from the high terrace gravel. In some places they were confused by Emmons and Jacob with the high terrace gravel on account of the failure at that time to understand the origin of the terraces. From a careful examination of the descriptions of Emmons, however, a fairly correct idea of the material constituting these beds may be obtained. He says:[6]

> The finest of the beds consist of a calcareous marl whose development seems to have been extremely local. The prevailing beds are a loose, friable sandstone, resembling granite decomposed in place, consisting largely of grains of quartz and feldspar, and often somewhat iron stained.

The only section of "lake beds" made in any detail in the Downtown district is that of the Owers drill hole,

[6] U. S. Geol. Survey Mon. 12, p. 71, 1886.

south of Leadville, near the head of Pawnee Gulch. This section is given below, with the original designations of the miners retained.

Section of Owers drill hole

	Thickness	Depth
	Feet	*Feet*
Wash [high terrace gravel]	48	48
Clean sand	2	50
Lake beds [probably finely stratified sand or clay]	255	305
Porphyry clay [probably poorly stratified gray to blue clay]	101	406
Coarse gravel	14	420
Porphyry clay	208	628
Lime clay [marl]	60	688
Bedrock.		

It appears from this section that the prevailing character of the "lake beds" is that of a fine-grained sand and marl mingled with clay. That occasional layers of gravel occur in them is not incompatible with a lacustrine origin. From descriptions of miners by whom shafts have been sunk it would appear that gravel occurs but rarely in these beds, which consist chiefly of interstratified clay and sand, with only a few layers of calcareous material. That the miner should always have distinguished between "wash" (high terrace gravel and moraines) and the underlying "lake beds" is sufficient to show that the distinction is sharp and clear.

Throughout the western portion of the Leadville district, where these materials are present, they have this easily recognizable character. Emmons mentions a number of places in which exposures were observed at the surface, notably Little Union Gulch, but from his descriptions it is evident that the material there belongs to the high terrace gravel and not to the "lake beds."

The east-west sections on Plates 14–17 show that the morainal material that covers the "lake beds" deepens westward. As the eastern edge of the high terrace gravel everywhere overlaps the "lake beds," no opportunity for their observation at the surface is afforded along the eastern or shore-line limit. Whether they do or do not crop out beneath the high terrace gravel as they are followed toward the west is not known, but owing to the increasingly greater thickness of high terrace gravel by which they are covered toward the west, it is doubtful if they emerge from beneath the gravel terraces even in the deeper gulches.

Capps, in the description above quoted (p. 16), mentions shafts between 60 and 80 feet deep in the high terrace gravel. Shaft bottoms of such shallow depth are usually far above the base of the gravel. If the "lake beds" have at any point emerged from beneath the terrace gravel in the Arkansas Valley, where they are cut through by the east-west gulches, it is doubtful whether the exposures would be recognized, for the overlying gravel must have crept down over them and obscured their outcrops. Moreover, it is by no means certain that these particular deposits extend uninterruptedly to the western limit of the high terrace gravel. The fact that an entirely covered basin filled with them exists in the Graham Park area (sections N–N′, pl. 17; D–D′, pl. 14; and D–D′, pl. 20) and that another isolated deposit beneath the terminal moraine of the Evans Gulch glacier is cut by the Third Term and Cady shafts (pl. 17, section O–O′, and fig. 5) suggests that they may have been somewhat local in their distribution. It is possible, however, that these small bodies have been separated from the main deposit by faulting and subsequent erosion during the interglacial stages.

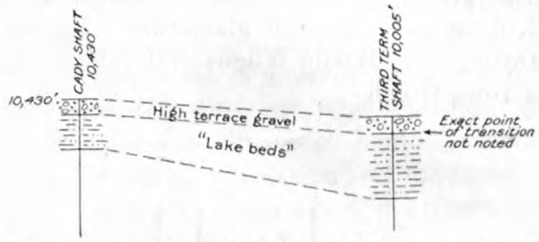


FIGURE 5.— Sections of Cady and Third Term shafts, showing relative depths of gravel and "lake beds"

It has been possible from a large number of shaft sections in which the material of the "lake beds" is sharply distinguished from that of the high terrace gravel to determine with considerable accuracy the eastern limit of the main deposit. As the "lake beds" are entirely covered by later deposits, they are indicated on Plate 7 as if seen through the high terrace gravel. The eastern limit extends southward from a point beyond the north edge of the area mapped, passes west of the Elgin smelter and nearly to the Delante shaft, bends eastward, and follows an irregular course close to the east city limit of Leadville as far as Stray Horse Gulch. It then curves around the western slope of Carbonate Hill, passes beneath California Gulch, and curves eastward beneath the long western slope of Rock Hill, where the Switzerland shaft (L–12, pl. 7) penetrated 90 feet of "lake beds" overlain by 250 feet of high terrace gravel. From this point it extends east by south past the Reindeer and Sullivan shafts and beyond the south boundary of the district, and its further extent is not known.

The thickness of the "lake beds" increases rapidly from their eastern margin to a maximum of 480 feet in the Prindle and Thompson shafts, beneath the moraine of Iowa Gulch glacier. The average thickness as disclosed by Downtown shafts is perhaps 400 feet.

Of the two outlying areas of "lake beds" the one beneath Graham Park is of particular interest. The "lake beds" here lie beneath a heavy cover of either morainal drift or high terrace gravel and occupy a deep depression whose eastern border is the rock face formed by the Mikado fault. The north, west, and south sides of the depression are concave. As a whole it resembles a half bowl with its broken edge against the Mikado fault. The depth of the "lake beds" and overlying gravel and the configuration of this depression may be seen from section D–D′, Plate 14, and sections M–M′ and N–N′, Plate 17.

The contact between the "lake beds" and underlying bedrock was nowhere observed by the writers, but it has been sufficiently distinct in several places where it has been cut by shafts to make the descriptions furnished by mine managers of some value. As a rule it is not sharply defined. Between bedrock and the bottom of the "lake beds" there usually intervenes an accumulation of angular fragments of bedrock which gradually merge downward into solid rock. Many of the fragments are much oxidized and decomposed. It is clear from these observations that the "lake beds" rest upon a disintegrated rock surface, which resembled the present unglaciated areas in the prevalence of frost-broken blocks, and that the deposition of the "lake beds" began at the culmination of a long period of oxidation and surface decay.

In many places angular fragments or boulders are reported to have been found in the "lake beds." These boulders were believed by Emmons to have been dropped by floating ice during the time when the "lake beds" were being laid down.

Deformation.—One of the most interesting and significant features of the glacial deposits and especially of the "lake beds" and the high terrace gravel is to be found in the effect produced in them by deformation. This subject is discussed at considerable length on pages 85–86.

The renewed movements that have taken place along the faults at Leadville in relatively recent time have faulted the "lake beds." The results are most easily seen along the eastern margin of the main deposit. The two isolated areas may, as already suggested, be due wholly or in part to such faulting followed by erosion. The eastward bulges cut by the All Right, Fairview No. 4, Wolcott No. 1, Hussey, Dillon, Jolly, and Weldon No. 1 shafts are portions of the "lake beds" that were raised on the east by movement along the Pendery fault zone. These relations are shown in the sections accompanying the geologic map of the Downtown district (pl. 18), which show several faults that have affected the "lake beds." Striking evidence of faulting is found also in the Thompson shaft, beyond the south edge of the Leadville district. This shaft, after passing through 230 feet of "lake beds," entered granite. The contact is a fault wall on the east side of the shaft, dipping so steeply that it required 22 feet of depth to cross the shaft. The "lake beds" lay directly against this fault and were unquestionably faulted into their present position. (See fig. 6.)

According to section IV, Plate 18, the "lake beds" had been eroded from the east side of the Niles fault before the deposition of the high terrace gravel. The high terrace gravel also has been affected by subsequent movements along the fault surfaces, but to a less degree.

Age.—Mammalian remains were found in the "lake beds" in a drift from the Bessie Wilgus shaft, which was driven from solid rock into these beds. These remains fix the approximate age of the "lake beds" as late Pliocene or early Pleistocene. As the "lake beds" underlie the high terrace gravel and an erosion interval appears to have elapsed between the times of their deposition, the "lake beds" must be regarded as belonging to an earlier and distinct stage. As Capps[7] has found indications of a possible stage of glaciation antedating the two well-defined stages in this region, it is reasonable to suggest that these "lake beds" were deposited during this earliest glacial stage, in late Pliocene or early Pleistocene time.

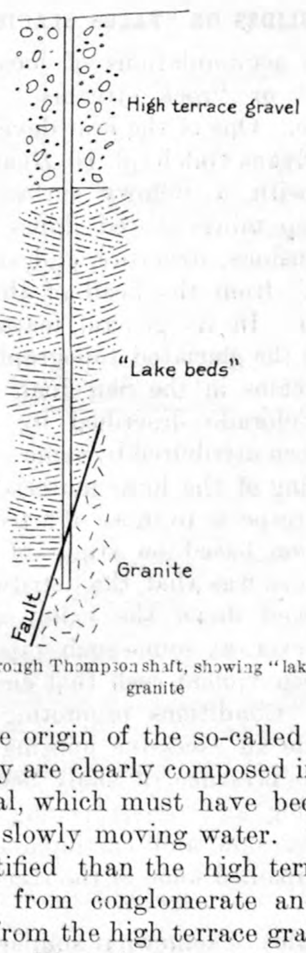


FIGURE 6.—Section through Thompson shaft, showing "lake beds" faulted against granite

Origin.—The origin of the so-called "lake beds" is obscure. They are clearly composed in greatest part, of fine material, which must have been deposited in quiet or very slowly moving water. They are more regularly stratified than the high terrace gravel, are relatively free from conglomerate and pebbles, and are separated from the high terrace gravel by an interval of erosion. That they are a considerably older formation is therefore beyond question.

It is conceivable that the glaciers of the first of the three glacial stages, as Capps's observations suggest, were the most extensive, and that those in the vicinity of Leadville coalesced in the Arkansas Valley and formed a local morainal obstruction, now eroded or covered by high terrace gravel, which caused a lake to

[7] Op. cit., p. 15.

form beneath the present city, but the "lake beds" themselves are the only direct suggestion of such a lake. The relations between such a lake and moraines of the first stage would be generally similar to those between the lake flat and moraine of the last stage at Lake Fork, across the Arkansas Valley from Leadville but at a higher altitude, which can be only roughly estimated owing to subsequent faulting and erosion.

The 14 feet of gravel interstratified with clay and marl at the Owers drill hole (p.18) indicates that some fluviatile deposition also took place during the "lake beds" stage. Some of the finer material may also be interpreted as a deposit from slowly moving water on a nearly horizontal alluvial plain, but the marl with its inclosed granite boulders, which were evidently dropped by floating blocks of ice, indicates that one or more bodies of standing water existed.

RECENT DEPOSITS

LANDSLIDES OR "TALUS GLACIERS"

Several large accumulations of loose rock, called "talus glaciers" or "rock streams," occur in the Mosquito Range. One of the best developed is found at the head of Evans Gulch (pl. 10, *B*) and occupies an elongate area, with a billowy surface that heads against the steep talus-covered slopes of the cirque wall. Its dimensions, structure, and surface suggest that it "flowed" from the head of the gulch to its present position. In its general features and close association with the glaciated topography it is similar to the rock streams in the San Juan Mountains of southwestern Colorado described by Howe.[8] Such deposits have been attributed by some to the slipping, creeping, or rolling of the loose material—movements similar in some respects to those of a true glacier; but Howe's conclusion, based on study of a number of these rock streams, was that the detritus constituting them had "flowed down the valley sides or basin floors; not, however, at some such rate as a glacier, but with a sudden violent rush that ended as quickly as it started." Conditions promoting such violent rock falls include an excessive jointing or shattering of the rock, the presence of shaly beds that afford planes of slipping, an oversteepening of the walls during glacial erosion, and earthquake shocks that may have accompanied some of the recent movements along faults.

Deposits of talus of somewhat similar character are present on the north slope of Printer Boy Hill, where the workings of the Lovejoy and other shafts penetrate extensive deposits of slide rock in concave depressions of the bedrock surface. The bare talus merges both northward and southward into tree-covered talus and is the latest of several rock slides that have built up the large deposit indicated on Plate 7 and in sections J–J′ and L–L′, Plate 16. There is a similar but smaller occurrence on the north spur of Ball Mountain.

Two older landslides, covered with vegetation, have been recognized—one just east of the ponds in upper Evans Gulch and one at the north base of Printer Boy Hill in California Gulch. These deposits were evidently formed in the same way as the "talus glaciers" but enough earlier to permit soil and vegetation to accumulate upon them.

[8] Howe, Ernest, Landslides in the San Juan Mountains, Colo.: U. S. Geol. Survey Prof. Paper 67, pp. 31–40, 49–53, 1909.

"WASH"

Those portions of the Leadville district which are not covered by glacial deposits are for the most part buried beneath an accumulation of broken bedrock. This material is called "wash" by the miners, who do not distinguish it from the morainal material or high terrace gravel. On the southwest slope of Carbonate Hill it is a very striking feature. The material is wholly different from any glacial deposit. It everywhere consists of fragments that have been derived from the immediately underlying rock or that have crept down from ledges higher up the slope. The porphyries, being the most abundant surface rocks, and likewise more easily disintegrated than the limestone, usually constitute the bulk of the slide rock.

The material consists of angular fragments of all sizes, generally from a few inches to more than 18 inches in diameter.

ALLUVIUM

Alluvial deposits are not extensive in the Leadville district, largely because glacial erosion has removed a great bulk of such deposits from the northern part of the district and none of them have accumulated on the slope that forms its western margin. The only alluvial deposits of consequence in the Leadville district are the gravel deposits that gathered during and since the last glacial stage in the bed of California Gulch, where placer mining formed so important a feature of the early production of the district. These deposits have been worked over and piled up to such a degree that it is difficult to show their outline, and therefore no attempt has been made to designate the area covered by them on the map of Quaternary deposits. Very little is known of the details of placer occurrence beyond what was written by Emmons in the Leadville monograph. The placers are now chiefly of historic interest.

PART II. GEOLOGY OF THE BEDROCK

CHAPTER 3. PRE-CAMBRIAN ROCKS AND SEDIMENTARY FORMATIONS

GEOLOGIC MAPS AND SECTIONS

Seven maps representing bedrock geology, six with accompanying structure sections, are included in this report. The areas covered by six of these maps are shown in outline in Figure 7. Although Plate 11 lacks much of the detail presented on the local larger-scale maps, it indicates the general geologic conditions and broader structural features of the region, which can not be adequately represented within the area of the Leadville district and a knowledge of which is helpful in an attempt to understand the local conditions.

The map of the Leadville district (pl. 13) has been constructed in part from reductions of the smaller, very detailed maps (pls. 18, 19, 22, 27, and 67) and in part by the direct plotting of data on a scale of 800 feet to the inch. The claims shown on Plate 13 were compiled on the topographic base by F. Edgar Frantz in the surveyor general's office at Denver.

The five smaller maps of large scale represent the complex structural features in the Downtown, Graham Park, Iron Hill, Fryer Hill, and Breece Hill areas. The degree of accuracy of these smaller maps and sections is greater than that of the Leadville map, because fewer inferences and assumptions have been necessary.

A word concerning the manner in which these maps have been compiled is pertinent.

Over the larger portion of the Leadville district the sedimentary formations are concealed by coverings of intrusive porphyry, glacial deposits, and "wash." From the few outcrops of these formations little clue is gained to the complicated geologic structure, which, together with the configuration of the bedrock surface, can be ascertained only by comparison of a vast number of observations taken underground. The accompanying maps therefore represent the bedrock surface as it would appear if the cover of surface materials were transparent. As this cover ranges in thickness from a feather edge next to the outcrops to more than 600 feet in the Downtown district and beneath the heavier moraines, the bedrock surface is very different from the ground surface, which is indicated by the contours. It is on the whole much more smoothly undulating. The formation boundaries on the geologic maps are accordingly more regular than they would be if the bedrock surface corresponded to the topographic surface, and in some places they extend in directions entirely different from those that would be suggested by the topography.

All the geologic data obtained in nearly all the drifts, tunnels, and shafts of the district were plotted on a

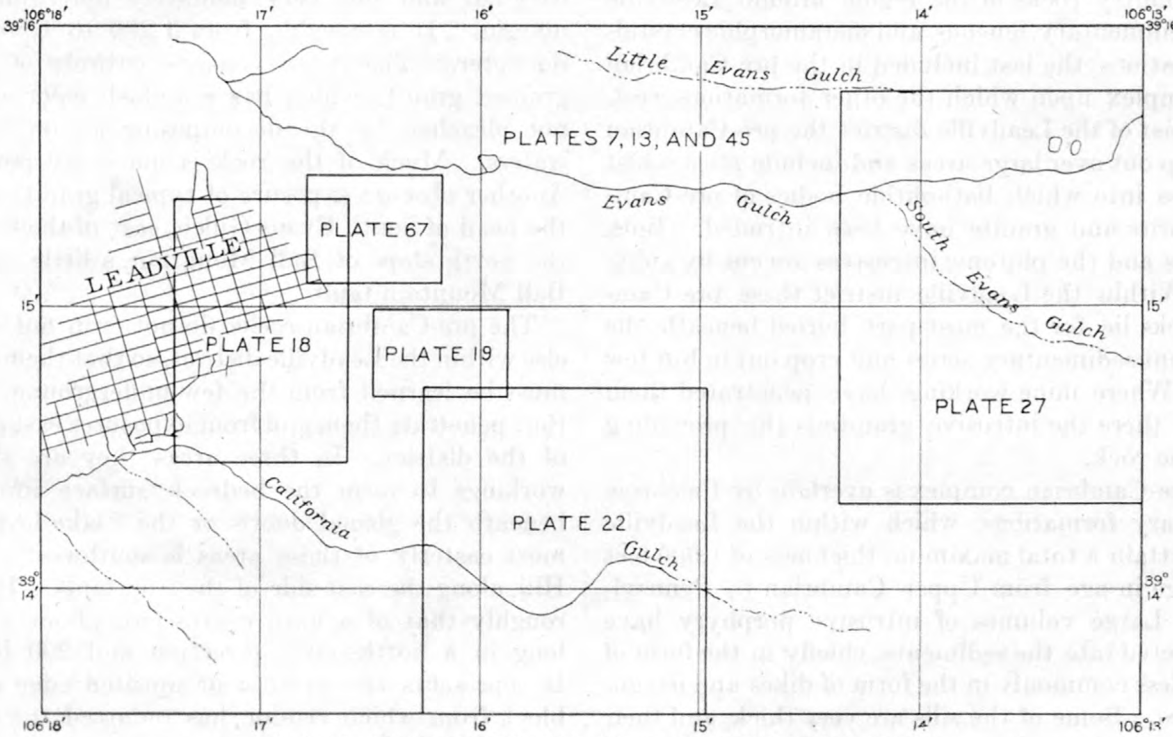


FIGURE 7.—Diagram showing location of areas represented by geologic maps

common map of large scale. Many sections were then made from which inferences were drawn as to continuity of formations, form of intrusive bodies, faults, and other structural features. Where the sections crossed one another the positions of formations were checked. The geologic contacts determined in these sections were projected up to the bedrock surface, and inferred connections were made between the points thus fixed. The geologic sections are therefore more accurate than the geologic map—the reverse of the usual relations, inasmuch as geologic maps are generally based in the main on surface observations, from which the underground structure is inferred.

GENERAL FEATURES

The country rocks of the region around Leadville include sedimentary, igneous, and metamorphic crystalline formations, the last included in the pre-Cambrian basal complex upon which the other formations rest. Not far east of the Leadville district the pre-Cambrian rocks crop out over large areas and include mica schist and gneiss into which batholithic bodies of pre-Cambrian diorite and granite have been intruded. Both the gneiss and the plutonic intrusives are cut by aplite dikes. Within the Leadville district these pre-Cambrian rocks lie for the most part buried beneath the superjacent sedimentary series and crop out in but few places. Where mine workings have penetrated them here and there the intrusive granite is the prevailing crystalline rock.

The pre-Cambrian complex is overlain by Paleozoic sedimentary formations, which within the Leadville district attain a total maximum thickness of 1,600 feet and range in age from Upper Cambrian to Pennsylvanian. Large volumes of intrusive porphyry have been injected into the sediments, chiefly in the form of sills but less commonly in the form of dikes and irregular masses. Some of the sills are very thick, and their aggregate thickness is much greater than the original thickness of the sedimentary strata. A few masses of rhyolitic agglomerate occupy pipelike volcanic conduits.

The sediments and intercalated porphyries have been slightly folded and profoundly faulted. The dominant faults run nearly north and cause a downthrow to the west, and the rocks have in general a low easterly dip. A given bed or sill is therefore met several times at nearly the same altitude by one crossing the district from west to east.

Erosion has cut deeply into the Paleozoic rocks and their interleaved porphyries and in its final stages has been accompanied and followed by the deposition of the heavy mantle of Pleistocene formations described in the preceding chapter.

The succession of formations, their geologic age, thickness, and lithologic character, and the obscure unconformities by which some of them are separated are set forth in the accompanying table and shown graphically in the columnar sections, Figure 8 and Plate 29.

PRE-CAMBRIAN COMPLEX

DISTRIBUTION

The pre-Cambrian rocks are exposed at the surface in two places within the Leadville district. In South Evans Gulch there is a low dome-shaped exposure of pre-Cambrian granite over which the glacial débris is extremely thin and from which an overlying sill of "White" porphyry and the Sawatch quartzite ("Lower" quartzite) dip away in all directions at low angles. This dome has roughly the plan of an ellipse, the longer axis of which extends northwest and which has a very irregular and not very definitely determined outer margin. It is roughly from 1,200 to 1,500 feet in diameter. The dome consists entirely of medium-grained granite which has a pinkish color where it is not bleached by the decomposing action of surface waters. Much of the rock is markedly porphyritic. Another obscure exposure of typical granite occurs at the head of South Evans Gulch, east of the railroad on the north slope of Ball Mountain, a little east of the Ball Mountain fault.

The pre-Cambrian rocks do not crop out anywhere else within the Leadville district, so that their character must be learned from the few underground workings that penetrate them and from exposures east and south of the district. In three areas they are shown by workings to form the bedrock surface immediately beneath the glacial débris or the "lake beds." The most easterly of these areas is southwest of Yankee Hill, along the east side of the iron fault. Its form is roughly that of a narrow crescent, about 1,300 feet long in a north-south direction and 200 feet wide. It represents the western or uptilted edge of a fault block from which erosion has removed the overlying Cambrian quartzite and which is now buried beneath the moraine of the Evans Gulch glacier. The second is a large semicircular area under the north end of the town of Leadville. Its limits are not definitely known and are merely inferred from evidence furnished by the Spurr drill hole, which entered granite after passing through "wash" and "lake beds." The third and largest area is a triangular one lying east of the Pendery fault and west of Revenue No. 1 shaft, in the southwest corner of the Leadville district.

The pre-Cambrian granite is also reached in several places by workings that penetrate the overlying Paleozoic rocks and porphyries. The exposures so furnished are generally scanty, for there is rarely any object in extending mine workings for any considerable distance into the pre-Cambrian complex except along the larger veins in the eastern part of the district. Although most of the shafts and other workings end before reaching the granite, the structural condi-

Tentative correlations of formations in Leadville and other districts of Colorado

System	Series	LEADVILLE Emmons, S. F., Geology and mining industry of Leadville, Colo.: U. S. Geol. Survey Mon. 12, 1886.	ALMA Patton, H. B., Geology and ore deposits of the Alma district, Colo.: Colorado Geol. Survey Bull. 3, 1912.	TENMILE Emmons, S. F., U. S. Geol. Survey Geol. Atlas, Tenmile district folio (No. 48), 1908.	ASPEN Spurr, J. E., Geology of the Aspen mining district, Colo.: U. S. Geol. Survey Mon. 31, 1898.	RED CLIFF Crawford, R. D., and Gibson, R., Colorado Geol. Survey Bull. 30, pp. 20–42, 1925.	BRECKENRIDGE Ransome, F. L., Geology and ore deposits of Breckenridge district, Colo.: U. S. Geol. Survey Prof. Paper 75, 1911.	CRESTED BUTTE Eldridge, G. H., U. S. Geol. Survey Geol. Atlas, Anthracite-Crested Butte, folio (No. 9), 1894.	MONARCH Crawford, R. D., Geology and ore deposits of Monarch and Tomichi districts, Colo.: Colorado Geol. Survey Bull. 4, 1913.	PIKES PEAK Cross, W., U. S. Geol. Survey Geol. Atlas Pikes Peak folio (No. 7), 1894.	DENVER BASIN Emmons, S. F., and Eldridge, G. H., Geology of Denver Basin in Colorado. U. S. Geol. Survey Mon. 27, 1896.	EAGLE RIVER Girty, G. H., Carboniferous formations and faunas of Colorado: U. S. Geol. Survey Prof. Paper 16, 1903.	LEADVILLE Emmons, S. F., Irving, J. D., and Loughlin, G. F., this report.
Quaternary.	Pleistocene.		[Patton makes no mention of any lake beds on the east side of the Mosquito Range. This tends to prove the correctness of Emmons's original theory that this material on the west side of the range is in reality a lake-bed deposit. Otherwise it would probably appear on both sides of the range.]										Moraines and low terrace gravel. High terrace gravel.
Quaternary or Tertiary.	Pleistocene or Pliocene.	Glacial or Lake beds.											"Lake beds."
Tertiary.			Absent (eroded?).										
Tertiary.	Eocene.		Absent (eroded?).					*Ruby formation:* Red, purple, and green sandstones and shales, with a few thin beds of conglomerate or eruptive débris; thin basal conglomerate with quartz pebbles. 2,500 feet. *Ohio Creek formation:* Conglomerate and gray sandstones. 200 feet.		Lake beds (Neocene and Eocene).	*Denver formation.* 1,450 feet. *Arapahoe formation.* 800 feet. —Unconformity—		Absent.
Cretaceous.	Upper Cretaceous.		Absent (eroded?).							Absent.	*Laramie formation:* Clays and sandstones with coal beds. 800 to 1,200 feet. [True Laramie.]		Absent.
			Absent (eroded?).		*Laramie formation:* White sandstone passing into brown and green thin-bedded friable shaly sandstones; sometimes carbonaceous. 500 to 600 feet.			*Laramie formation:* Succession of sandstones and shales, with coal beds. 2,000 feet. [Not true Laramie but of Montana age.]		*Montana formation:* Gray to yellowish-brown arenaceous shales, containing clay ironstone concretions. A few hundred feet.	*Montana group (Fox Hills and Pierre):* Clays (arenaceous) and sandstones, containing clay ironstones. 8,700 feet.		
					Montana formation: Gray-black shales carrying thin siliceous limestones. About 4,000 feet.			*Montana formation:* Leaden-gray sandstones containing lenses of limestone, also interbedded arenaceous clays and sandstones. 2,800 feet.					
			Absent (eroded?).		Colorado formation. *Niobrara limestone:* Gray limestone; grades up into Montana formation. 100 feet.		*Upper Cretaceous shale:* Dark shales with a few thin layers of limestone and of gray quartzite. Contains Benton, Niobrara, and possibly Montana fossils. 3,500 to 5,500 (?) feet.	*Niobrara limestone:* Gray calcareous shales and light-colored limestone. 200 feet.		*Colorado formation:* Dark-gray shales with a complex of fine limestone beds about midway in the series; brown sandstone near top. 500 feet.	Colorado group. *Niobrara formation:* Arenaceous shales and clays with limestone bands. 400 feet.		
			Absent (eroded?).		*Benton shales:* Black calcareous shales. 350 feet.			*Benton shale:* Black bituminous shales containing ironstone concretions; thin fossiliferous limestone. 150 to 300 feet.			*Benton formation:* Black shales with limestone band at top, and ironstones. 600 feet. —Unconformity—		
			Absent (eroded?).		*Dakota formation:* Massive white sandstone with local variations. 250 feet.		*Dakota sandstone:* Buff sandstone passing locally into white quartzite, with more or less gray shale. May include some Lower Cretaceous and some Morrison formation (Lower Cretaceous or Jurassic). 200 to 300 feet.	*Dakota formation:* White quartzitic sandstone, shaly at top, and conglomeratic at base. 50 to 300 feet.		*Dakota formation:* Fine white or gray sandstone, usually friable and of uniform texture, with fine conglomerate at base. 300 feet.	*Dakota formation:* White or gray sandstone with fine conglomerate at base. 350 feet.		
Cretaceous (?).	Lower Cretaceous (?).		Absent (eroded?).		*Gunnison formation (Triassic):* Gray or yellow sandstone, often calcareous, overlain by reddish, grayish, or variegated shaly sandstones. 300 to 400 feet. Unconformity		Not definitely recognized. Some Morrison formation may be included with the rocks mapped as Dakota.	*Gunnison formation:* Upper two-thirds dark green, yellow, and pink clays with thin limestones; base a heavy white quartzite. 350 to 500 feet.		*Morrison formation:* Prevailingly greenish, pinkish, or grayish shales and marls, containing sandstone at the base and as intercalated members at higher horizons. 350 feet.	*Morrison formation:* Gray shales and marls, with sandstone and limestone bands. 200 feet. Unconformity	Sandstone and marl, limestone, shaly sandstone. 1,000 feet.	Absent.
Jurassic.													
Triassic (?).													
	Permian (?).		Absent (eroded?).	*Wyoming formation:* Brick-red sandstone with some red shale and local coarse conglomerate. 1,500 feet. No fossils.[a]	*Triassic:* Red sandstones; light red below, darker above, 2,600 feet.[a]		"*Wyoming*" *formation:* Brilliant red sandstones and shales. Probably equivalent or nearly so to the Lykins formation of the Boulder district, Colo. 0 to 1,000 feet.[a]		(?)	[Lykins formation is present in southeastern part of quadrangle.]	*Upper Wyoming formation:* Brilliant red sandstones and shales; with heavy sandstone at top and thin limestones at base. 400 to 600 feet.	Red, white, and pink sandstones. 1,000 feet.	Absent.
Carboniferous.	Pennsylvanian.	*Upper Coal Measures:* 1,000 to 1,500 feet [not present in Leadville district, but present to east and north].	Absent (eroded?).	*Maroon formation:* Coarse gray and red sandstones with associated conglomerates and limestone. 1,500 feet.	*Maroon formation:* Dark-red grits and thin shaly limestone; pass gradually into overlying sandstone. 4,000 feet.	*Maroon and Weber formations undifferentiated:* 4,000 feet.	Absent.	Unconformity *Maroon conglomerate:* Upper part conglomerate and sandstone in heavy beds, the material derived chiefly from the arkose and particularly from the early Carboniferous beds; occasional thin beds of fossiliferous limestone. 2,500 feet. Lower part quartzose conglomerate, grit, and sandstone, varying amounts of pebbles derived from Carboniferous, which sometimes form the bulk of the deposits; color yellowish gray; there are thin interbedded limestone layers, and these and the limestone pebbles are fossiliferous. 2,000 feet.	*Kangaroo formation:* Gray to brown and blue or light-green quartzite, mingled with conglomerates and metamorphosed shales. 3,000 feet. Unconformity	[Lyons ("Creamy") sandstone is present in southeastern part of quadrangle.]			Absent.
		Weber grits. 2,500 feet [940 feet in Leadville district].	*Weber grits:* At base 150 to 300 feet of variegated shale (Weber shales), passing upward into alternating arkose grits, quartzites, and shales (Weber grits). 2,800 feet.	*Weber formation:* Mainly coarse gray sandstones and grits (Weber grits, 2,500 feet) with some carbonaceous shales near base and a few thin beds of dolomitic limestone (Weber shales, 300 feet). 2,800 feet.	(?) *Weber formation:* Thin-bedded carbonaceous limestone and calcareous shales. 1,000 feet.		Absent.		*Garfield formation:* Alternate coarse sandstones, quartzites, and conglomerates at the base, containing in places thin lentils of limestone; passes upward into black shale containing thin layers of quartzite and impure limestone, which contain more sandstone in the middle and upper thirds of the formation. 2,600 to 2,800 feet.	*Fountain formation:* Red sandstone, grits, and conglomerates. Estimated at 1,000 feet.	*Lower Wyoming formation:* Red sandstones and conglomerates; "Creamy sandstone" at top. 200 to 2,400 feet.	Conglomeratic sandstones and interlaminated shales, with coarse white sandstone. 2,500 feet.	*Weber (?) formation:* 1,000± feet.
		Weber shales. 150 to 300 feet.						*Weber limestone:* Dark-gray to black shale with thin limestones carrying black chert. 100 to 500 feet.	Unconformity	Unconformity			
	Mississippian.	*Blue limestone:* Compact, heavy-bedded dark-blue dolomitic limestone; black chert concretions near top. 200 feet.	*Leadville limestone:* Dark bluish-gray dolomitic limestone containing black chert nodules at top; contains *Eozoon* ribbing; usually extremely fine-grained; sometimes shaly at base. Between 150 and 200 feet.	*Blue or Leadville limestone:* (not exposed). 200 feet.	*Leadville limestone:* Thick-bedded gray-blue dolomite grading upward into gray-blue limestone. 350 feet.	*Leadville limestone:* 170–222 feet. Lower 70–90 feet tentatively put in Devonian.	Absent.	*Leadville limestone:* Upper third massive, blue, and cavernous; lower two-thirds bedded gray to brown dark cherts. 400 to 525 feet.	*Ouray limestone:* Argillaceous or arenaceous at the base, passing into fairly heavy bedded gray to blue, yellow, and white dolomitic limestone; about 150 feet below top is bed of black dolomite 20 to 40 feet thick. 570 to 800 feet.	*Millsap limestone:* Thin-bedded dolomite, with a few thin sandstone layers; chert nodules in the upper limestone layers. 30 feet.			*Leadville limestone* ("*Blue*" *limestone.*) 200 feet.
Devonian (?).		—Unconformity—								Unconformity			—Unconformity—
Ordovician.		*Parting quartzite:* White quartzite. 40 feet.	*Parting quartzite:* Fairly coarse hard quartzite, resembling "Lower" quartzite and averaging 50 feet in thickness. Considered by Girty to be Ordovician.	*Yule limestone:* Light-drab thin-bedded limestone, 120 to 160 feet, overlain by 15 to 60 feet of siliceous beds generally known as Parting quartzite. (Not exposed.)	*Parting quartzite:* Thin-bedded quartzite and dolomite. 60 feet.	*Ordovician or Devonian quartzite, etc.* 50 feet.	Absent.	*Yule limestone:* At the top 80 feet of green, pink, and yellow shale and blue limestone; middle portion massive gray limestone with white chert; lower portion white quartzite 75 to 100 feet thick. Total thickness 350 to 450 feet. [The equivalent of the "Parting" quartzite believed by Spurr to be represented by the upper 60 to 90 feet of Yule limestone, consisting of green, yellow, red, and white shales with more or less arenaceous and calcareous layers the latter passing into thin limestones.]	*Tomichi limestone:* 230 to 290 feet of bluish-gray to gray cherty limestones; overlain by 28 to 30 feet of blue to gray quartzite, which weathers white to reddish brown and is locally called "parting quartzite," although no attempt is made to correlate it with the Parting quartzite of Leadville district; above this quartzite is 100 feet of non-cherty gray limestone, dolomitic in upper part, capped by a few feet of argillaceous limestone and calcareous shale. 400 feet.	*Fremont limestone:* Bluish-gray or pink dolomite, sometimes arenaceous. 100 feet. [Chiefly or wholly Upper Ordovician (Richmond).] *Harding sandstone:* Fine, even-grained saccharoidal sandstone in alternating bands of light-gray, pinkish, or variegated colors, with a few bands of dark-red or purplish sandy shale; lower part sometimes calcareous. 100 feet. [Of Middle Ordovician age.]			Yule limestone. "*Parting*" *quartzite member.* 10 to 70 feet.
		White limestone: Light-gray siliceous dolomitic limestone, with white chert concretions. 160 feet.	*White limestone:* Light-drab to white to dark-gray or blue-gray dolomitic limestone 120 to 170 feet; averages 150 feet.		*Yule formation:* Hard, compact gray-blue to yellowish-brown dolomites. 250 to 400 feet.		Absent.		—Unconformity—	*Manitou limestone:* Fine-grained pink or reddish dolomite. 100 feet. [Of Lower Ordovician age.]			"*White*" *limestone member.* 120 feet.
Cambrian.	Upper Cambrian.	*Lower quartzite:* White quartzite, passing upward into calcareous and argillaceous shales. 150 to 200 feet.	*Cambrian:* White, heavy-bedded quartzite, passing into 1-foot layer of fine quartz conglomerate at the base; overlain by more thinly bedded quartzites weathering brownish on exposure; top of formation marked by red-cast beds of Emmons. 150 to 200 feet.	*Sawatch quartzite:* White and generally thin-bedded quartzite, with conglomerate at base; grades upward into greenish calcareous and argillaceous shales. 160 to 200 feet.	*Sawatch formation:* White quartzite, conglomeratic at base, grading upward into sandy, dolomitic, and occasionally glauconitic varieties. 200 to 400 feet.	*Sawatch quartzite.* 302 feet.	Absent.	*Sawatch quartzite:* Upper third quartzite containing glauconite; lower two-thirds white quartzite containing conglomerate at the base, the pebbles of white quartz. 350 feet.	*Sawatch quartzite:* Hard white quartzite, ranging from a maximum of 20 feet to a feather edge. Present over a large part of the district. Upper portion apparently eroded prior to the deposition of the Tomichi limestone.	Small thickness of quartzite and cherty limestone containing *Lingulepis, Obolella,* and *Ptychoparia.* [No formation name given. Thickness not stated.]			*Sawatch quartzite* ("*Lower*" *quartzite*). 50 to 180 feet.
		—Great unconformity—											—Unconformity—
Pre-Cambrian.		Archean granite and schist.	Archean gneisses and schists.	Archean gneiss, granite, and schist.	Granite, gneiss, and schist.	Pre-Cambrian.	Pre-Cambrian.	Archean granite, gneiss, and schist.	Pre-Cambrian granite and gneiss.	Algonkian quartzites, schists, granite, and gneiss.	Archean granites, gneisses, and metamorphic rocks.		Pre-Cambrian granite, schist, and gneiss.

[a] Age assignment given in this table is based on probable correlation with Lykins formation.

tions in some places make passage through it necessary for development. For this reason some of the shafts and drill holes enter the pre-Cambrian granite for short distances, either by penetrating completely the overlying Paleozoic sediments or by passing across faults that have brought the pre-Cambrian up against the younger rocks. Such structural relations occur in nearly all parts of the district. Many drifts likewise are run through the granite from shafts that have crossed the large faults in order to reach the ore horizons on the downthrown side. The Yak tunnel extends through granite in two places where it cuts the uptilted edges of successive fault blocks.

In such workings the character of the pre-Cambrian rock has been determined in the Downtown district, Rock Hill, Iron Hill, Fryer Hill, East Fryer Hill (?), Breece Hill, Evans Gulch, South Evans Gulch, and California Gulch. Beneath the southern and western slopes of Ball Mountain it is so deeply buried beneath sedimentary rocks and intruded porphyries that it will probably never be reached by mine workings.

The pre-Cambrian exposed in the workings consists exclusively of granite with two known exceptions—an exposure of a few feet in the Yak tunnel beneath Breece Hill and one in a west crosscut from the Garbutt vein in the same vicinity. At both these places the rock is hornblende schist, tilted at a high angle, which probably represents portions of some older pre-Cambrian formation projecting downward into the great pre-Cambrian granite mass.

The small granite masses, separated by considerable areas of gneissoid and schistose rocks, on the east side of the Mosquito Range, mapped by Patton, are probably offshoots of the large single body or batholith.

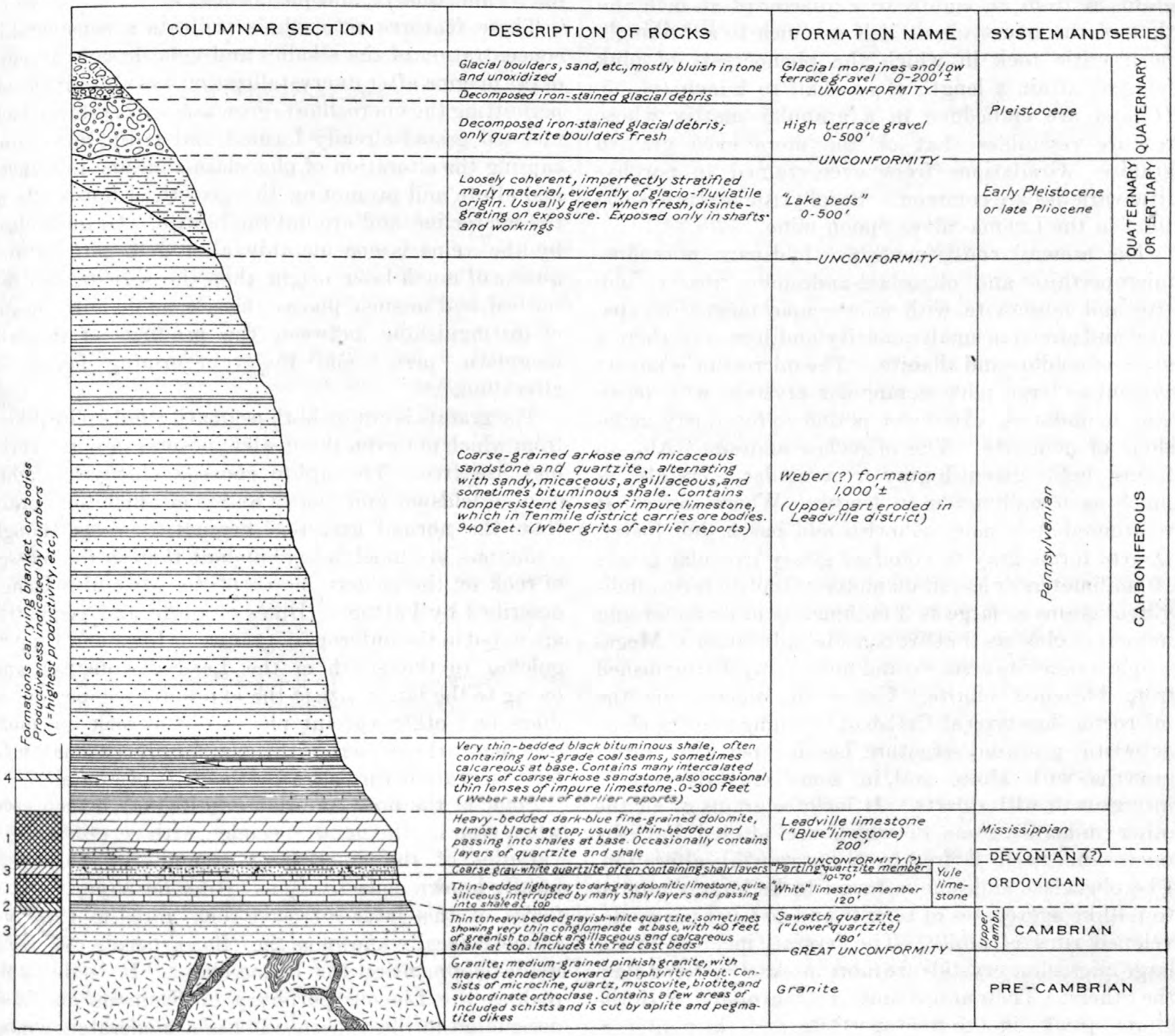


FIGURE 8.—Stratigraphic column of the Leadville district

PETROGRAPHY

The granite as viewed in the hand specimen varies considerably in color and texture. It usually has a pinkish tone, due to the color of the prevailing feldspar, except where bleached by surface waters or mineralizing solutions, and from that it varies locally to a dull gray. In texture it ranges from an even-grained rock in which the diameter of the feldspar and quartz grains is from an eighth to a quarter of an inch and that of the micas about half as much to a strikingly porphyritic rock in which the phenocrysts of pink feldspar attain a length of one-half to 1 inch (pl. 35, *D*) and are embedded in a granular matrix whose texture resembles that of the more even grained granite. Gradations from even-grained to porphyritic varieties are common. Porphyritic texture is distinct in the Luema-Silver Spoon mine.

The mineral constituents are feldspars (microline-microperthite and oligoclase-andesine), quartz, biotite, and muscovite, with microscopic magnetite, apatite, and zircon in small quantity and here and there a grain of epidote and allanite. The microcline is mostly present as large pink rectangular crystals, with irregular boundaries. Its color is due to fine dusty inclusions of hematite. The oligoclase-andesine (Ab_{65-70}) forms light greenish-gray rectangular crystals as much as 6 millimeters in length. Where somewhat weathered it is pale yellowish and has a dull luster. Quartz forms gray to colorless glassy irregular grains 10 millimeters or less in diameter. Biotite forms individual grains as large as 3 millimeters in diameter and numerous clusters that are considerably larger. Megascopic muscovite is scarce and not readily distinguished from bleached biotite. Under the microscope the microcline has typical Carlsbad twinning and the characteristic gridiron structure, besides perthitic intergrowths with albite and, in some crystals, graphic intergrowth with quartz. It incloses grains of all the other minerals, some of which are altered, but the microcline itself is free from noteworthy alteration. The oligoclase-andesine is found to be largely altered to feltlike aggregates of sericite and to have partly developed rims of albite. The crystals inclosed in the large microcline crystals are more intensely altered than the others. Their albite rims are continuous with the albite streaks in the microperthite, and their appearance as a whole suggests that the alteration took place during the crystallization of the microperthite, which with quartz was the last primary mineral to form. The quartz shows typical undulatory extinction. It incloses a few grains of oligoclase-andesine, but most of its contacts with biotite are irregular. Biotite is intergrown to some extent with muscovite and incloses grains of apatite and zircon. Where inclosed in microcline biotite has partial borders of muscovite. A few biotite grains are inclosed in plagioclase, but most of them lie between plagioclase and quartz and have irregular contacts with both minerals. In some places biotite is partly altered to chlorite. Muscovite, besides being associated with biotite, forms irregular streaks penetrating microcline. Some of the streaks suggest perthitic intergrowth; others may be secondary. Magnetite, apatite, zircon, and epidote are typically developed and present no noteworthy features. One grain of allanite 5 millimeters in diameter partly incloses microcline, quartz, and plagioclase.

These features as a whole indicate a considerable concentration of the alkalies and volatile constituents of the magma after its crystallization was well advanced, permitting the microcline to grow as large crystals which inclosed grains already formed, and at the same time causing the alteration of oligoclase-andesine to sericite and albite and promoting the growth of muscovite in the microcline and around the biotite. Granite close by the veins is considerably altered to sericite and quartz of much later origin than the sericite just described, and in such places there is no definite means of distinguishing between the products of the late magmatic period and the vein-forming period of alteration.

The granite is cut by both pegmatite and aplite dikes, from which not even the small exposures in mine workings are free. The aplite consists chiefly of light-colored feldspar and quartz and is of much finer grain than the normal granite. Pegmatite veins, though numerous, are much less abundant than in the masses of rock on the eastern slopes of the Mosquito Range described by Patton.[1] Dikes of aplite and pegmatite are noted in the outcrops of granite in Iowa and Empire gulches, to the south of the Leadville district, and owing to the larger size of the exposures the pegmatite dikes and other variant phases of the rock are more prominent there than in the comparatively small field for observation furnished by the drift of a mine.

Some of the pre-Cambrian granite may be confused when seen in the hand specimen with certain coarser varieties of the much later granodiorite porphyry, locally known collectively as "Gray porphyry." One facies of this later intrusive rock noted in the Yak tunnel is locally known as the "Bazoo porphyry," from its development on the Bazoo claim. It is the same rock as the Lincoln porphyry of Emmons and is so designated in this report. It has a moderately coarse grained groundmass and large phenocrysts of orthoclase. The microscope at once identifies the large crystals, however, as orthoclase instead of microcline and reveals the fine-grained groundmass typical of the "Gray" porphyry.

The granite wherever found in any considerable masses is intersected by dikes and irregular masses of porphyry, which represent the conduits through which

[1] Patton, H. B., Hoskin, A. J., and Butler, G. M., Geology and ore deposits of the Alma district, Park County, Colo.: Colorado Geol. Survey Bull. 3, pp. 40-47, 1912.

the magma that formed the sills and irregular bodies in the overlying sedimentary rocks ascended. In some places within the granite zones of the Yak tunnel they are so numerous that their aggregate width is probably more than that of the granite between them.

When subjected to the action of mineralizing solutions the granite has undergone less alteration than any other rock in the Leadville district. Ores are unknown in it except in the form of veins, and where veins are contained within granite walls they have in general been very poor in metallic content.

STRATIFIED ROCKS

SAWATCH QUARTZITE ("LOWER" QUARTZITE)

NAME

Lying directly upon the eroded surface of the pre-Cambrian complex is the formation which Emmons called "Lower quartzite" and which was later designated Sawatch quartzite in reports on several districts of central Colorado. The name "Lower" quartzite was applied at Leadville to distinguish it from the "Parting" quartzite, which occurs stratigraphically about 120 feet above. Throughout the Leadville district it is also called the Cambrian quartzite, but there is a possibility that some of the upper shaly beds included in the formation by Emmons may represent the lowermost beds of the Ordovician. Because of the long local usage of the term "Lower" quartzite in the Leadville district, that term is, for the convenience of the mining public, freely used in the other chapters of this report without quotation marks.

OLD EROSION SURFACE ON WHICH THE QUARTZITE WAS LAID DOWN

The contact between the Sawatch quartzite and the underlying granite or other pre-Cambrian rocks is remarkably even and free from undulations. It so closely approaches a perfectly plane surface that except in those localities where a great length of outcrop is exposed in a single section, any lack of parallelism between the bedding of the quartzite and its contact with the granite below is difficult to detect. The smoothness of the contact of the sedimentary formations with the granite is well illustrated in the photograph of Sheridan Mountain taken from the head of Empire Gulch (pl. 30, *A*). In only two places are any noticeable inequalities observable in the pre-Cambrian surface. One is at the head of Buckskin Amphitheater, where slight undulations in the surface are noticeable. There the surface of the granite rises very gently, so that the lower layer of quartzite thins out and is overlapped by the next succeeding layer. The other is on the southwest face of Zion Mountain, where a small hill of granite was noted by Emmons as the only place where direct evidence was afforded of any considerable inequalities in the pre-Cambrian surface. When the thickness observed in various parts of the district are compared with one another, however, the variations in the total thickness of the quartzite are seen to be considerable. This indicates a deposition surface not quite reduced to a plane. Evidently, however, the pre-Cambrian surface was thoroughly baseleveled in pre-Cambrian time, to be later depressed beneath the sea and covered with successive layers of sand and other Cambrian sediments. Similar conditions farther east have been described by Crosby.[2]

PETROGRAPHY

The Sawatch quartzite at Leadville consists of a lower member composed largely of white, glassy quartzite, 120 feet thick, and an upper shaly member, 50 feet thick, herein called "transition shales," but the character of the strata varies considerably in different parts of the Mosquito Range. The basal bed of the white, glassy quartzite member is usually a conglomerate ranging from a few inches to a foot in thickness, although in a few places, as in the Yak tunnel, it is absent. This basal conglomerate is made up of rounded and finely polished grains of bluish translucent quartz, most of them not larger than a pea. The lower portion of the quartzite is invariably the freest from calcareous or argillaceous impurities and on the west side of the Mosquito Range is 100 to 120 feet in thickness. On the east side of the range the thickness seems to diminish somewhat and in places is only 40 feet. This white quartzite is remarkably uniform and persistent. It is everywhere readily distinguishable as a white band in the numerous sections exposed along the canyon walls of the range. Most commonly it is thick bedded, and such is its prevailing character throughout the Leadville district, but it passes in places into rather thin-bedded white sugary quartzite. The component round quartz grains are clearly visible. Under the microscope they show enlargement and appear as interlocking grains without any interstitial material except a little very fine grained sericite. Here and there a soft white bed resembling the local "White" porphyry and likely to be impregnated with minute grains of pyrite is present. One of these on the thirteenth level of the Ibex No. 3 shaft near its junction with the Garbutt vein consists of round grains of quartz 0.5 millimeter in diameter impregnated with sericite in a feltlike matrix of sericite. The pyrite is in the sericite matrix. Where mineralization has been intense the quartzite is much sericitized and crumbly.

The upper beds of the quartzite are thinner, and some of them are cemented by calcium carbonate instead of silica. They are therefore softer and disintegrate to loose sand. In the Red Cliff district, north of Leadville, such a calcareous bed has been replaced by ore at its intersection with the Bleak House vein.

[2] Crosby, W. O., Archean-Cambrian contact near Manitou: Geol. Soc. America Bull., vol. 10, pp. 141-164, 1899.

Limestone beds are occasionally found in the quartzite. One in Buckskin Gulch is mentioned by Emmons as being very low in magnesia.

The upper shaly member, 50 feet thick, is more or less argillaceous and calcareous. Its contact with the quartzite below is sharp in some places and gradual in others. It passes upward by almost imperceptible transition into the siliceous part of the "White" limestone and is therefore locally called the "transition shales." Because of this transition and the presence of calcareous beds, nearly all the local mining companies have regarded this shaly member as part of the "White" limestone, rather than as part of the sharply contrasted quartzite, although some of them have represented it as a distinct member in their maps and sections. Much of the information compiled from company records indicates the uppermost hard quartzite bed as the top of the "Lower" quartzite and makes no mention of "transition shales." In this report these shales are regarded as the upper member of the Sawatch quartzite, because they have been so designated not only in the Leadville monograph but in reports on neighboring regions as well.

Emmons states that at the top of what he regards as distinctively Cambrian there is one especially persistent bed of sandy limestone, generally about a foot in thickness, which is useful in determining the horizon on account of the striking appearance of its weathered surface. It is a siliceous dolomite, generally whitish on fresh fracture, and contains spots of dark brick red, resembling casts of fossils, on account of which the term "red-cast beds" was applied to it. (See pl. 36, *B*.)

Patton[3] states that the most conspicuous feature about the "Lower" quartzite is its division into two distinct members—a lower, very white heavy-bedded quartzite, occupying about half of the formation, and an upper thinner-bedded member ("transition shales") which passes by gradual alternations in its upper part into the "White" limestone. He says that the "red-cast beds" are extraordinarily persistent throughout the Alma district, and he therefore, like Emmons, regards those beds as marking the passage from the Cambrian quartzite to the overlying limestone. The "red-cast beds," however, are missing in many parts of the Leadville district, and in some parts they lie immediately above the hard white quartzite, suggesting that the upper shaly member has been eliminated at an unconformity. Furthermore, the unweathered beds may not be readily identifiable in mine workings. They are therefore unsatisfactory for the exact determination of the upper limit of the Sawatch quartzite.

The shaly member consists in nearly all places in the Leadville area of thin-bedded shale, much of it dense in texture and readily confused with the "White" porphyry, especially when seen in drill cores where the bedding is obscure. On Carbonate Hill the shales are 40 feet in thickness and at the base pass by insensible gradations through alternating bands of quartzite, limestone, and shale into the quartzite below. These shales are missing in the Tucson mine, on Iron Hill, where the "White" limestone passes into a thin layer of "red-cast beds" and thence directly into the underlying solid quartzite. Elsewhere throughout the district the "White" limestone is underlain by these shales, and in no other locality than the Tucson mine are they known to be absent. This fact is of great practical importance because in some places the calcareous beds in the shales appear to be more favorable for the deposition of ore than the "White" limestone above; also because their frequent confusion with the "White" porphyry has sometimes led to unfortunate mistakes in mining development. Not only has proper search not been made in them for ores, but expensive diamond-drilling operations have been rendered worthless by their incorrect determination as porphyry.

Emmons also mentions the presence in the shaly member of the "Lower" quartzite of amphibole and pyroxene and of considerable serpentine derived from them. No such occurrences have been observed by Irving and Loughlin in the Leadville district, although they may be present, particularly near contacts with intrusive porphyry.

GEOLOGIC AGE

The correlation table facing page 22 shows that the Cambrian quartzite of Leadville is apparently traceable throughout the central and southwestern portions of Colorado, although the exact correlation is perhaps uncertain in places.

The only fossils found in the "Lower" quartzite near Leadville are those mentioned by Emmons in the Leadville monograph. These fossils were not obtained within the limits of the Leadville district. Emmons[4] describes the occurrence as follows:

> The only fossil remains found in this series occur in a bed of greenish chloritic shales on the east flank of Quandary Peak, about a mile above the Monte Cristo mine. They belong to the genus *Dikellocephalus* and resemble closely *Dikellocephalus minnesotensis* of the Potsdam formation.
>
> Owing to the thick covering of forest immediately east of the point where these fossils were found, it was impossible to fix with absolute certainty the exact horizon of the bed in which they occur. They are immediately above a heavy white quartzite and beneath a bed of white marbleized limestone, which is in turn overlain by the quartzite which carries the Monte Cristo ore deposit. From analogy with other sections, however, it seems safe to assume that it occurs above the main body of quartzite and near the base of the transition series.

Fossils were likewise obtained by Cross from a reddish-brown sandstone 45 feet above the pre-Cam-

[3] Patton, H. B., Hoskin, A. J., and Butler, G. M., Geology and ore deposits of the Alma district, Park County, Colo.: Colorado Geol. Survey Bull. 3, p. 49, 1912.

[4] U. S. Geol. Survey Mon. 12, p. 60, 1886.

brian on the east bank of Trout Creek, in Manitou Park, among which was an elongate form of *Lingulepis* allied to *L. pinnaformis* of the Cambrian sandstone of Wisconsin. These fossils, according to Schuchert,[5] are of Upper Cambrian or more probably of basal Ordovician age. The fauna from the red calcareous sandstones alternating with white limestone 105 to 122 feet above the pre-Cambrian in the Manitou region is of Lower Ordovician character. These facts seem to indicate that only the heavy quartzitic portion, which constitutes the lower member of the formation referred by Emmons to the Cambrian, may be safely so referred, and that the upper shaly member may possibly be of Ordovician age. Until more conclusive evidence is available both the quartzite and the "transition shales" will continue to be classified as Upper Cambrian.

In his report on the Alma district Patton[6] describes fossils presumably from this formation as follows:

> The only fossils from the Cambrian found in the Alma district were collected from a talus slope at the foot of a cliff on the south side of Buckskin Gulch. These were brachiopods and were determined by Mr. Edwin Kirk, of the United States Geological Survey, as probably referable to *Billingsella coloradoensis* (Shumard) and are considered by him as undoubtedly Upper Cambrian.

In discussing the Cambrian of Colorado Walcott[7] says:

> That the Upper Cambrian zone is represented is fairly well proved by the Mosquito Range section and that of Trout Creek of the Colorado Range, and it is very probable that the sandstones, correlated with the Potsdam, really belong within the Upper Cambrian horizon.
>
> From our present knowledge the Upper Cambrian zone is the only portion of the group represented in Colorado.

This conclusion makes it nearly certain that strata representing Middle and Lower Cambrian time are absent from the region of the Sawatch and Front ranges and confirms the supposition that this entire area, including the Leadville district, was a land surface at that time.

YULE LIMESTONE

The rocks in the Leadville district that were designated by Emmons "White limestone" and "Parting quartzite" together correspond to the Yule limestone of the Anthracite-Crested Butte and other areas of central Colorado, and in Emmons's report on the neighboring Tenmile district they were designated Yule limestone. In the present report, therefore, these rocks are collectively called Yule limestone and are divided into a limestone member below and a quartzite member above. For the convenience of the mining public the familiar descriptive terms "White" limestone and "Parting" quartzite are here retained to designate the subdivisions of the Yule limestone in the Leadville district, and throughout the text, except the stratigraphic chapters, the names are used without quotation marks.

"WHITE" LIMESTONE MEMBER

NAME

To the dolomitic limestone that intervenes between the upper shaly member of the "Lower" quartzite and the lowermost layers of the "Parting" quartzite Emmons applied the term "White limestone." This term is, however, a misnomer, because much of the limestone so closely approaches the Leadville or "Blue" limestone in color, especially where the latter has been bleached by mineralizing action or has been partly recrystallized by contact metamorphism, that in some parts of the field the two are not distinguishable by appearance, but only by stratigraphic position.

DISTRIBUTION

The "White" limestone occurs on the bedrock surface only as narrow strips extending about north and south, and it crops out only in a few widely scattered places. North and west of Leadville a large area of "White" limestone has been represented from which it is believed the overlying rocks have been eroded. No satisfactory evidence from shafts or drill holes is available in this area, and the occurrence as indicated is mainly hypothetical, though in accord with the characteristic Leadville structure. The existence of the hypothetical fault west of the Cloud City fault is rendered extremely probable by the record of the Spurr drill hole, and on the basis of this assumption the "White" limestone has been here represented.

THICKNESS

The thickness of the "White" limestone member averages about 120 feet.[8] In some places it is slightly thicker, but many of the shaft and drill-hole records collected show a smaller thickness.

Owing to its thin bedding and shaly character, the "White" limestone contains more intrusive sheets of porphyry than the Leadville limestone. This is particularly noticeable in the Iron Hill region, where the "White" limestone is so much divided up by intrusions of "Gray" porphyry that its thickness in several places is increased to fully twice the normal.

PETROGRAPHY

The "White" limestone consists mainly of light-gray thin-bedded siliceous dolomitic limestone, invariably crystalline, interbedded with very thin layers of shale, most of them very dark green, some almost black. The proportion of shale differs in different places. Toward the top the passage to the "Parting" quartzite member is in places marked by a series of transition shales similar to those in the upper part of the Sawatch

[5] Written communication to J. D. Irving.

[6] Op. cit., p. 51.

[7] Walcott, C. D., U. S. Geol. Survey Bull. 81, pp. 353-354, 1891.

[8] Records of mining companies, which include the "transition shales" (p. 26) in the "White" limestone, give the average thickness as 160 feet.

quartzite, though thinner. These are usually thin-bedded gray to yellowish clay shales, which separate so as to present a smooth, gray, impermeable surface in the roof of a stope or tunnel. In some places they begin to appear 15 feet below the "Parting" quartzite, into which they grade by becoming interleaved with thin layers of quartzite. The transition from limestone to quartzite is therefore gradual in most places, and locally the shaly layers appear at brief intervals throughout the quartzite member, so that unless the quartzite is very carefully sought its presence may be missed entirely.

The "White" limestone is much less uniform than the "Blue" limestone both in lithologic character and in chemical composition, and is much more commonly interrupted by beds of clay shale and sandy shale at various horizons. Few of the individual beds of limestone are more than 3 or 4 inches in thickness, and layers of dark-greenish shale separate the pure limestone layers even where the limestone greatly preponderates. Where the limestone is decomposed into a soft material by the action of surface waters the thin-bedded character is usually still recognizable.

Some of the purer limestone layers throughout the district are more coarsely crystalline than the Leadville or "Blue" limestone; others are fine grained. The individual grains in the coarser limestone are as much as a millimeter or more in diameter and those in the finer-grained beds average 0.02 millimeter. Grains of dolomite predominate over those of calcite.

Some calcite grains are readily discernible in thin section by means of the twinning planes parallel to $-\frac{1}{2}$ R, and they can also be recognized in powdered samples by their index of refraction. Where identified in thin section they have irregular outlines and tend to surround dolomite grains. In all specimens of the "White" limestone examined calcite is present in considerable quantity, and on the whole is uniformly distributed. The dolomite grains are of the same size as those composed of calcite, and in thin section have a more distinctly rhombic outline. The rhombs are slightly clouded with a very fine dust, but some have a clear outer zone. Rhombic grains may be confused in thin section with similar grains of manganosiderite, which is abundant around ore bodies, but the distinction can readily be made by powdering the material and determining its index of refraction in oils. Thin sections of less pure limestone show a small amount of quartz, which fills interstices among dolomite grains and partly or completely incloses some of them. A little very fine-grained mineral resembling sericite is also present.

The insoluble residues of specimens from the Mikado and Star Consolidated mines consist mostly of minute flakes of kaolin or some similar aluminum silicate, with considerable pyrite in minute cubic grains. No quartz was identified here, but considerable amorphous or cryptocrystalline silica may be present, obscured by the conspicuous flakes of kaolin (?).

One of the most characteristic features of the "White" limestone is the occurrence at certain horizons of concretions and seams of white or cream-colored chalcedony or chert, evidently due to segregation of silica from impurities in the limestone. These chert lenses are often useful, especially underground, for distinguishing beds of the "White" limestone from those of the Leadville limestone. Chert also occurs in the Leadville limestone but is everywhere of a nearly black color. It has not been possible to detect in the white chert any trace of the minute organisms found in similar concretions in other limestones. The white chert layers remain unaltered in solid masses of sulphide ore that has completely replaced the inclosing limestone. (See pl. 31, *B*.)

Another characteristic feature of the "White" limestone, to which attention has been called by Patton,[9] is the presence of irregular lenticles, usually arranged parallel to the stratification, in which the silica is more abundant than through the body of the rock. Where the rock is unweathered these lenticles are imperceptible, but on weathered surfaces they stand out in relief.

CHEMICAL COMPOSITION

The "White" limestone is interrupted by so many layers of clay shale that its average chemical composition could be determined only by an average sample cut through the whole thickness of 160 feet from the base to the top. The single analysis quoted in the Leadville monograph can therefore have value only in determining the composition of the pure layers of limestone. No analyses were made of the shaly layers, so that their composition may only be inferred from their lithologic character.

Analyses of "White" limestone

	1	2
CaO	26.60	24.26
MgO	17.41	15.48
FeO	.83	
CO_2	40.01	36.26
SiO_2	11.84	22.71
Al_2O_3	1.66	1.18 (with Fe_2O_3)
Fe_2O_3	1.51	
Na_2O	.029	
K_2O	.017	
H_2O	.48	
SO_3		.07
P_2O_5	Trace.	.10
Cl	.05	
I	Trace.	
Organic matter		Trace.
	100.436	100.06

Two analyses of the unmineralized limestone layers are given above. The first, by W. F. Hillebrand, is

[9] Patton, H. B., op. cit., p. 51.

quoted from the Leadville monograph and represents a specimen from the quarry in California Gulch. The second is quoted from the description by Ricketts.[10]

The calculated mineral composition of No. 1 is as follows:

Mineral composition of "White" limestone from California Gulch

		Per cent
Calcite		1.5
Dolomite	$CaCO_3$, 44.70; $MgCO_3$, 36.54; $FeCO_3$, 1.39	82.6
Quartz		10.1
Aluminum silicate		2.6
Calcium silicate		1.5
Ferric oxide		1.5
Alkali and calcium chlorides		.1
Water (in aluminum silicate, ferric oxide, and chlorides)		.5
		100.4

This calculation agrees closely with minerals found in thin sections and insoluble residues, although the percentage of calcite may be lower than the average, and the ratio of quartz to aluminum silicate appears higher than in the insoluble residues examined. The presence of a small amount of iron carbonate is characteristic of most dolomite rock. It may also indicate a slight impregnation of the rock by manganosiderite, but that mineral is confined to the immediate vicinity of ore bodies. The aluminum silicate is too finely divided to be determined accurately. Its mean index of refraction (about 1.56), together with the deficiency of potash, shows that very little, if any, sericite is present. No calcium silicate was recognized, and the amount recorded merely expresses an excess of lime over the available carbon dioxide. Ferric oxide is present as minute dustlike grains, some of which are evidently derived from pyrite.

The ratio of dolomite to calcite in the Yule limestone is further illustrated by the following table recalculated to 100 per cent from partial analyses by Hillebrand—Nos. 1 and 2 given above and the others in the Leadville monograph, page 598.

Ratio of dolomite to calcite in Yule limestone

		1	2	3	4	5	6	7
Dolomite	$CaCO_3$	53.1	50.4	53.5	44.6	44.0	47.3	54.3
	$MgCO_3$[a]	45.1	42.3	45.0	37.5	37.0	39.7	45.7
		98.2	92.7	98.5	82.1	81.0	87.0	100.0
Calcite		1.8	7.3	1.5	17.9	19.0	13.0	0.0
		100.0	100.0	100.0	100.0	100.0	100.0	100.0

[a] Includes also (FeMn)CO_3.

[10] Ricketts, L. D., The ores of Leadville and their mode of occurrence as illustrated in the Morning and Evening Star mines, Princeton, 1883.

1. Quarry in California Gulch.
2. Carbonate Hill, Morning Star or Evening Star mine.
3. Dyer Mountain, marbleized beds.
4. Below Dyer mine, Dyer Mountain (light blue, compact).
5. Below Dyer mine, Dyer Mountain (pinkish, decomposed).
6. Red Amphitheater, Buckskin Gulch.
7. Pure dolomite for comparison.

These recalculated analyses indicate that the "White" limestone as a whole contains considerable calcite. The original analyses, not quoted here, indicate that its shaly material ranges from very little to nearly 50 per cent of the rock by weight. In both of these respects the "White" limestone is strikingly different from the Leadville limestone, which is a nearly pure dolomite rock throughout.

ALTERATION

In certain places underground the "White" limestone is disintegrated and falls to a loose sand when struck with a hammer. Comparison of a sample of this sand with solid rock from the same bed in the Star Consolidated mine showed no appreciable difference in composition. The sand as well as the solid rock consists mostly of dolomite with considerable calcite and insoluble residue of kaolin (?) and pyrite. The rock has evidently been leached along the boundaries of its component grains. Calcite was presumably more readily dissolved than dolomite, but only a small part of it has been removed. Similar sand derived from the Leadville or "Blue" limestone is more abundant and is discussed on page 36.

GEOLOGIC AGE

The "White" limestone and the "Parting" quartzite were included by Emmons in the Silurian, but there now seems to be little doubt that both are of Ordovician age. In the "White" limestone no fossils in place were discovered by Emmons. He stated, however, that casts of *Rhynchonella* between *R. neglecta* and *R. indianensis* of the Niagara (middle Silurian) epoch were obtained from a prospect shaft in California Gulch not far from the "White" limestone quarry, in such a position as to suggest that they had been derived from beds of this formation at least 50 feet above its base. On the other hand, specimens obtained by Emmons from the talus slopes at the foot of cliffs in Dyer Amphitheater and on West Sheridan Mountain, in a matrix of light-drab limestone that renders it reasonably certain that they were derived from some of the beds of this horizon, contained the following species which according to Schuchert [11] suggest basal to Middle Ordovician: *Leptaena melita*, *Orthisina* like *O. pepinensis*, siphon of an *Endoceras*.

Patton cites certain indeterminable cystids in a poor state of preservation obtained about halfway up the slope of Pennsylvania Mountain, on the east side of the Mosquito Range and states that, according to Edwin Kirk, of the United States Geological Survey, they represent types so far known only from the Ordovician.

Some of the fossils collected by Emmons are discussed by Girty [12] in the following paragraph:

> There is but little evidence of the existence of Upper Silurian strata in Colorado. Emmons states (Leadville monograph, p. 61): "Casts of a *Rhynchonella*, between *R. neglecta* and *R. indianensis* of Niagara epoch, were found in the prospect shaft in California Gulch, not far below the White limestone quarry, in such a position that they must have been derived from the beds of this horizon at least 50 feet above the base of the formation." The evidence of this one species is not important, nor is the deduction drawn from it by Mr. Emmons that any portion of the Yule limestone is of Upper Silurian age; and in view of the extreme rarity of Upper Silurian strata in the West, considering besides that none are known elsewhere in Colorado, and that the Yule limestone has in many places furnished an Ordovician fauna, it is only fair to reason that Upper Silurian time is not, so far as known, represented in the rocks of the State, and that the evidence for its existence near Leadville is due to the imperfect condition of the fossils or to ill-considered identifications.

From the comparative certainty with which the "White" limestone of Leadville may be correlated with the Yule limestone of the Tenmile district and the probable accuracy of its correlation with the same limestone in the Aspen, Crested Butte, South Park, and other districts of central Colorado, there would seem to be every reason for regarding the geologic age of the "White" limestone as unquestionably Ordovician.

"PARTING" QUARTZITE MEMBER

NAME

Above the "White" limestone and below the Leadville or "Blue" limestone occurs a comparatively thin stratum of quartzite which is remarkably persistent both in the Leadville district and throughout the Mosquito Range region. To this quartzite the name "Parting quartzite" was given by Emmons, as it separates the two limestones. Its persistence has made it valuable above all other beds in the Leadville region for the determination of the amount of movement which has taken place along faults. As explained on preceding pages, this quartzite corresponds to the upper part of the Yule limestone, and it is therefore here treated as a member of the Yule.

PETROGRAPHY

In its characteristic development the "Parting" quartzite is a rather thick bedded quartzite which ranges from 10 to 70 feet in thickness and averages 40 feet. Its thickness and the changes in its lithologic character may be appreciated by an examination of the shaft sections shown in Figure 9 and Plate 29. It is in few places sharply marked off from the blue Leadville limestone above and the "White" limestone below but generally appears to pass into these limestones through a series of very thin shaly beds, which are in some places calcareous, in others argillaceous, and in still others sandy. Locally there are successive alternations of thin beds of quartzite, limestone, and shale of different kinds. These shaly beds between limestone and quartzite have customarily escaped the observation of those interested in mining. In nearly all records of drill holes and shafts they are included without further comment in the limestone or are set down as porphyry. Besides marking the transition of quartzite into the adjacent limestones they occur in variable thickness and at irregular intervals through the quartzite itself. In some places the "Parting" quartzite is divided into as many as five different layers of quartzite and shale, the shale layers equaling those of quartzite in thickness. As the shaly layers, especially if calcareous, are more readily replaced by mineralizing solutions many of the ore bodies that are said to occur in the quartzite are due merely to the replacement of shaly layers between the quartzite beds. The shaly layers have also afforded paths for intrusive porphyry bodies, and sills of both the "White" porphyry and the "Gray" porphyry are found here and there within the "Parting" quartzite.

The quartzite layers consist of grains of bluish-white quartz which range from 0.25 to 5 millimeters in diameter and average about 0.5 millimeter. In places large pebbles of quartz are present. Component quartz grains are seen under the microscope to consist of more or less well-rounded grains enlarged by the addition of interstitial silica. It is usually very difficult to detect the boundary between the newly added quartz and the original grain, but the addition of cementing material has imparted to the grains an interlocking character. In the less pure beds the matrix consists partly or wholly of carbonates and aluminum silicates. The original quartz grains are filled with a great profusion of indeterminable minute inclusions and are presumably derived from the pre-Cambrian granite and related rocks that constituted the land surface from which the material was derived. Inclusions of

[11] Written communication to J. D. Irving.

[12] Girty, G. H., The Carboniferous formations and faunas of Colorado: U. S. Geol. Survey Prof. Paper 16, p. 156, 1903.

muscovite and minute rutile needles are present locally in the quartz grains.

Conglomerate occurs in a few places at the base of the quartzite. Where it is weathered some of the quartzite has a sandy appearance, as corrosion of the matrix has left the original detrital quartz grains.

In many places where oxidation is deep and the solvent action of ground water has been increased by acids derived from the oxidation of ore bodies the quartzite, particularly in the beds with carbonate matrix, has been completely disintegrated into a loose quartz sand. In the Roberts shaft such a sand was charged with water and was so completely disintegrated that it became a quicksand and made mining operations for a time very difficult. This condition is particularly common in the Downtown district.

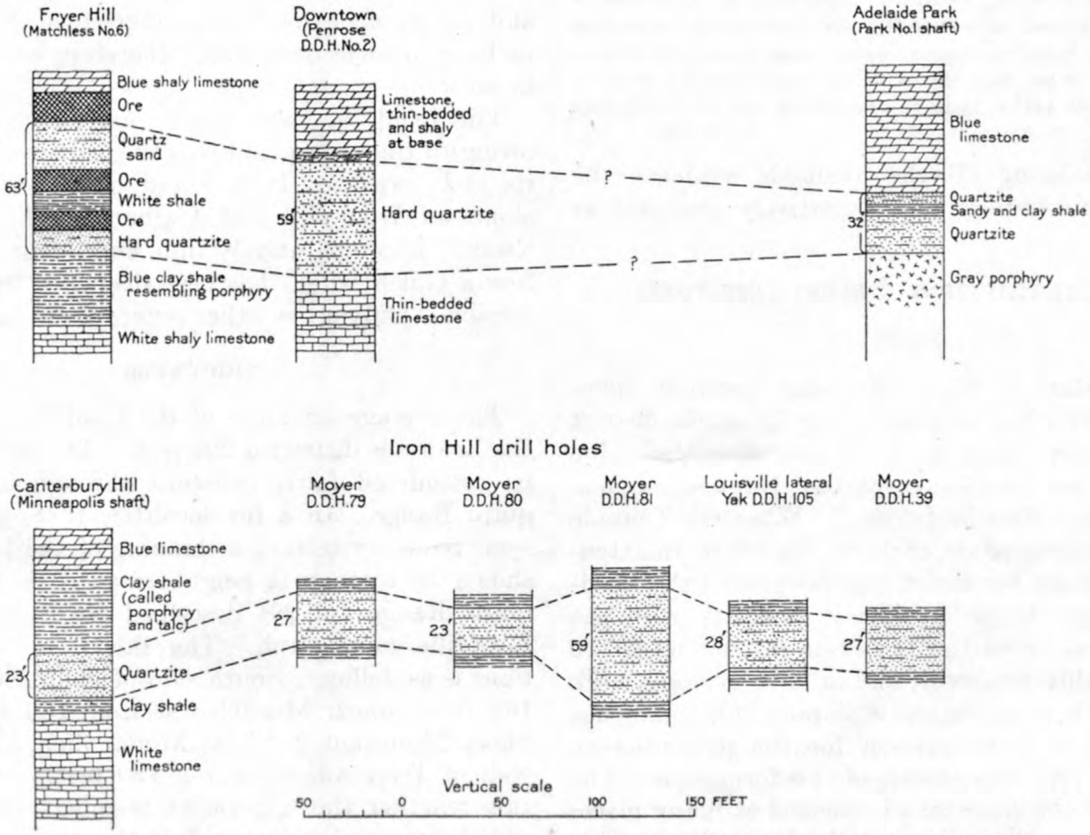


FIGURE 9.—Columnar sections showing variations in thickness and lithology of "Parting" quartzite in Leadville district

RELATION TO MINERALIZATION

The "Parting" quartzite has in most places been singularly resistant to the action of mineralizing waters. In a few places, however, ore bodies formed by replacement of the limestone above or below extend into or even through the quartzite. Where the quartzite is considerably mineralized, it is appreciably altered to finely divided sericite, which has accumulated first as patches between the quartz grains and then has replaced the grains themselves until a large mass has accumulated in the midst of the quartzite. Sulphides are commonly present in the central parts of such sericitic masses.

GEOLOGIC AGE

The "Parting" quartzite is generally in apparent conformity with the blue Leadville limestone above and the "White" limestone below, at least so far as can be determined by observations within the Leadville district. Emmons, however, noted what he believed to be an unconformity between the quartzite and the Leadville limestone on the East Fork of Arkansas River. He also mentions a peculiar brecciated structure at the base of the Leadville limestone which he interprets as an indication of unconformity.

Patton[13] mentions two places where the "Parting" quartzite is absent. One of these is on the summit of Mount Lincoln, the other a cliff section on the side of a gulch running east from the summit of Mount Bross. This absence may be indication of a stratigraphic break. Furthermore, the few fossils thus far found in adjacent formations suggest stratigraphic breaks at both its upper and its lower contact.

The Leadville limestone is probably in its lower members Devonian. The Silurian appears to have no representatives in the Leadville district. An unconformity would therefore indicate that during the entire Silurian and part at least of Devonian time a land surface must have existed that was subject to erosion.

No fossils have ever been recorded as having come from the "Parting" quartzite in the Leadville region. Its geologic position can not therefore be accurately

[13] Op. cit., p. 52.

stated. Spurr in his Aspen monograph correlates the "Parting" quartzite in the Aspen district with that at Leadville and on the basis of the evidence furnished by fish remains assigns the quartzite to the Devonian. This matter is considered at some length by Girty,[14] who sums it up as follows:

Although Spurr found Devonian fishes in the Parting quartzite at Aspen, it should be borne in mind that similar fish remains of Devonian types occur in the Harding sandstone, whose Ordovician age seems to be secure, and in the calcareous division of the Yule limestone in the Crested Butte quadrangle, of whose Ordovician age there is also little doubt. In view of these facts the force of this evidence is largely destroyed. Considering that the only known Paleozoic horizon in Colorado distinguished for its fish remains is in the Ordovician, that the Parting quartzite is separated from the Leadville limestone, at Leadville at least, by an erosional unconformity, and that the lower portion of the Leadville limestone contains over large areas a Devonian fauna, it seems to me that the evidence preponderates in favor of the Ordovician rather than the Devonian age of the Parting quartzite.

After considering all the available evidence the "Parting" quartzite is here tentatively classified as Ordovician.

LEADVILLE LIMESTONE ("BLUE" LIMESTONE)

NAME

The formation to which the name Leadville limestone is applied has throughout the Leadville district and over a much greater area a prevailing dark-blue color, and it was for this reason that Emmons applied to it the term "Blue limestone." When the Tenmile district was surveyed, in 1881–82, the northern extension of the same formation was designated the Leadville limestone, in order that its identity with the "Blue" limestone of the Leadville district might be the more readily apparent, and in later geologic work by other authors in central Colorado this name has become fixed as a designation for the paleontologic and stratigraphic equivalents of this formation. The blue color of the limestone is masked at many places in the mineralized portions of the Leadville district, owing to the decolorizing action of either igneous intrusives or mineralizing solutions or both, so that the designation "blue" is not everywhere descriptive.

The use of the term "ore-bearing limestone" employed by Emmons has been abandoned as misleading. When the Leadville monograph was written there were reasons for believing that the ore would prove to be confined mainly to this formation, but the extensive exploration since that time has shown that the "White" limestone also has been extensively replaced by ore.

The Leadville limestone lies for the most part in apparent conformity upon the "Parting" quartzite and extends upward to the so-called "Weber shales," which appear to lie conformably above it.

[14] Op. cit., p. 161.

DISTRIBUTION

The Leadville limestone is present throughout the Leadville district except at a few localities where it has been eroded. One of these localities is just northeast of the Colorado Prince fault, where granite, porphyry, and Cambrian quartzite occupy the surface.

The Leadville limestone reaches the bedrock surface in several comparatively narrow, sinuous bands crossing the district in a general north-south direction. A very wide band of it having a roughly S-shaped form is indicated on the geologic map as present beneath the city of Leadville. It extends both north and south to the limits of the Leadville district. Data for the exact location of this limestone band are not available, and its presence has been determined by inference; its boundaries as drawn may therefore be considerably in error.

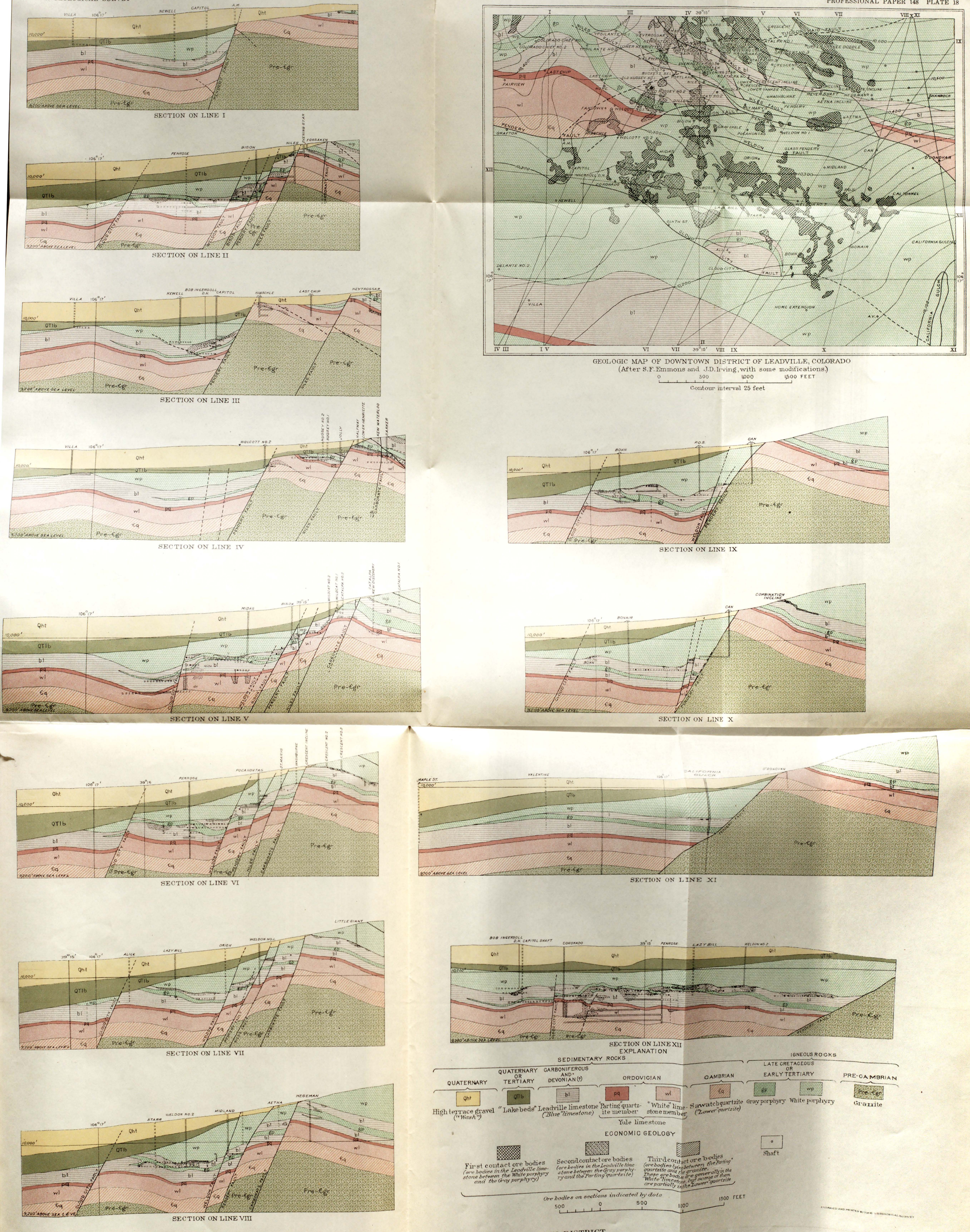
The Leadville limestone is rarely seen in outcrop, owing to the widespread covering of the glacial deposits and "wash." It is found on the steep western slopes of Iron Hill and Carbonate Hill, where the "wash" is comparatively thin, and in the bed of California Gulch, which has been deepened by postglacial erosion. Only a few other outcrops are known.

THICKNESS

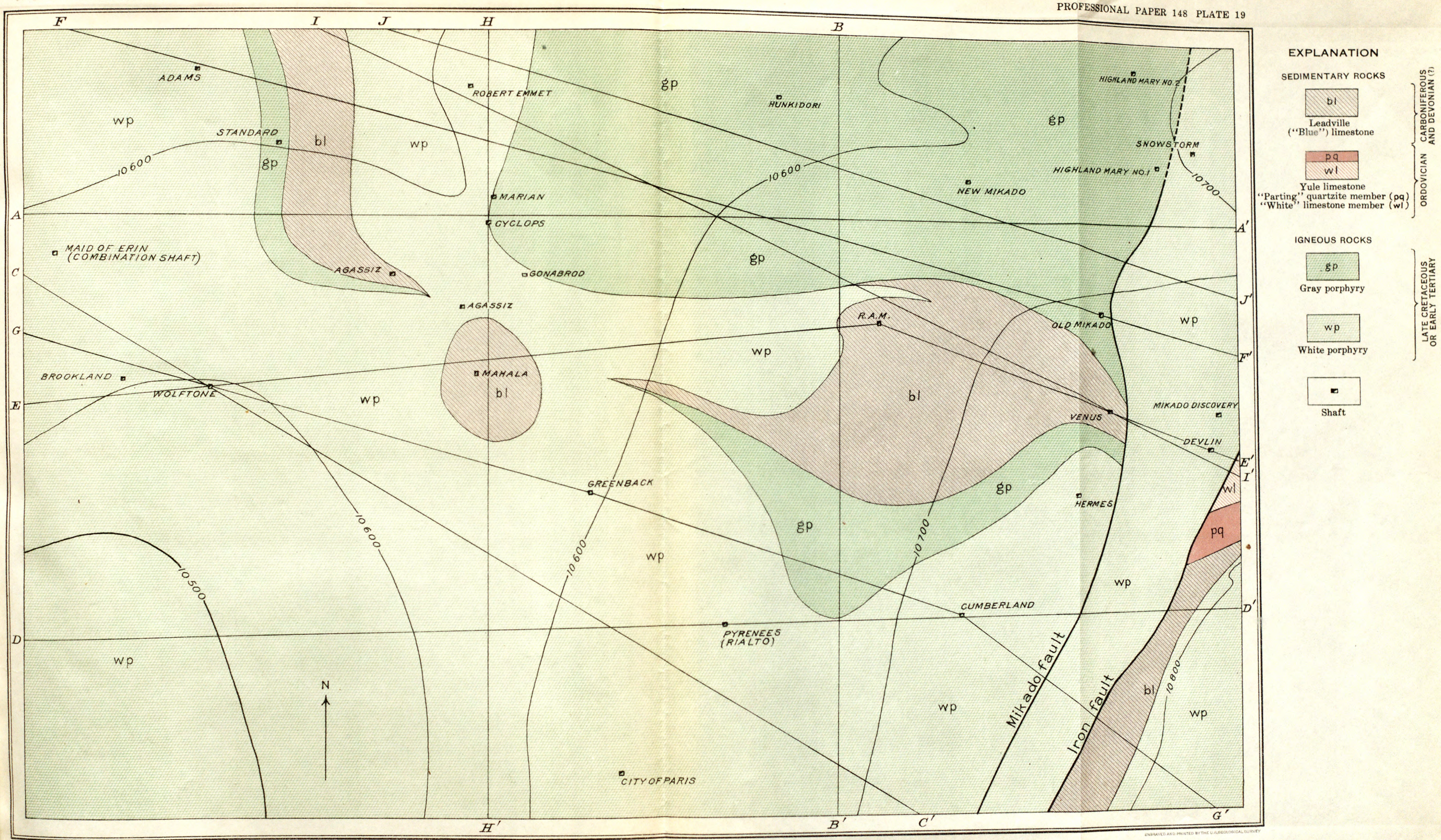
The average thickness of the Leadville limestone in the Leadville district is 200 feet. This thickness may be considered fairly constant throughout the Mosquito Range. In a few localities there seems to be some tendency toward a thinning of the formation, as shown by sections in neighboring parts of the Mosquito Range (pl. 29) described by Emmons in the Leadville monograph. The thickness in these sections is as follows: South side of Red Amphitheater, 160 feet; south Mosquito section, 130 feet; top of Sheep Mountain, 200 feet; Mount Zion, 125 feet; east wall of Dyer Amphitheater, 150 feet. It is not certain whether the uppermost members of the Leadville limestone are included in the first two of these sections. In the Downtown area there is a slight thinning of the Leadville limestone toward the west.

In spite of these variations in thickness, which may be ascribed to unequal sedimentation, the mine explorations have shown conclusively that over the larger portion of the Leadville district the Leadville limestone varies very little from its average thickness of 200 feet.

It must be remembered that this formation is nearly everywhere divided into several fractions by the porphyry sheets that have been forced into it. (See geologic sections on pls. 14–18, 20, 21, 23–26, and 28.) Where an intrusive sheet is very thick it may at first appear that the limestone is thinner than the average, but further exploration is likely to find the remainder of the limestone beyond the intrusive sheet.



GEOLOGIC MAP AND SECTIONS OF DOWNTOWN DISTRICT
1927

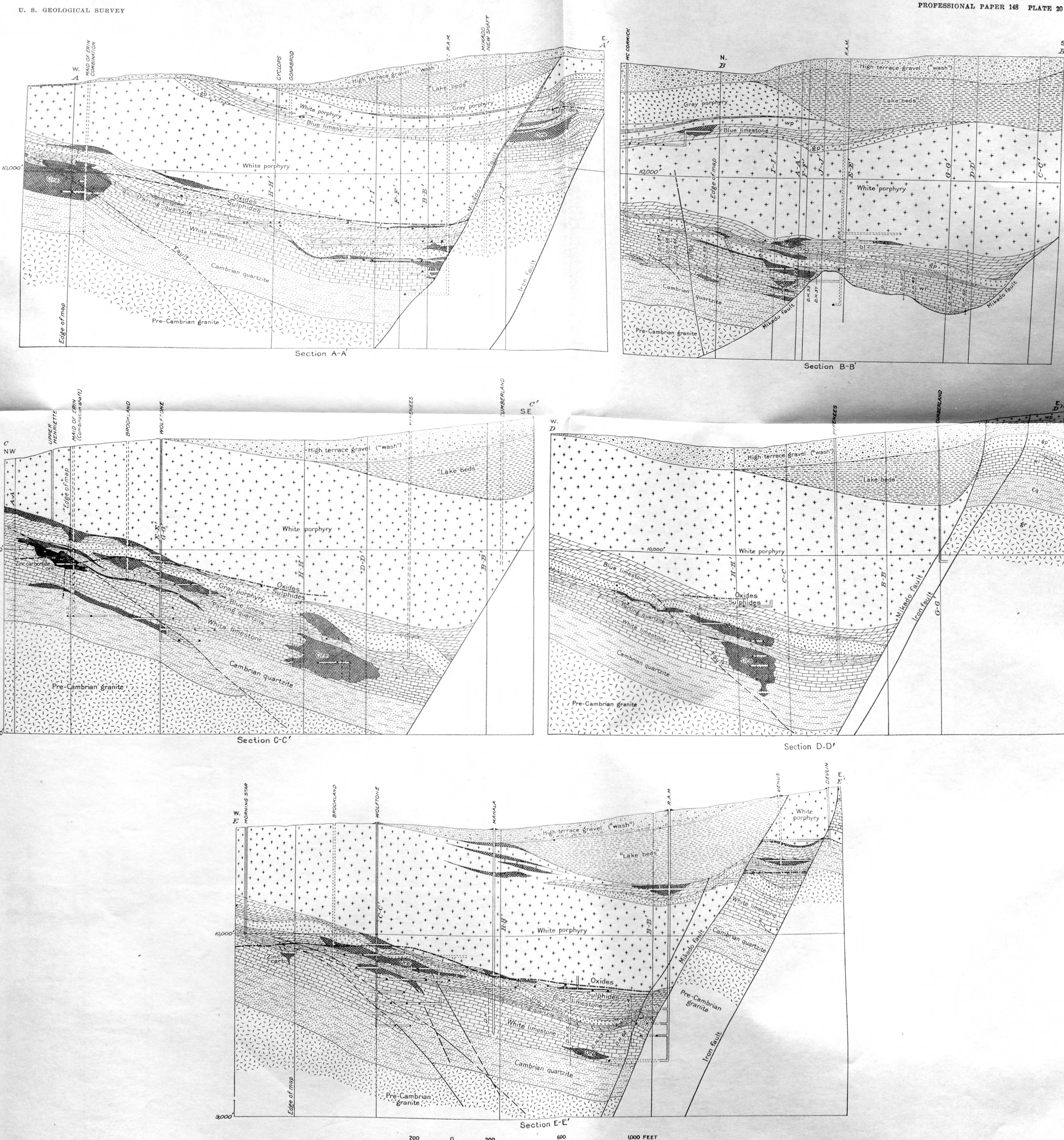


GEOLOGIC MAP OF GRAHAM PARK, LEADVILLE MINING DISTRICT, COLORADO

0 500 1,000 Feet

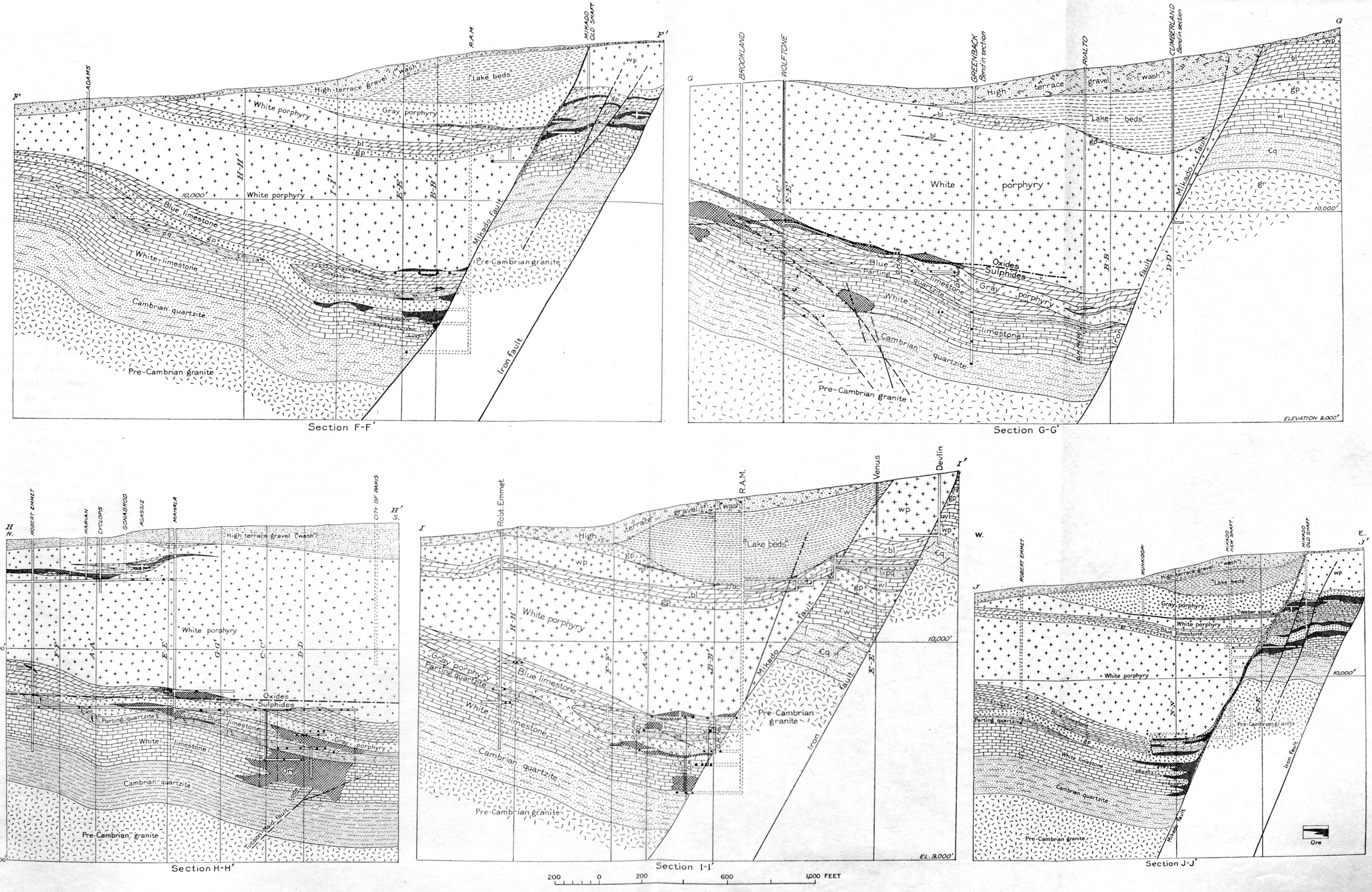
Contour interval 100 feet

1927



GEOLOGIC SECTIONS IN GRAHAM PARK

For lines of sections and explanation of symbols see Plate 19



GEOLOGIC SECTIONS IN GRAHAM PARK

For lines of sections and explanation of symbols see Plate 19

Correlations made in the manner above set forth also reveal a series of interesting variations in total thickness which are the result of mechanical deformation produced by the intrusives. In some places an irregular intrusive mass of porphyry occupies for a short horizontal distance almost the entire space between the underlying "Parting" quartzite and the overlying "Weber shales" or the "White" porphyry. Such a mass of porphyry has made room for itself by thrusting aside the limestone that formerly occupied the space. Evidences of such thrusting are numerous throughout the district and consist of steep and varying local dips, the effects of crushing, bedding faults, and results of other dynamic phenomena. The thickness of the Leadville limestone is locally increased in this way to as much as 250 feet, as illustrated in the sections on Plate 18 and in the Stevens mine on Rock Hill.

In some places portions of the limestone have been entirely surrounded by the intrusive porphyry. These inclusions are probably more numerous than has yet been noted, especially in the Breece Hill area to the east of the North Mike and South Mike shafts. The occurrence of a large, valuable ore body in one such inclusion of limestone was revealed in the Moyer mine by exploration based on recognition of the undue thinness of the Leadville limestone below the porphyry. The limestone throughout the mine between the "Parting" quartzite and the overlying "White" porphyry had a thickness of only 125 feet. The great width over which this undue thinness extended rendered its explanation by distortion due to the porphyry intrusion inapplicable. It was at first supposed that the missing 75 feet had been floated up on top of the "White" porphyry mass and had been removed by erosion from above what is now the top of Iron Hill. Some doubt as to this supposition existed in the minds of the managers, and it was decided to put up drill holes into the porphyry roof to ascertain whether additional limestone might not have been wholly inclosed in the porphyry mass. These drill holes disclosed the missing limestone, which was almost entirely replaced by ore.

PETROGRAPHY

The characteristic color of the typical Leadville limestone ranges from dark bluish gray in the coarser-grained beds to nearly black in the finer-grained beds, which are conspicuous in the upper part of the formation. Its basal beds are light gray. The bluish color is due to abundant uniformly distributed dustlike inclusions, most of which can not be identified even under the highest powers of the microscope. Emmons recognized that some of these inclusions were cavities, in which bubbles or drops of liquid were discernible. These he interpreted as alkaline chlorides, which the chemical analyses on page 35 show to be present. Some of the inclusions have been identified as pyrite or as limonite derived from pyrite; but most of them are bituminous matter, as shown by chemical tests of the insoluble residue.

Where the limestone is exposed on cliff faces its bedding is made clearer by weathering and usually shows individual beds that range from 6 inches to more than 3 feet in thickness. The average thickness of single beds in the upper two-thirds of the formation is about 3 feet. The lower third is thinner bedded. The bedding planes in some places are indicated by very thin, slightly more argillaceous layers. Underground the bedding is usually less conspicuous, and where surface waters have affected it they have robbed it completely of all semblance to bedding, so that in the oxidized zone the dip and strike are commonly difficult to determine.

Even the finest-grained varieties are distinctly crystalline and impervious. Calculation from the specific gravity of a specimen before and after reduction to powder indicates a porosity of only 0.03 per cent by volume. In the finer-grained beds single grains are barely discernible without a microscope; in the coarser-grained beds they may exceed a millimeter but are mostly only 0.2 or 0.3 millimeter in diameter. The coarsest grain is most conspicuous near ore bodies and intrusions of porphyry and in places where the rock has been deformed and recrystallized.

The rock consists almost entirely of dolomite in irregular interlocking grains, a few of which approach a rhombohedral outline (pl. 35, *A*). No other minerals may be recognizable in thin section, but the insoluble residue consists largely of irregular quartz grains dusted with black specks, a little alkalic feldspar (microcline and perhaps albite or oligoclase), pyrite in places altered to limonite, and bituminous matter. Some residues examined contain minute grains resembling fluorite, and others, well removed from ore bodies, grains resembling zinc blende.

A characteristic feature of the blue dolomite beds throughout the region is the presence of white streaks and patches of coarse-grained dolomite. The White dolomite commonly forms short parallel streaks between streaks of typical blue dolomite, and the combination has been aptly termed "zebra rock." Small vugs are commonly present in the white parts and are lined with rhombohedral crystals of dolomite, some of them with characteristic curved faces. On Carbonate and Iron hills and in the Red Cliff district, to the north, these patches of zebra rock are commonly found near ore bodies. Chemical tests show no appreciable difference in chemical composition of the white dolomite from that of the original rock, and the white dolomite is evidently the result of recrystallization during the period of ore deposition.

Chert ("flint"), shale, and quartzite are also present in the formation. Nodules and thin layers or seams of black chert are characteristic of the upper 50 feet and particularly the upper 20 feet of the dolomite. Where outcrops are considerably weathered these nodules remain as loose lumps of various odd shapes covering the ledge. Some nodules contain remnants of fossils, and some are hollow, with their interiors lined with quartz and pyrite crystals and perhaps filled with water. Where cherty dolomite has been replaced by white clay or "talc" along contacts with overlying porphyry, the chert nodules remain inclosed in the clay and become a conspicuous feature of the contact.

In several places 100 to 120 feet above the "Parting" quartzite prominent beds of dark-blue cherty silica or "flint" ranging in thickness from 2 to 9 feet are present. They underlie many of the oxidized ore bodies in the Downtown and Fryer Hill districts, but are also found where ore bodies are absent. For example, a "flint" bed of unusual persistence has been disclosed in workings beneath Poverty Flat, just north of the city limits (fig. 10). Some question has been raised as to whether these "flint" beds are original or were formed by replacement of certain beds of dolomite or limestone. No conclusive evidence on this question has been found, but the second view is favored.

At Iron Hill the Leadville limestone contains thin beds of quartzite which, where unaffected by surface waters, closely resemble the "Parting" quartzite and have frequently been mistaken for it. In the Downtown district the equivalent of these beds is leached to a loosely compacted sand. It is possible that these quartzite beds have been confused with the "Parting" quartzite in some of the workings beneath Fryer Hill, where the Leadville limestone is unusually thin; but the strata are so isolated between thick sheets of porphyry and so few of the workings reach the "White" limestone that the identity of some of the quartzite must remain in doubt. As already stated, these quartzite beds are the only lithologic suggestion of a boundary between the Mississippian part of the Leadville limestone above and the Devonian (?) part below.

Shale is mostly limited to the lowest and highest portions of the Leadville limestone. In some places the blue dolomite is in sharp contact with the underlying "Parting" quartzite; in others 10 to 20 feet of shale intervenes. The lower third of the limestone, more thinly bedded than the average, locally contains layers of finely laminated green shale from 6 inches to 4 feet thick. Beds of this kind were found in the Wolftone mine on the third level 150 feet southeast of the shaft, in the roof of a stope. The transition to these shale beds is commonly marked by lenticular banding and a structure resembling intraformation breccia, with lenses or fragments of limestone embedded in shale. Greenish shale has also been found along a drift connecting the Star and Bon Air shafts in the Downtown district. Thin alternating beds of shale and limestone are locally present at the top of the Leadville limestone and are apparently transitional into the overlying "Weber shales," but in most places the contact between blue dolomite and the black "Weber

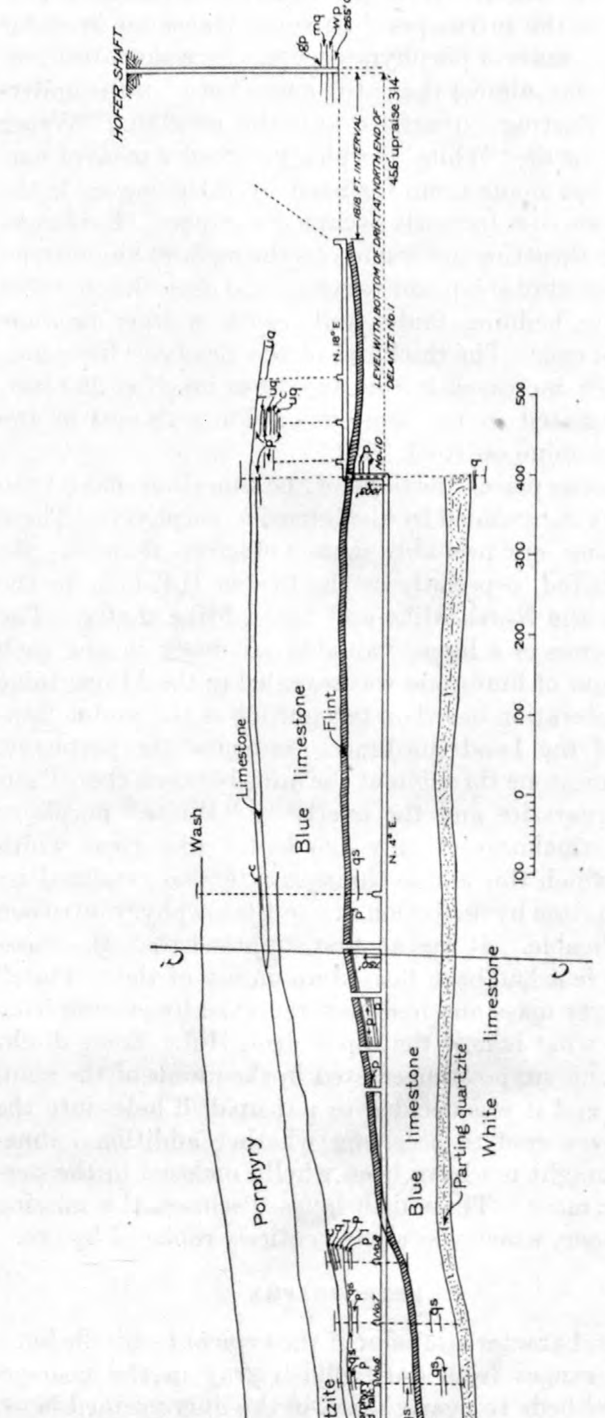


FIGURE 10.—Geologic section between Delante No. 1 and Hofer shafts showing "flint" layer in "Blue" limestone. By S. W. Mudd. *c*, Contact; *q*, quartzite; *l*, limestone; *p*, porphyry; *qs*, quartzitic sandstone; *hq*, hard quartzite; *gp*, Gray porphyry; *uq*, upper quartzite; *mq*, micaceous quartzite; *wp*, White porphyry

shales" is abrupt, and the evidence furnished by fossils indicates a stratigraphic break there.

CHEMICAL COMPOSITION

In chemical composition the Leadville limestone has been shown by Emmons to be singularly uniform and to approach closely the composition of a normal dolomite. The question of dolomitization was not thoroughly considered during the early survey, and in the smaller area covered by the second survey no evidence was found that would add appreciably to that already published on the origin of dolomite. The original chief constituent of the rock was presumably calcium carbonate, which was replaced by dolomite before the rock became consolidated. The four analyses quoted by Emmons are repeated below, together with two made in the laboratory of the United States Geological Survey by J. G. Fairchild.

Analyses of Leadville limestone

	1	2	3	4	5	6 Soluble in 1:3 HCl	6 Insoluble
CaO	30.79	30.43	29.97	27.26	29.84	30.64	
MgO	21.14	20.78	21.52	20.05	21.32	21.23	
FeO	.24	.38	.13	.57	.71	.27	
MnO	Trace.	.05	.20	.06	.19	Trace.	
CO_2	46.84	46.93	47.39	43.79	45.18	46.88	
SiO_2	.21	.70	.27	7.76	.34	.04	0.19
Al_2O_3	.27	.17	.04	.11	.22	.06	.15
Fe_2O_3	.21	.11	.22	.10	.09	.00	
Na_2O	.062	.094	.016	.037	.59		.11 (with K_2O)
K_2O	.03	.046	.013	.017	Trace.		
H_2O-	.22 (with H_2O+)	.04 (with H_2O+)	.07 (with H_2O+)	.05 (with H_2O+)	.15	.00	
H_2O+					.32	.18	
SO_3	Trace.			Trace.		.03	
P_2O_5	Trace.	.12	.03	.07	Trace.	Trace.	
Cl	.10	.143	.041	.062	Trace.	.08	
FeS_2	Trace.	Trace.		Trace.	.35		.00
TiO_2					.00		.00
Organic matter	.03	.025	.015	.07	[a] .17		.26
	100.142	100.018	99.925	100.006	99.47	100.12	

[a] Approximate.

1. Upper part of Leadville ("Blue") limestone, Silver Wave mine. Analyst, W. F. Hillebrand.
2. Upper part of Leadville ("Blue") limestone, Dugan quarry. Analyst, Anthony Guyard.
3. Partly disintegrated rock from upper part of Leadville ("Blue") limestone, Glass-Pendery mine. Analyst, Anthony Guyard.
4. Near base of Leadville ("Blue") limestone, Montgomery quarry. Analyst, Anthony Guyard.
5. Dump of Stephens mine; exact horizon not known. Analyst, J. G. Fairchild. Specific gravity in hand specimen, 2.774; specific gravity of powder, 2.865; calculated porosity by volume, 0.0319 per cent.
6. Lower beds in quarry at south end of Iron Hill. Shows no weathering or other alteration. Sample collected in 1922. Analyst, J. G. Fairchild.

Calculated mineral composition of Leadville limestone

	1	2	3	4	5	6
Dolomite: $CaCO_3$	53.18	52.00	53.40	48.53	53.30	52.82
Dolomite: $MgCO_3$	44.39	43.68	44.86	42.03	44.77	44.40
Dolomite: $FeCO_3$	.38	.70	.24	.92	1.16	.44
Dolomite: $MnCO_3$	Trace.	.08	.35	.07	.36	Trace.
Calcite	.10	2.00	.00	.00	.00	.00
Calcium phosphate	Trace.	.27	.07	.15	Trace.	Trace.
Excess lime	.95	.00	.00	.00	.00	[a] .64
Gypsum (or anhydrite)	Trace.			Trace.		.07
Quartz	.55 (with feldspar)	.50	.23	7.65	.62 (with feldspar)	.55
Feldspar and aluminum silicate		.36	.09	.24		
Ferric oxide	.21	.11	.22	.10	.09	.00
Sodium chloride	.12	.18	.05	.07	Trace.	.00
Potassium chloride	.07	.07	.02	.03	Trace.	.00
Calcium chloride						.13
Water	.22	.04	.07	.06		.17
Pyrite	Trace.	Trace.		Trace.	.35	
Organic matter	.03	.03	.02	.07	.17	.26
	100.20	100.02	99.62	99.92	100.82	99.51
Lead carbonate		Trace.			.42	

[a] Aside from experimental error the excess CaO may be largely combined with organic matter.

The calculated mineral composition based on these analyses shows that the Leadville limestone is on the whole a typical dolomite rock with little insoluble impurity. Without an opportunity for microscopic examination of the samples from which analyses 1 to 4 were made an exact correlation of the chemical with the mineral constituents is impossible, but the following statement is believed to be approximately correct. The ferrous oxide (FeO) and manganous oxide (MnO) are nearly if not quite all present as carbonate in the original dolomite grains; but the manganese in Nos. 3 and 5 may be largely present as an oxide Analysis 1 shows a fraction of 1 per cent and analysis 2 about 2 per cent of calcium carbonate in excess of that required to form the original ferruginous dolomite. In analysis 1 a little more lime (CaO) is apparently present than is required to combine with the available carbonate, silicate, and chloride radicles; the determination of carbon dioxide (CO_2) may therefore be a trifle low. In analyses 3, 4, and 5 there is not quite enough lime to make the ratio of 1:1 with magnesia required for dolomite, and the deficiency is somewhat greater if the ferrous oxide in dolomite is considered, thus suggesting the presence of a little of the secondary carbonate manganosiderite, which is so abundant around the ore bodies. The presence of a little zinc, which would be calculated as magnesia unless determined separately, may account for the small excess of magnesia in the analysis. The chlorine, as shown by Cross, Hillebrand, and Guyard,[15] is present as chlorides in minute fluid inclusions within the dolomite. It is sufficient to form chlorides with all the potash and soda, and Guyard reported traces of magnesium and calcium chlorides as well. The excess lime with chloride and sulphate radicles in the soluble part of No. 6 indicate the presence of calcium chloride and sulphate, whereas the alkalies and alumina in its insoluble part are present in feldspar, which has been detected in the insoluble residue. The soda recorded in No. 5 is unaccountably high and is probably due to an error in calculation. The phosphorus pentoxide (P_2O_5) is presumably present as tricalcium phosphate, but no phosphate minerals have been identified in the limestone. The silica is present in feldspar and quartz.

ALTERATION

DOLOMITE SAND

A characteristic feature of the Leadville limestone in the vicinity of oxidized ore bodies is its disintegration into dolomite sand by the leaching action of acid waters. This material retains the appearance of solid rock along the walls of drifts but falls to a loose sand when struck with a pick or hammer. This sand has been found as much as 500 or 600 feet below the surface. Plate 32, *C* and *D*, shows the process of alteration into dolomite sand. The concavities shown in *C* were originally partly filled with dolomite sand which retained in large measure the original solid appearance of the unaltered rock. In *D* the reverse side of the same specimen is shown, and it is seen that a small coating of dolomite sand is still clinging to the solid core.

The dolomite sand under the microscope shows an aggregate of grains which differ in no respect from the dolomite grains in the solid rock mass. They show very little if any tendency toward rounding by solution and have apparently been developed by a simple separation of the interlocking grains from one another.

Partial analyses of dolomite sand from the Fortune mine are given below.

Analyses of dolomite sand

Determinations

	1	2	3	4
$CaCO_3$	54. 15	53. 90	55. 14	54. 09
$MgCO_3$	44. 19	44. 10	44. 29	43. 79
	98. 34	98. 00	99. 43	97. 88

Recalculated to 100 per cent

	1	2	3	4	Pure dolomite
$CaCO_3$	55. 08	54. 97	55. 46	55. 26	54. 30
$MgCO_3$	44. 92	45. 03	44. 54	44. 74	45. 70
	100. 00	100. 00	100. 00	100. 00	100. 00

These analyses, as well as those of the solid rock are close to the theoretical composition of pure dolomite. They indicate the presence of a very small quantity of calcite, thus resembling analyses 1 and 2 on page 35. A qualitative test made on a specimen of fresh-appearing "Blue" limestone from the Mikado mine showed that it disintegrated to dolomite sand when immersed for several hours in dilute acetic acid. The dissolved material consisted of lime, magnesia, and a very little iron.

Part of the sample represented by analysis 6 on page 35 was leached with dilute acetic acid by J. G. Fairchild with the following results:

Material dissolved from "Blue" limestone in 15 minutes' treatment with dilute acetic acid.

Strength of acid	CaO (per cent)	MgO (per cent)	FeO (per cent)	Molecular ratio, CaO : MgO
1:3	2. 23	1. 55	0. 00	1. 03 : 1
1:6	3. 16	2. 19	. 00	1. 04 : 1
1:9	2. 83	1. 87	. 00	1. 09 : 1

As no calcite was found in this sample, the dissolved material evidently came from dolomite, from which the $CaCO_3$ was leached a little more rapidly than the

[15] U. S. Geol. Survey Mon. 12, p. 645, 1886.

$MgCO_3$, especially with the more dilute acid. Although no iron was leached from this sample in 15 minutes, the results obtained in the longer leaching of the Mikado sample show that iron carbonate is very slowly soluble. The presence of a little calcite would hasten the disintegration of dolomite rock, but the experiments just cited show that acid waters penetrating along the boundaries between grains will attack the dolomite itself sufficiently to reduce the rock to sand.

This tendency of the Leadville limestone to alter into dolomite sand is often the occasion of serious difficulty in shaft sinking and in mining operations, for the sand mingled with water runs into workings like quicksand. Indeed, some drifts driven into it have filled with such rapidity that miners have been barely able to escape with their lives.

CONTACT METAMORPHISM

In some places where the limestone has been affected by the heat of adjacent intrusive bodies it is bleached so that it approaches typical "White" limestone in color. Aside from this bleaching and a slight marbleization, which may nearly everywhere be as readily attributed to recrystallization during deformation as to the effect of intrusive masses, the Leadville limestone has been singularly little affected by the intrusives. Here and there, however, notably in the Ibex and Penn mines, it is thoroughly altered to silicates of magnesia and lime. Later alteration has nearly everywhere changed these silicates into serpentine, but the rock has been so greatly altered in the Ibex and Penn mines that much of it can be distinguished from the fine-grained intrusive rock only by the bedding planes.

GEOLOGIC AGE

The upper part of the "Blue" limestone is regarded as Mississippian, and the lower part is tentatively assigned to the Devonian. Fossils are scarce and have been found only in the upper part. None were found during the resurvey of the district, and the original specimens collected by Emmons and his assistants were redetermined and commented on by Girty [16] in 1903 as follows:

> The presence of a retzioid of the type *Eumetria verneuiliana* would, if the determination were based on adequate material, be almost conclusive; but as it is, the value of this evidence is somewhat diminished. This occurrence, however, the absence of characteristic and common Upper Carboniferous species, the affinity and sometimes identity with Mississippian forms of such as are present, together with the stratigraphic and zoologic relations of this fauna with other Mississippian faunas of Colorado, seem to me satisfactory evidence of its Mississippian age at least.

[16] U. S. Geol. Survey Prof. Paper 16, pp. 221, 222, 1903.

Distribution of Mississippian species in the Leadville limestone of the Leadville district

	2372	2373	2374	2375	2376	2377	2378	Total
Coelenterata:								
Zaphrentis? sp. b	---	---	×	---	---	---	---	1
Brachiopoda:								
Orthothetes inaequalis	---	---	---	---	---	( )	---	(?)
Spirifer sp. a	---	---	---	---	---	×	---	1
Spirifer sp. b	×	×		×	---	×	×	5
Seminula subquadrata	---	---	---	×	---	×	×	3
Eumetria woosteri	---	---	---	(?)	---	---	---	(?)
Pelecypoda:								
Myalina arkansana?	×	---	---	---	---	×	---	2
Conocardium sp	---	---	---	×	---	---	---	1
Gastropoda:								
Straparollus cf. S. spergenensis	---	---	×	---	×	---	---	2

In the opinion of Girty,[17] the fauna of the upper part of the Leadville limestone is of early Mississippian age, equivalent to the Kinderhook and possibly lower Burlington of the Mississippi Valley, and is more closely related to that of the Millsap limestone of the Front Range than to that of similar limestones in the Aspen and Crested Butte districts, which lie to the west of the Sawatch Range, and suggests that this range marks the site of a more effective zoologic barrier than any interpolated by the known pre-Cambrian rocks of the Front Range. This suggestion is strengthened by the westward thinning of the Leadville limestone and by the presence of quartzitic beds in its western part (p. 34).

Emmons had inferred that the "Blue" limestone and the upper portion of the overlying formations up to and including the Cretaceous at one time arched over large pre-Cambrian protaxes that lie between South Park and the Front Range, a mountainous area consisting of pre-Cambrian and volcanic rocks, and having a width in an east-west direction of about 210 miles. Lee [18] has shown that the Cretaceous was continuous over this area, but the manner in which the Cretaceous formations lap over the pre-Cambrian at Breckenridge [19] throws some doubt on a former possible continuity of the Leadville limestone, in spite of the affinities of its fossils with those of the Millsap limestone.

The possible Devonian age of the lower part of the Leadville limestone is based on its stratigraphic equivalence with limestones in the Crested Butte, San Juan, and Salida regions, as shown in the table opposite page 22. The faunas in the lower parts of these limestones

[17] Idem, pp. 217, 229.

[18] Lee, W. T., Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 95, pp. 27-58, 1916.

[19] Ransome, F. D., U. S. Geol. Survey Prof. Paper 75, pp. 66-67, 1911.

have Devonian characteristics. The following quotation from Girty[20] bears upon this point:

It seems probable that it [the Devonian fauna] will also be found, if sought for, in the lower part of the Leadville limestone at Leadville and in fact wherever this formation is exposed in Colorado.

WEBER (?) FORMATION

NAME

Above the "Blue" or Leadville limestone, in apparent conformity, is a series of strata to which collectively Emmons has applied the names "Weber grits" and "Weber formation" and which he subdivided into a lower shaly division called "Weber shales" and an upper quartzitic and sandy division called "Weber grits proper." The name Weber was apparently derived from the Weber quartzite of the Wasatch Mountains of Utah, with which a correlation was made that now seems to be of doubtful accuracy. For the convenience of the mining public, however, the name is retained in this report, the doubt regarding its appropriateness being indicated by a question mark, and its subdivisions are designated by the familiar though questionable terms "Weber grits" and "Weber shales."

DISTRIBUTION, THICKNESS, AND STRUCTURAL RELATIONS

The distribution of the Weber (?) formation is shown on Plate 11. Although it does not crop out within the Leadville district west of Breece Hill, its lower shaly portion, ranging from 20 to 300 feet in thickness, is singularly persistent in mine workings farther west. Where a limestone mass is included between sheets or sills of porphyry a few feet or inches of black shale overlying it suffices to prove that it represents the uppermost beds of the Leadville ("Blue") limestone. The contact between shale and limestone is usually sharp, but in some places is represented by a zone of alternating layers of limestone and shale.

The greatest thickness of the Weber (?) formation within the Leadville district is in the northeast corner. There it is approximately 1,000 feet, as near as it may be estimated by continuation of the structure from known underground workings near by. Its thickness in neighboring regions, however, as estimated by Emmons, inclusive of the 150 to 300 feet of "Weber shales," is from 2,650 to 2,800 feet.

PETROGRAPHY

On the first map of the Leadville district the two divisions of the Weber (?) formation were mapped separately. Extensive exploration in later years, however, has shown that the line of separation between them is usually difficult to locate with accuracy, so that the two members of the formation can not be satisfactorily distinguished on the map. They have therefore been indicated by one color on Plates 11, 13, and 27.

The lower or shaly division consists nearly everywhere of extremely thin-bedded black shale, the individual layers of which are mostly less than one-sixteenth of an inch thick. They are heavily charged with bituminous matter, and many thin seams of impure bituminous coal are found with them. The black shale has rarely yielded to the replacing action of mineralizing waters. It therefore forms in many places a comparatively smooth, even roof for the blanket ore bodies which are so common in the limestone below. In some localities, as on Iron Hill, the place of the black bituminous shale is taken by a greenish shale with little or no bituminous matter, which is somewhat more easily replaced by ore than the usual black variety. The place of the black shale in certain other places is taken by calcareous shale. Throughout the series, except in the lowermost layers, intercalated beds of coarse micaceous quartzite are common.

The contact between the shale and the overlying coarse sandy beds of the "Weber grits" is in some places sharp but more commonly is a transition through an alternating series of shale and sandstone.

The upper and major part of the "Weber grits" consists mainly of coarse sandstone or "grits" passing into conglomerate. The typical rock, which in many places forms massive beds of considerable thickness and constitutes a prominent feature in the sections afforded by canyons, is coarse grained and white and consists of well-rounded grains and pebbles, mainly of white and in part of pinkish quartz. In the coarser conglomerate feldspar can often be distinguished, and this mineral is widely disseminated in fine grains throughout the sandstone; but fragments of recognizable pre-Cambrian schist are rarely seen. It would seem, therefore, that these beds were derived mainly from the coarser pre-Cambrian granite.

Next to the pebbly sandstone and conglomerate the most abundant constituents of the formation are quartzose shale and micaceous sandstone, which are generally coarse grained and of a greenish hue and resemble mica schist. The lamination of these beds is very regular, and they commonly weather out in slabs or flags of considerable size. The mica, which is mostly white mica, or muscovite, is generally very prominent, although it forms only a subordinate part of the rock. It is in large brilliant flakes parallel to the surfaces of the sedimentary laminae. The sandstone contains in

[20] Op. cit., p. 162.

some places a large quantity of carbonaceous material which is insoluble in ether, alcohol, or bisulphide of carbon and is probably either graphite or anthracite.

Microscopic examination shows that in the sandstone feldspar is always present with the quartz, and in some thin sections both plagioclase and microcline can be distinguished. Although the muscovite may, in part, be derived from the alteration of the feldspars in place, the prevailing parallelism of the flakes to the bedding planes indicates a direct derivation from pre-Cambrian débris.

At irregular intervals throughout the formation are found beds of fine black shale or carbonaceous argillite, generally very thin and locally calcareous, passing into impure limestone. About the middle of the formation is a tolerably persistent dolomitic limestone of the usual blue-gray color. Its thickness, however, varies greatly from one locality to another. It was best observed in Big Sacramento Gulch, a short distance above the London fault, where there are two beds of limestone with associated shale, about 50 feet apart and each about 10 feet in thickness.

AGE AND CORRELATION

A fairly extensive fauna has been collected from the Weber (?) formation and shows it to be of Pennsylvanian age. As the most fossiliferous beds are the shales that occur in the basal part, the entire formation can be definitely assigned to that epoch, and although the earliest Pennsylvanian deposits of the Appalachian region may not be represented here, the lower part of the Weber (?) appears to be not only Pennsylvanian but early Pennsylvanian. As the underlying Leadville limestone is believed to be early Mississippian, the interval represented between the two formations must be considerable, comprising much of Mississippian and probably part of Pennsylvanian time. The immediate superjacence of Pennsylvanian sediments on early Mississippian rocks is common in the West and is probably due to widespread pre-Pennsylvanian erosion.

The Weber (?) formation may apparently be correlated closely with the Hermosa formation of southwestern Colorado and also in a general way with the Magdalena limestone of New Mexico. In a general way also it may be correlated with the Weber quartzite of northeastern Utah, but whether it has exactly or even essentially the same limits can not be stated.

The fauna of the Weber (?) formation as it is known from this area was listed in the Leadville monograph[21] and in Professional Paper 16.[22] Complete lists and additional details can be obtained from these reports. A condensed list of the fauna is as follows:

[21] U. S. Geol. Survey Mon. 12, p. 69, 1886.
[22] U. S. Geol. Survey Prof. Paper 16, pp. 242, 243, 258 et seq., 1903.

Echinocrinus several sp.	Myalina wyomingensis.
Polypora whitei var. insculpta.	Pinna peracuta.
Lingula carbonaria.	Parallelodon obsoletus.
Rhipidomella carbonaria.	Parallelodon tenuistriatus.
Derbya crassa.	Pleurophorus occidentalis?
Chonetes geinitzianus.	Euconospira taggarti.
Productus cora.	Phanerotrema grayvillense.
Productus hermosanus.	Bellerophon crassus.
Pustula nebraskensis.	Pharkidonotus percarinatus.
Marginifera ingrata.	Patellostium montfortianum.
Spirifer rockymontanus.	Domatoceras sp.
Squamularia perplexa.	Phillipsia major.
Composita subtilita.	Phillipsia trinucleata.
Aviculipecten rectilaterarius.	Ostracoda.

From micaceous schist in the upper part of the formation between Lamb and Sheep mountains were obtained abundant casts of Equisetaceae.

YOUNGER SEDIMENTARY FORMATIONS IN NEIGHBORING REGIONS

The upper part of the Weber (?) formation and all the other formations that overlie it in neighboring areas have been eroded within the Leadville district. Higher formations, however, occur in the Tenmile district, immediately north of the Mosquito Range, and are likewise found east of Fairplay in South Park and in the Aspen district. In order that the general geologic discussions that follow may be clear and that the estimates made as to the presumable thickness of the geologic cover that once lay above the present formations in the Leadville district may be more readily comprehended, the following partial descriptions of these formations as they are known in the Tenmile district are given.

MAROON FORMATION

The name Maroon has been applied to about 1,500 feet of beds that lie above the Weber (?) formation in the Tenmile district, and it is retained in this report for the convenience of those familiar with the earlier reports on this region, although the beds designated Maroon formation in the Tenmile district apparently correspond to only a part of the typical Maroon conglomerate of the Anthracite-Crested Butte area. In the Tenmile district these beds consist predominantly of coarse gray and red feldspathic sandstones, in some places passing into conglomerate, with many irregularly developed beds of shale and limestone. The red color of the sandstones appears not to be original with deposition and is more noticeable than that in the Weber (?) formation. though less pronounced than that in the beds of the overlying "Wyoming" formation. It results from oxidation of the abundant iron in the matrix of the rock. Hence in depth, as shown in underground workings, the red color generally gives way to a greenish gray.

Many of the shale beds are black, and a few contain coal. They are much more abundant than would appear from a hasty inspection of the hill slopes, where their outcrops are obscured by the débris from the harder rocks.

The limestones of the Maroon formation constitute its most characteristic feature and, independently of color, seem to afford the safest means of distinguishing it from the "Weber grits," as they have a conchoidal fracture and are low in magnesia and insoluble matter, whereas those in the Weber (?) formation have a rough granular fracture and are high in magnesia and insoluble matter. In the absence of definite faunal distinctions the limestone beds have been used to define the limits of the formation in the Tenmile district, the base being taken at the base of limestone locally known as the Robinson limestone, and the top at the top of the limestone locally known as the Jacque Mountain limestone. According to Emmons these limestones contain an invertebrate fauna typical of the "Upper Coal Measures." The formation is therefore assigned to the Pennsylvanian series of the Carboniferous.

"WYOMING" FORMATION

To the 1,500 feet of beds that lie above the Maroon formation in the Tenmile district the name "Wyoming formation" was given in former reports on that region, because by their position and lithologic character they seemed most nearly to correspond to beds east of the Front Range that in an earlier report had been designated "Wyoming group."[23] Later work, however, has led to the opinion by Ransome that the "Wyoming" formation of the neighboring Breckenridge district (with which these deposits in the Tenmile district are doubtless to be correlated) is probably equivalent to only the upper part of the "Wyoming group," or the Lykins formation. The name "Wyoming group" has long since been abandoned by the United States Geological Survey, as not only inappropriate but unnecessary, the deposits having been subdivided and the subdivisions named. In view, however, of the fact that the name "Wyoming formation" is the one by which these deposits in the Tenmile district have long been known, the name is, for convenience, here retained in a quotational sense from the earlier reports. The "Wyoming" formation of the Tenmile district consists principally of sandstone of intensely brick-red color where not metamorphosed, with a moderate quantity of thin-bedded shale between the more massive beds. Limestone is practically absent, being found only at a few isolated points, generally at about the same horizon. The sandstone is commonly coarse grained, some of it conglomeratic, and is composed mainly of distinctly recognizable pre-Cambrian débris. Feldspar and mica are the most abundant constituents next to quartz. Where metamorphic action has been most pronounced the red color has disappeared, and the rock has become dark and quartzitic and contains much bright-green epidote. The development of the epidote was contemporaneous with the disappearance of the red color and in most places with a silicification of the rock. Metamorphism also extends into the igneous rocks, so that it is in some places difficult to distinguish altered porphyry from metamorphosed sandstone, especially where the sandstone contains a large percentage of feldspar grains.

The so-called "Wyoming" formation of the Tenmile and Breckenridge districts and the probably contemporaneous deposits in the Aspen district have yielded no fossils but have heretofore been assigned to the Triassic, because of stratigraphic relations and lithologic similarity to deposits of other areas that have been considered to belong to that period. More recent s udies, however, have shown, from fossil evidence, that the "Wyoming" group east of the Front Range is chiefly or wholly Carboniferous, the basal formation (the Fountain) being of Pennsylvanian age, the middle formation (the Lyons sandstone) of Permian age, and the upper formation (the Lykins) of Triassic (?) and probably Permian age. If Ransome's correlation of the "Wyoming" formation of the Breckenridge district with the Lykins formation is correct, then it is probable that these deposits in the Tenmile district are chiefly or wholly of Carboniferous age. If, however, these deposits should prove to be younger than the Lykins formation, then they may possibly be Triassic.

MESOZOIC FORMATIONS

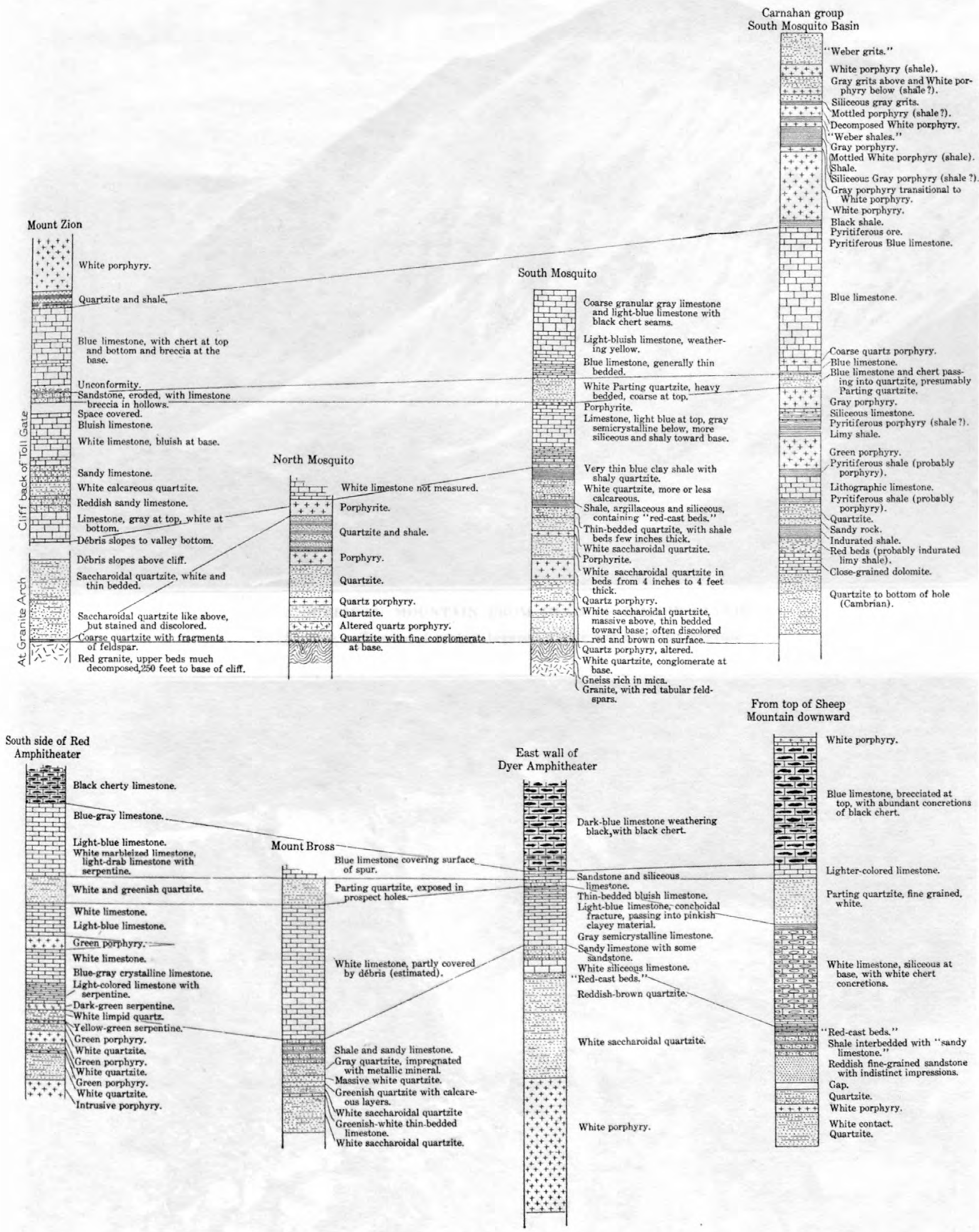
No Mesozoic strata have been found within the Leadville district, and none of proved Triassic age in the surrounding region. In South Park Cretaceous strata lie upon the Permian without angular unconformity, and Emmons concluded that they once arched over the crest of the range and were folded and faulted with the Paleozoic formations. This conclusion has been confirmed by Lee,[24] who has shown that strata of Upper Cretaceous age once extended continuously over the Rocky Mountains of Colorado, New Mexico, and Wyoming and were deposited on a nearly baseleveled surface. Their thickness, as shown on page 42, ranges from 5,500 to 9,600 feet.

TERTIARY FORMATIONS

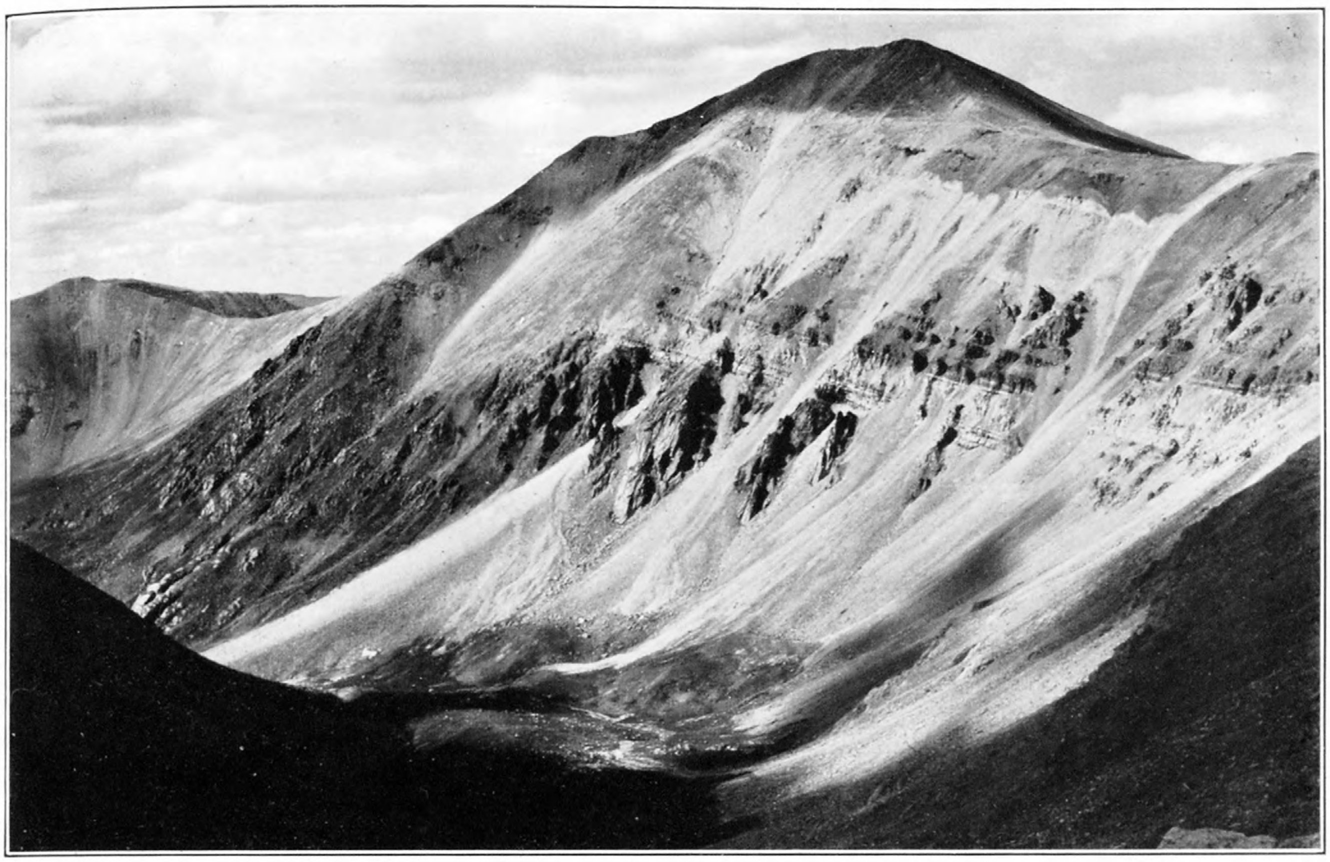
During Tertiary time the Leadville district was undoubtedly a land surface, and with the possible exception of the "lake beds" (p. 17), which are of either late Pliocene or early Pleistocene age, there are no Tertiary deposits in the district. The Pleistocene deposits formed during the glacial epoch are described in chapter 2 (pp. 9–21).

[23] Emmons, S. F., Cross, Whitman, and Eldridge, G. H., Geology of the Denver Basin in Colorado: U. S. Geol. Survey Mon. 27, pp. 51-60, 1896.

[24] Lee, W. T., Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico: U. S. Geol. Survey Prof. Paper 95, pp. 27-58, 1916.



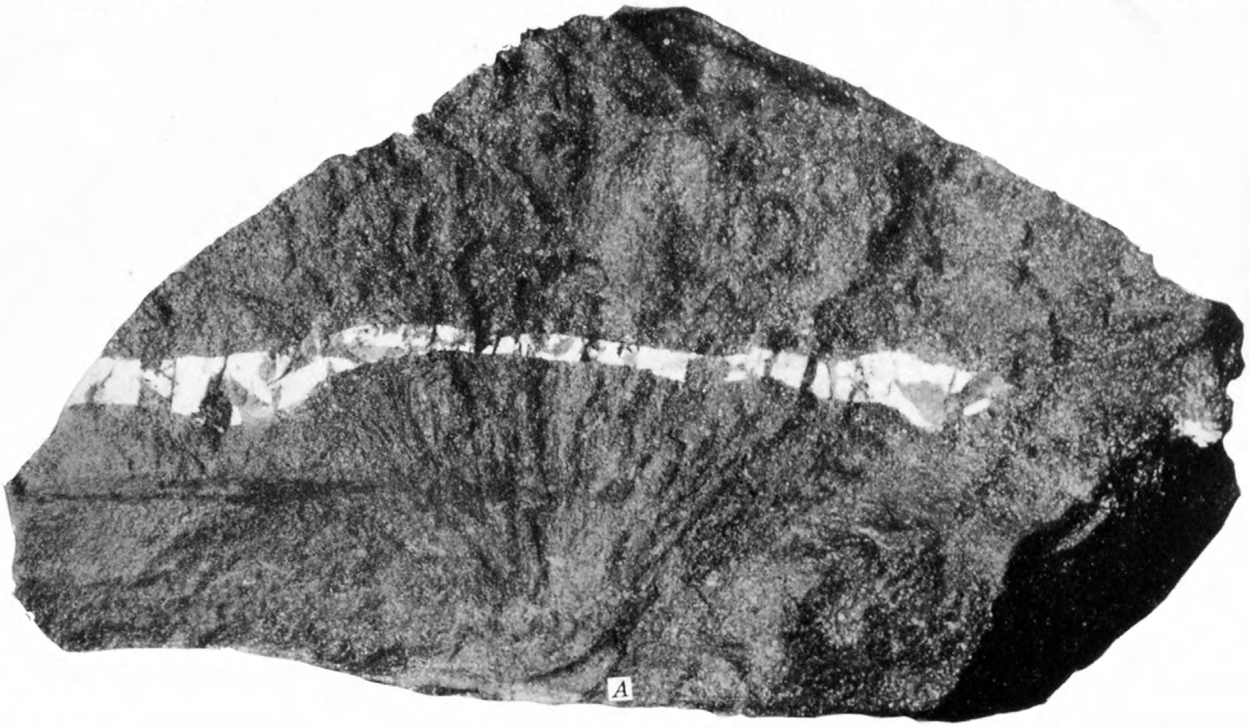
COMPARATIVE STRATIGRAPHIC SECTIONS IN MOSQUITO RANGE

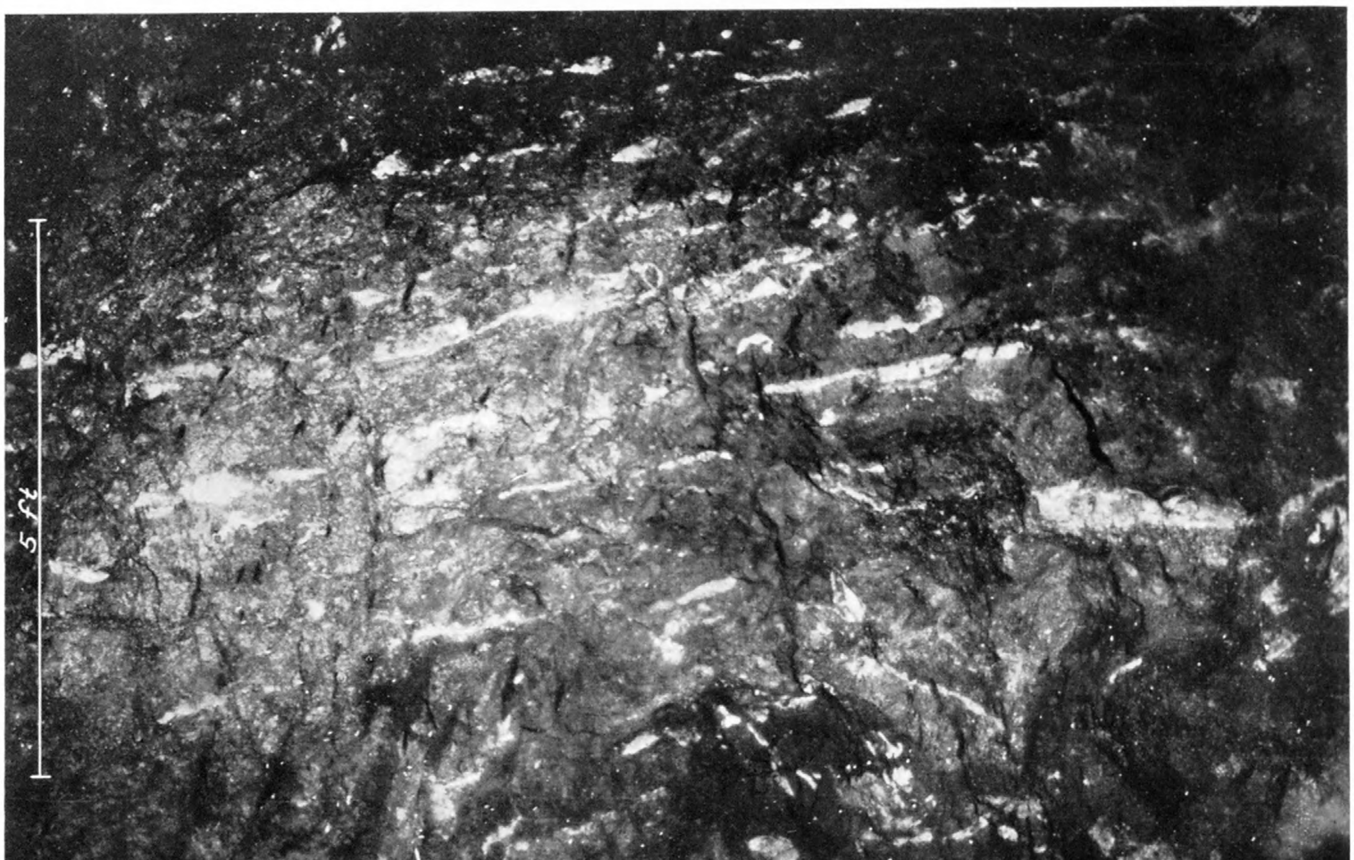


A. SHERIDAN MOUNTAIN FROM HEAD OF EMPIRE GULCH

Showing uniformity of contact between granite and overlying quartzite

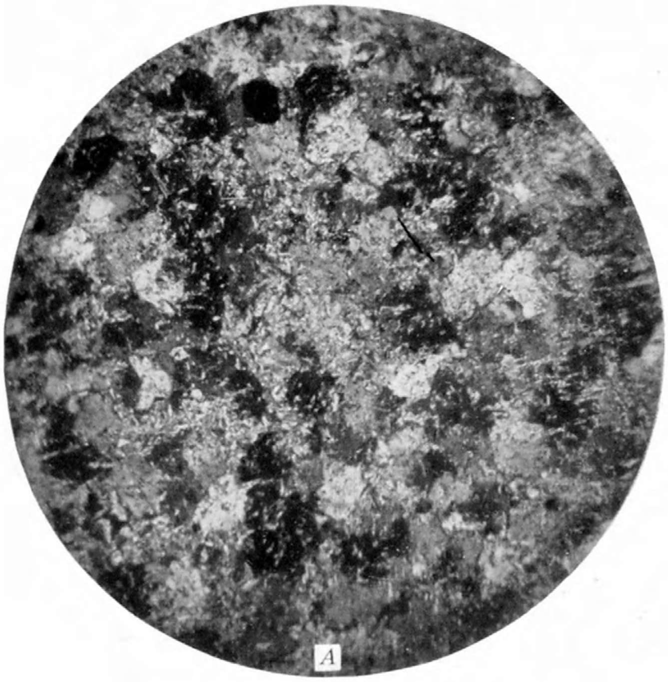
B. SERICITIZED TONGUE OF GRANODIORITE PORPHYRY SURROUNDED ON ALL SIDES BUT ONE BY MASSIVE SULPHIDE ORE, MOYER MINE

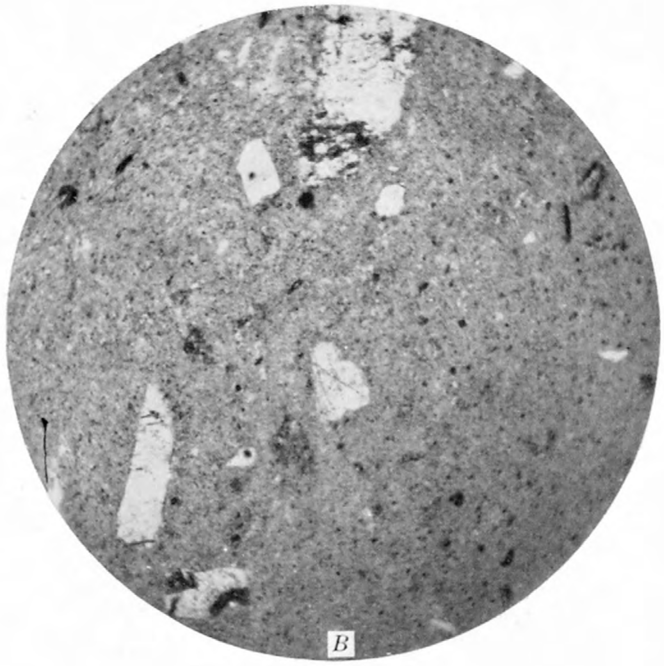




A. SPHALERITE-GALENA ORE FROM REPLACEMENT BODY IN THE WHITE LIMESTONE, TUCSON MINE

B. CHERT LENSES IN SULPHIDE (PYRITE) ORE BODY IN R. A. M. MINE, 1898





A. THIN SECTION OF COARSE-GRAINED VARIETY OF WHITE PORPHYRY

Showing uniform size of quartz and feldspar grains, which are not readily distinguished. The feldspars are impregnated with minute white sericite crystals. The quartz grains are clear but less conspicuous. Enlarged 20 diameters

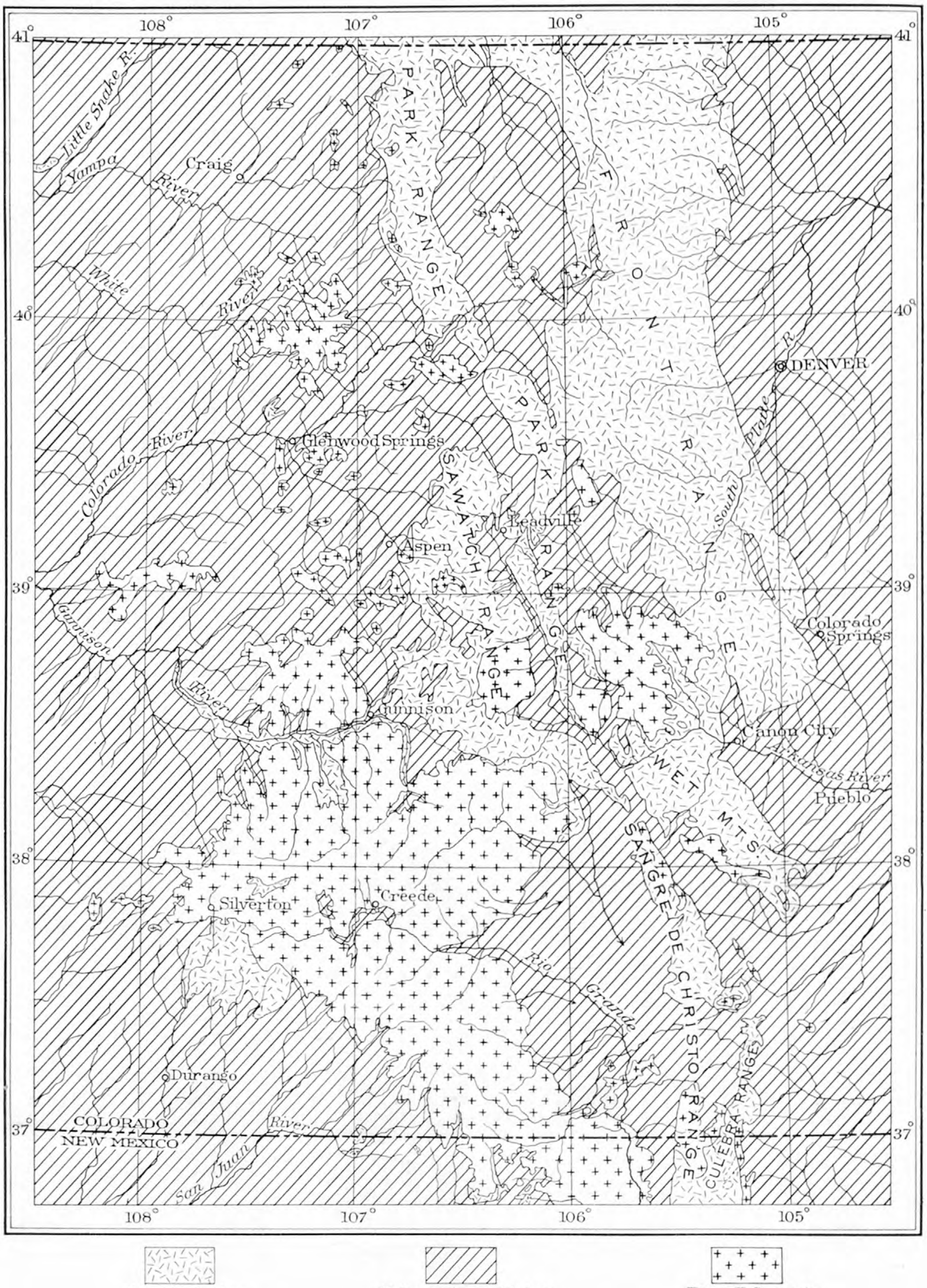
B. THIN SECTION OF FINER-GRAINED PHASE OF WHITE PORPHYRY

Showing fine aggregate of quartz and feldspar forming the groundmass and scattered feldspar phenocrysts. Enlarged 20 diameters

C. SPECIMEN OF LEADVILLE OR BLUE LIMESTONE, PARTLY TRANSFORMED INTO DOLOMITIC SAND BY SOLVENT ACTION OF SURFACE WATERS

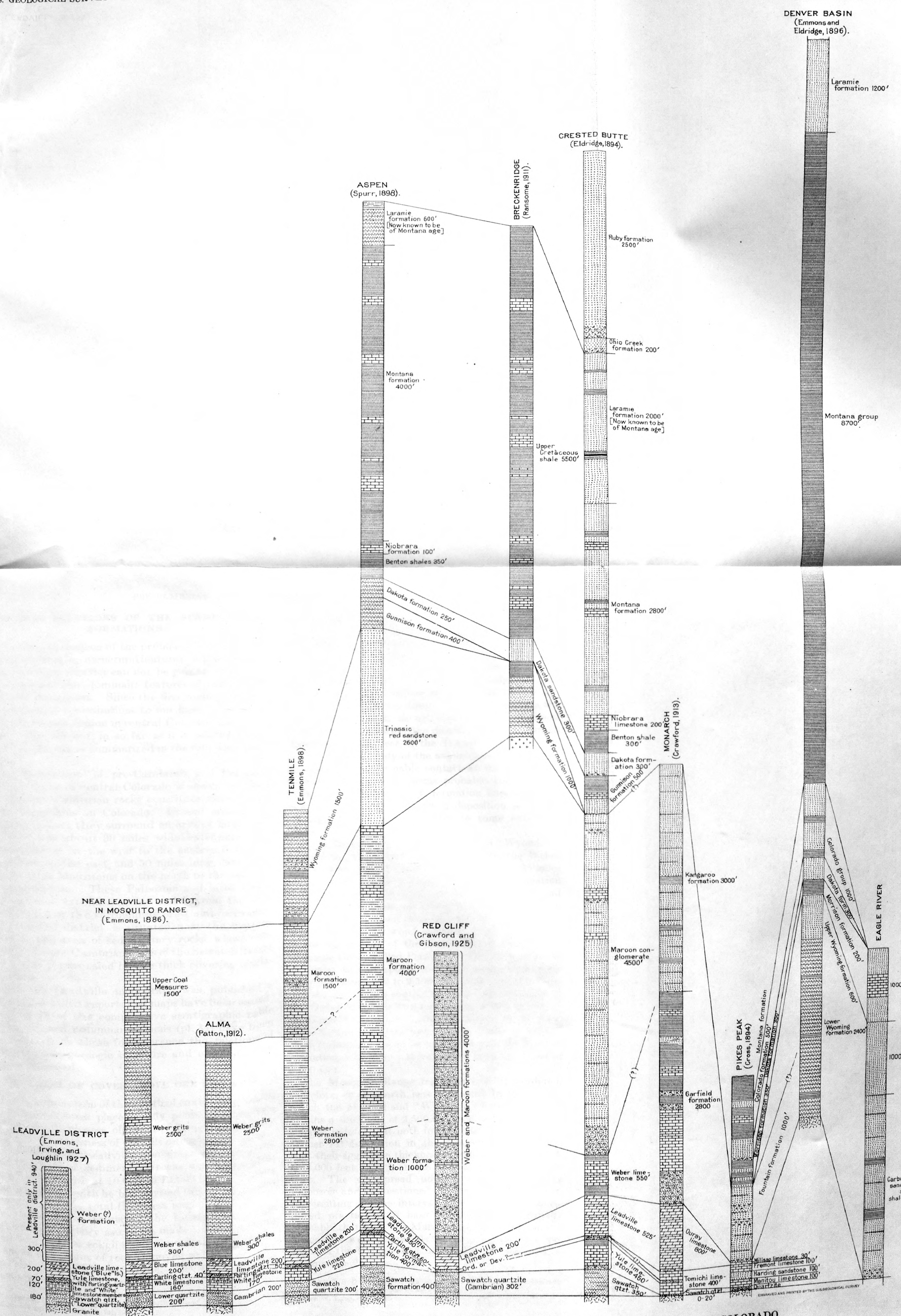
Note the intersecting concave solution depressions

D. REVERSE OF SPECIMEN REPRESENTED IN *C*, SHOWING DOLOMITIC SAND STILL CLINGING TO THE EDGES OF THE SOLUTION DEPRESSIONS



GEOLOGIC MAP OF PORTIONS OF COLORADO AND NEW MEXICO

Compiled from U. S. Geological Survey map of North America, 1911, and Colorado Geological Survey map of Colorado, 1913



COMPARATIVE STRATIGRAPHIC COLUMNS OF LEADVILLE AND OTHER DISTRICTS IN COLORADO

REGIONAL RELATIONS OF THE SEDIMENTARY FORMATIONS

A full understanding of the problems bearing on the age and origin of the structural features and ore deposits of the Leadville district can not be gained without an appreciation of the dominant features of the geologic history of the region. Since the first monograph was written several contributions to our knowledge of the Rocky Mountain region in central Colorado have been made. The subject, in so far as it is related to the present problems, is summarized in the following paragraphs.

The distribution of pre-Cambrian and Paleozoic and later rocks in central Colorado is shown on Plate 33. The pre-Cambrian rocks constitute most of the Rocky Mountains in Colorado. In and around the Leadville district they surround an area of later sedimentary rocks about 30 miles wide, extending from Arkansas River on the west to the eastern border of South Park on the east, and 50 miles long, extending from the Gore Mountains on the north to the canyons of the Arkansas. These Paleozoic and later strata once probably extended across and beyond the area now occupied by the surrounding pre-Cambrian rocks. The Leadville district is situated near the western border of this area of sedimentary rocks, whose contact with the pre-Cambrian rocks of the Sawatch Range on the west is concealed by the thick covering of glacial débris.

Since the Leadville monograph was published a number of detailed reports and maps have been issued, and from them the comparative stratigraphic table (opp. p. 22) and columnar sections (pl. 34) have been compiled. With these for reference the relations of stratigraphy to geologic structure and ore deposition may be discussed.

THICKNESS OF COVER ABOVE ORE DEPOSITS

The determination of the depth of cover under which ore deposition took place at any point involves two factors—the thickness of the overlying sedimentary rocks and the thickness of the sills intruded into them.

Emmons in the Leadville monograph estimated the total thickness of sedimentary rocks within the Mosquito Range region at 10,000 to 12,000 feet. A short time before his death he had revised this estimate and concluded that the total thickness might be somewhat less, but, as shown presently, the estimate of 10,000 feet is as satisfactory as can be made. Any estimate must be at best a rough approximation, owing to the unknown quantities of rock removed at intervals during Paleozoic and Mesozoic time. According to Schuchert's paleogeographic maps [25] the region was exposed to erosion in no less than nine periods of greater or less duration before the uplift in Tertiary time which took place subsequent to ore deposition and gave rise to the present topography.

The strata that remain uneroded at Leadville, including the Leadville limestone and older formations, aggregate about 560 feet, and ore has been mined at several horizons from their top down. Above these strata the Weber (?) formation, though eroded to a thickness of 1,000 feet or less within the district, has a maximum thickness of 2,800 feet in the Tenmile district, to the north. From a study of the available maps and from the apparent conformable contact at the top of the Leadville limestone, it seems probable that the full thickness of the Weber (?) formation once extended over Leadville, but the hiatus in deposition, as shown on page 39, leaves the matter to some extent in doubt.

In the Tenmile district the Maroon and "Wyoming" formations, each 1,500 feet thick, overlie the Weber (?) formation, but in the Breckenridge district, 25 miles northeast of Leadville, the "Wyoming" formation rests unconformably upon pre-Cambrian rocks and has a total thickness of 1,000 feet. The absence of the Maroon formation there may be due to overlap or to an unconformity which is known to exist elsewhere in the upper part of the Carboniferous. Strata on Fourmile Creek, called Permian by Peale, are believed by Girty to correspond to the Maroon formation. They are from 2,000 to 2,500 feet thick. In the Monarch district, to the south, Crawford [26] identified above the Ouray limestone two formations which he named the Garfield formation, 2,500 feet thick, and the Kangaroo formation, 3,000 feet thick. Parts at least of these formations are to be correlated with the Maroon formation, which may there have a total thickness of 2,800 feet.

The Mosquito Range region is roughly bordered, therefore, on the north, east, and south by districts in which the Maroon and "Wyoming" formations each attains a thickness of 2,500 feet or more, and it is reasonable to infer that both formations once overlay the Weber (?) formation in the Leadville district, and that their aggregate thickness may have been as much as 3,000 feet, as it is in the neighboring Tenmile district. The widespread unconformity between the Paleozoic and unquestioned Mesozoic rocks, however, representing a time interval when the region was reduced practically to base level, renders it equally probable that both the Maroon and the "Wyoming" formations were completely removed before the deposition of the Dakota sandstone and later rocks of Cretaceous age.[27]

[25] Schuchert, Charles, Paleogeography of North America: Geol. Soc. America Bull., vol. 20, pp. 427–606, pls. 46–101, 1910.

[26] Crawford, R. D., Geology and ore deposits of the Monarch and Tomichi districts, Colo.: Colorado Geol. Survey Bull. 4, pp. 66–72, 1913.

[27] Lee, W. T., op. cit., pp. 32–34.

According to Lee[28] the Dakota sandstone and later Cretaceous rocks in all probability once extended over the entire Rocky Mountain region in Colorado, and no large islands persisted throughout the Cretaceous period, as was formerly maintained by Emmons and others. These rocks are 6,750 feet thick at Canon City, 8,500 feet at Boulder, 9,600 feet at Coal Basin (south of Glenwood Springs), 5,500 feet at Breckenridge,[29] 5,850 feet at South Park (30 miles north of Como), and 5,565 feet at North Park. They are separated from the overlying Tertiary rocks by an unconformity. Their thickness prior to upheaval was therefore somewhat greater than is indicated by the foregoing figures, and an estimate of a thickness of 5,500 feet at Leadville is decidedly moderate. As ore deposition took place prior to upheaval, this thickness must be considered in estimating the amount of cover above the horizon of ore deposition.

The estimated aggregate original thickness of strata is summarized as follows:

	Feet
Cretaceous rocks	5, 500
Maroon and "Wyoming" formations	3, 000
Weber (?) formation	2, 800
Leadville limestone and lower formations	560
	11, 860

If all the Maroon and "Wyoming" formations and perhaps part of the Weber (?) formation had been eroded before the deposition of the Cretaceous rocks the thickness of the sedimentary rocks may have been reduced to about 8,000 feet.

This thickness was increased by the sheets of porphyry intruded at many horizons in the sedimentary formations. The increase varied locally, but the general conformity of the porphyry sheets with the strata and their continuity afford a reasonable basis for estimate. In the Leadville district, as shown by the sections on Plates 14–17, the aggregate thickness of porphyry below the Weber (?) formation ranges from 600 to more than 1,200 feet. Within the Weber (?) formation the sills where present reach 500 feet or more in aggregate thickness and average about 250 feet. In the Tenmile district, however, sills in the Weber (?), Maroon, and "Wyoming" formations aggregate about 1,900 feet in thickness. The minimum total increase in thickness due to the sills is therefore placed at 2,500 feet, and the total thickness of rocks above the pre-Cambrian contact at about 14,300 feet if the Maroon and "Wyoming" formations are included, or at 10,500 feet otherwise.

As revealed by mining, ore was deposited in the Leadville district in fissures at horizons from the pre-Cambrian granite upward to the "Weber grits," a vertical range of at least 900 feet; but the horizon of most extensive deposition was at the top of the Leadville limestone. Deduction of the thickness of this and older formations, 560 feet, and of the porphyry sills in them, about 80 feet, leaves 9,800 to 12,700 feet of rock above the horizon of maximum ore deposition, a result which agrees closely with Emmons's estimates.

[28] Idem, pp. 34-55.

[29] Ransome, F. L., U. S. Geol. Survey Prof. Paper 75, pp. 26 and 39, 1911.

CHAPTER 4. POST-CAMBRIAN IGNEOUS ROCKS

SUMMARY

The post-Cambrian igneous rocks of the Leadville district and the neighboring region include a widespread group of porphyries of varying texture and appearance, presumably of late Cretaceous or early Tertiary age, and a few cylindrical or funnel-shaped masses of volcanic agglomerate, occupying pipelike conduits and probably of late Tertiary or early Quaternary age. Other than the agglomerate, no volcanic rocks occur within the Leadville district, although they are prominent in places to the north and south.[1]

The intrusive porphyries occur mainly as sills, which in the Leadville district are associated with stocklike masses beneath Breece and Printer Boy hills and Adelaide Park. They also form dikes, which are most conspicuous in areas of pre-Cambrian rocks. The sills attained a minimum aggregate thickness of 2,500 feet (p. 42) and in some parts of the region were much thicker. Irving, after a study of available data, has roughly estimated that the total volume of these intrusive rocks prior to erosion amounted to 45 cubic miles or more in an area of 20 by 30 miles about Leadville. Two principal kinds of porphyry, known as the "White" porphyry and "Gray" porphyry, have been recognized since the earliest days of the district, and for the convenience of the mining public those designations are freely used in this report in a titular sense. The White porphyry is the older and corresponds to a muscovite granite or salic granodiorite, and the younger Gray porphyry includes varieties ranging from granodiorite to quartz monzonite; but both rocks are in general so much altered that an exact classification is not practicable.

These two principal varieties are readily identified in the western part of the district, but in the Breece Hill area their distinction from each other is difficult, as some varieties of altered Gray porphyry closely resemble the White porphyry, and the delimitation of areas occupied by each rock is obscured on the surface by the covering of débris and underground by the scarcity of mine workings. The Gray porphyry is much the more abundant in this area, however, and except where the White porphyry can be identified with certainty all the porphyry has been mapped as Gray porphyry on Plates 13 and 27.

[1] U. S. Geol. Survey Mon. 12, pp. 86–88, 319–357, 1886.

PORPHYRIES

WHITE PORPHYRY

DISTRIBUTION AND STRUCTURE

The White porphyry, as originally shown by Emmons,[2] forms a group of areas extending southeastward from Carbonate and Iron hills to Empire Gulch, and another area including the summits of Mount Sherman, Mount Sheridan, and Peerless Mountain and the adjacent eastern slope of the Mosquito Range. Narrow bands (sheets) extend southward from these areas, and a few small areas are found to the east. In all these places the White porphyry occurs mainly as a great intrusive sheet directly overlying the Blue limestone but is also found at lower horizons. The maximum thickness of the main sheet, 1,500 feet, is found at White Ridge, southeast of Mount Sherman, where the principal vent through which the White porphyry was intruded was supposed by Emmons to be located. Irving, however, suggests that this rock was intruded from the same principal vent as the Gray porphyry, at Breece Hill. In both places the evidence is obscure. In fact, dikelike masses of the White porphyry are comparatively few. The only prominent one is exposed near the head of Iowa Gulch, between Iowa and Dyer amphitheaters, and is bounded on the southwest by the South Dyer fault. Several small dikes and a few small sheets are found on the slopes of Mount Lincoln, Mosquito Peak, and London Mountain, on the east slope of the Mosquito Range, and on Little Zion, north of Leadville.

Within the Leadville district (pl. 13) the White porphyry is most conspicuous on Carbonate, Iron, and Printer Boy hills, where it forms nearly the entire surface. It is also prominent on Yankee Hill, and forms the bedrock surface beneath glacial deposits in the Downtown, Fryer Hill, and Rock Hill areas. North of Fryer and Yankee hills it is overlain by an extensive sheet of the Gray porphyry.

All these occurrences are parts of what was originally one large sheet, which branched into two or more members north of Carbonate and Iron hills. A group of sills, whose exact structural relations are somewhat obscured by faulting, is present in the eastern part of the district in a narrow area extending

[2] U. S. Geol. Survey Mon. 12, pp. 77–78, atlas sheets 6 and 7, 1886.

from the southeast slope of Ball Mountain to the bottom of Evans Gulch. The largest of these sills occur at the lower horizons of the sedimentary rocks, whereas the great sill lies mostly at the top of the Blue limestone.

The White porphyry is cut by many closely spaced joints, which cause it to weather into small angular and flat fragments that cover the ground where the rock has been exposed. Outcrops are few and inconspicuous. This jointing has loosened the rock to considerable depths and has frequently caused difficulty in supporting mine excavations. Many drifts driven through apparently solid White porphyry have had to be heavily timbered, as the rock rapidly breaks along joint planes into small fragments. Ricketts[3] states that workings run through ground of this character need to be much more heavily timbered than those which have been run through soft, claylike masses. This characteristic jointing often extends to depths of 400 or 500 feet from the surface. It may be due, in part at least, to withdrawal of support due to shrinkage of the underlying limestone during replacement by ore, or to shrinkage of the ore bodies during oxidation; but neither Emmons nor Irving correlated the distribution of shattered zones in the porphyry with that of the ore bodies.

PETROGRAPHY

The White porphyry is of creamy white to very light gray color, except where stained along joint planes by brown oxide of iron or by dendritic films of black manganese oxide. These dendritic films (pl. 35, *C*) are so common that in shaft records the White porphyry has usually been designated "forest rock." Dark minerals crystallized from the magma are almost completely absent, and there is little contrast in color between the phenocrysts and the fine-grained groundmass. Rock practically free from alteration is rarely seen but has been reported from the Diamond shaft at a depth of 800 feet and from a dike in Empire Gulch. Specimens of this supposedly unaltered White porphyry, however, are so similar to the late Tertiary rhyolite in the agglomerate masses that their correlation is questionable. This unaltered rock consists of a gray groundmass with thinly scattered colorless phenocrysts of feldspar and quartz and very few small black scales of biotite; but in the typical altered rock both phenocrysts and groundmass have been bleached and the porphyritic texture is detected only on close inspection.

The phenocrysts of the typical altered rock are mostly 1 to 2 millimeters in diameter, though a few feldspars are somewhat larger. Some of the feldspars show the multiple twinning of plagioclase, but most of them are too much altered to be identified. Some of the quartz phenocrysts are double pyramids. The groundmass is mostly very fine grained, but in some places, particularly near contacts and in small dikes, it is dense and renders the phenocrysts more conspicuous. Alteration has intensified the granular appearance of the groundmass, which appears to consist of rounded grains cemented together; but no such texture appears under the microscope. A banding or flow structure has been noted along the edges of small dikes but is uncommon.

In some places six-sided crystals of dark muscovite are present, and on Printer Boy Hill and in areas to the east there are small clusters of the same mineral. The six-sided crystals were regarded by Emmons[4] as original constituents of the rock, but Cross[5] regarded them as probably secondary, in view of the abundance of undoubtedly secondary muscovite. A similar rock at Aspen has been described by Knopf.[6] Minute grains of muscovite or sericite (see pl. 35, *B*) are usually abundant and give to the rock a faint silky luster.

Under the microscope the feldspar phenocrysts prove to be plagioclase (andesine, Ab_6An_4). Some of them form clusters, but most of them are single short, stout prisms. Most of them are thoroughly impregnated with minute sericite crystals. The few quartz phenocrysts form typical clear grains, some of which approach the outline of double pyramids and show some degree of resorption. The quartz, and to a less extent the feldspars, contain minute inclusions in rows or irregularly distributed. Some of these inclusions are fluid and others indeterminate. The biotite is found unaltered in only one thin section, but in the common altered variety of the rock pseudomorphism of muscovite and iron oxide after biotite can occasionally be found.

The groundmass of the common variety consists of irregular grains 0.1 millimeter or less in diameter of plagioclase, orthoclase, and quartz. The plagioclase (oligoclase) has a roughly rectangular outline and, like the phenocrysts, is thoroughly sericitized. The orthoclase, which approximately equals the plagioclase in quantity, shows no tendency to crystal outline but partly surrounds the plagioclase grains. It also is considerably sericitized. The quartz is abundant, and its irregular grains are commonly interstitial among the feldspars. Magnetite and apatite are very scarce, but minute grains of zircon and rutile are rather abundant. The groundmass of the dense variety is so fine grained that the component minerals can not be identified. The common and dense varieties are illustrated in Plate 32, *A* and *B*.

[3] Ricketts, L. D., op. cit., p. 22.

[4] U. S. Geol. Survey Mon. 12, p. 77, 1886.

[5] U. S. Geol. Survey Mon. 27, p. 324, 1896.

[6] Knopf, Adolph, Recent developments in the Aspen district Colo.: U. S. Geol. Survey Bull. 785, pp. 8-10, 1926.

None of the distinct six-sided muscovite crystals were seen in thin section by the present writers. The muscovite seen occurred partly as distinct flakes scattered through the rock or in clusters, and partly as aggregates of minute sericite grains. The single flakes reach 1 millimeter or more in diameter and form a network with quartz grains. Only rarely do they appear to replace feldspar. Some of them appear to have crystallized a little later than the quartz and others earlier, and the two minerals on the whole appear contemporaneous. The only cluster of muscovite seen in thin section was in an elliptical geodelike body about 3 millimeters in diameter. It was in parallel intergrowth with quartz, the two minerals forming a shell which was filled with calcite. The muscovite and quartz are similar in appearance to the grains disseminated in the groundmass. The evidence as a whole implies that the muscovite grew under pneumatolytic conditions, which marked the last stage of the White porphyry intrusion. Biotite phenocrysts may have been replaced by muscovite at that time. In some places, presumably where pneumatolytic activity was vigorous, the rock consists essentially of quartz and muscovite, with only a few remnants of altered feldspar.

The sericite that impregnates the feldspars and forms fringes around some of the larger muscovite crystals is distinctly later than the mica already described, and may be correlated with the period of ore deposition. A little epidote and calcite, distinctly later than the quartz and earlier muscovite, are scattered through the groundmass and may be contemporaneous with the sericite. Small crystals of pyrite are present in the vicinity of ore bodies. Its prominence in some places led to the designation of a special type of "pyritiferous porphyry" in the Leadville monograph, but later studies have shown that the rock so named consists in part of pyritized White porphyry but mostly of pyritized Gray porphyry. Kaolin and similar claylike materials are products of weathering and are prominent along the contact of the White porphyry and the Blue limestone in the vicinity of oxidized ore bodies.

CHEMICAL COMPOSITION AND CLASSIFICATION

The chemical composition of the White porphyry is shown below in column 1, quoted from the Leadville monograph, and column 2, quoted from Ricketts.[7] A sample intended to illustrate the pyritized rock but exceptionally high in orthoclase is represented in analysis 3, and muscovite phenocrysts in analysis 4.

[7] Op. cit., p. 21.

Analyses of White porphyry and its muscovite

	1	2	3	4
SiO_2	70.74	74.98	66.37	45.03
Al_2O_3	14.68	15.27	11.15	38.14 (with Fe_2O_3)
Fe_2O_3	.69	1.27 (with FeO)	None.	
FeO	.58		.32	
MgO	.28	Trace.	Trace.	A little.
CaO	4.12	1.03	.18	Trace.
Na_2O	2.29	1.89	.56	.71
K_2O	2.59	2.10	9.03	9.44
H_2O+	2.09 (with H_2O-)	2.00	.44	4.06 (with H_2O-)
H_2O-			.14	
CO_2	2.14		None.	
TiO_2			.23	
ZrO_2			.02	
P_2O_5		Trace.	None.	
MnO	.06	1.07		
BaO	.03		.10	
SrO	Trace.			
SO_3		Trace.	.35	
Cl	Trace.			
FeS_2			10.75	
	100.29	99.61	99.64	97.38
Specific gravity	2.680			

1. White porphyry from quarry in California Gulch at the southwest base of Iron Hill. Specimen somewhat altered. Analysis made by W. F. Hillebrand for Leadville monograph (Mon. 12, p. 326).

2. White porphyry presumably from Evening Star or Morning Star claim on Carbonate Hill. Analysis quoted from "The ores of Leadville," p. 21, published at Princeton in 1883 as thesis for the degree of Ph. D. by L. D. Ricketts.

3. Pyritiferous White porphyry (?) from Yak tunnel. The specimen was one of the least decomposed fragments of supposedly White porphyry obtainable, but its chemical composition is so different from that of the White porphyry as a whole that its exact relationship to typical White porphyry is open to question. The only evidence of alteration was the presence of minute crystals of pyrite. Analysis made by R. C. Wells. Specific gravity of specimen, 2.652; of powder, 2.736. Calculated porosity 3.07 per cent.

4. Muscovite from White porphyry, south slope of Little Zion. Mon. 12, p. 589, 1886. Not complete; made to prove identity of mineral.

Nos. 1 and 2 both represent rock that was somewhat altered but as fresh as could be obtained. The excess of silica in No. 2 is balanced by the excess of lime and carbon dioxide in No. 1, which appears to be the more altered rock. Iron oxides in both rocks and magnesia in No. 1 are surprisingly high, in view of the scarcity of mafic minerals and magnetite. The magnesia and ferrous oxide may be present in part as carbonate. The alkalies in both rocks are lower than in typical unaltered rocks of similar composition, and their ratio to alumina reflects the abundance of mica, as does the rather high content of water.

The norms of rocks so greatly altered as Nos. 1 and 2 would be of little significance. The mode or mineral composition has been approximately calculated below, however, on the assumption that the analysis of muscovite in column 4 (equivalent to $2H_2O.(K,Na)_2O.3Al_2O_3.6SiO_2$) is fairly representative.

Mineral composition of White porphyry

[Corresponding to analysis 1, p. 45]

	Per cent
Quartz (SiO_2)	43.8
Orthoclase ($K_2O.Al_2O_3.6SiO_2$)	1.4
Muscovite ($2H_2O.K_2O.3Al_2O_3.6SiO_2$)	20.3
Kaolin ($2H_2O.Al_2O_3.2SiO_2$)	.0
Excess water (H_2O)	1.0
Albite ($Na_2O.Al_2O_3.6SiO_2$)	19.4
Anorthite ($CaO.Al_2O_3.2SiO_2$)	7.0
Chlorite (pennine) ($4H_2O.5(Mg,Fe)O.Al_2O_3.3SiO_2$)	1.9
Magnetite (Fe_3O_4)	.9
Calcite ($CaCO_3$)	4.9
Baryta (BaO) and manganous oxide (MnO)	.1
	100.7

If all the alumina is present in feldspars, muscovite, and chlorite there is 1 per cent of excess water. If this apparent excess water represents kaolin that mineral amounts to nearly 7 per cent, muscovite drops to 11 per cent, and orthoclase rises to 8 per cent. The true percentages of these minerals are doubtless somewhere between the limits stated above. According to the ratios of the feldspars the White porphyry is a granodiorite porphyry, but it is unusually low in mafic minerals or their alteration products. The abundance of muscovite and its close association with quartz would favor its designation as a sodic muscovite granite porphyry.

The pyritic porphyry represented by analysis 3 was not found among the specimens left by Irving, and no petrographic description of it is available. It evidently contains very little muscovite and much more orthoclase than the rocks represented by analyses 1 and 2. If the lime and soda are calculated as plagioclase the ratio of the remaining alumina to potash allows for only 0.8 per cent of muscovite and 52.8 per cent of orthoclase. Even if all the alumina were available, muscovite would amount to only 5.6 per cent and orthoclase to 49.5 per cent. Quartz also is lower than in the other samples, amounting to 28 per cent. These data, even with allowance for the pyritic replacement, suggest an alkali granite, which is an unusual variation from the typical White porphyry, if indeed it is not a different rock whose relations have been obscured by alteration.

GRAY PORPHYRY GROUP

As originally used in the Leadville monograph the term "Gray porphyry" was applied only to a variety of porphyry represented by a type specimen from Johnson Gulch. It has since become customary, however, to use the term to distinguish all varieties of porphyry that are markedly porphyritic from the White porphyry, just described. The Gray porphyry group therefore includes several varieties, some of them granodiorite porphyries, some quartz monzonite porphyries, and perhaps some quartz diorite porphyries, although no members of the last-named group are represented by chemical analyses, and none have been definitely recognized even by a careful restudy of the original thin sections used by Cross.

Quartz-free varieties are shown by the microscope to be entirely absent in the Leadville mining district, and Emmons's descriptions include few from the entire Mosquito Range area.

Four varieties of the Gray porphyry are recognized within the Leadville district—the Lincoln porphyry, the Johnson Gulch porphyry, the Evans Gulch porphyry, and the Mount Zion porphyry.

LINCOLN PORPHYRY

DISTRIBUTION

The Lincoln porphyry was named from Lincoln Mountain, northeast of the Leadville district, where it is best developed. It forms the summit of that mountain and the summit and parts of the slopes of Mount Bross, to the south, and is reported by Emmons to occur also on the east side of the Platte Valley. In the area represented on Plate 11 it forms several sheets at the top of the Blue limestone and in the lower part of the "Weber grits," one sheet in the Cambrian quartzite, and some small dikes in the pre-Cambrian rocks. Within the Leadville district rock similar in megascopic appearance to the Lincoln porphyry and therefore correlated with it is found on Little Ellen Hill, on Printer Boy Hill, and in the Yak tunnel. In the Yak area the rock is locally known as the "Bazoo porphyry," on account of its prominent development on the Bazoo claim. It closely resembles the quartz monzonite porphyry of Brewery Hill, in the Breckenridge district, described by Ransome, but seems to be generally so high in plagioclase that it should be classed as a granodiorite porphyry.

PETROGRAPHY

The rock on weathered surfaces and where intensely altered is of a light cream color but elsewhere is gray to greenish gray. It contains large phenocrysts of orthoclase and quartz and smaller phenocrysts of plagioclase and of altered biotite and hornblende, embedded in a dense matrix. The large orthoclase crystals are Carlsbad twins, usually pink, and range from half an inch to 2 inches in length. They contain numerous inclusions of altered plagioclase and biotite, and some are impregnated with calcite. In thin section they appear clouded by minute specks of kaolin and iron oxide, and a few cracks contain sericite, which is evidently derived from the inclosed plagioclase. Though these phenocrysts are very conspicuous, they are shown by measurements to constitute only 8 per cent by volume of the rock in the Bazoo claim. In the rock from Little Ellen Hill they are very prominent, and where the rock is disintegrated they and the large quartz crystals have weathered out and lie scattered along the outcrop. (See pl. 36, *A*.)

The plagioclase phenocrysts, though less conspicuous, are more abundant and constitute 35 to 40 per cent of the volume of the rock. They range from 0.25 to 2.15 millimeters in length (average 1.03 millimeters) and where not too much altered show typical twinning striations. Under the microscope the optical properties of unaltered remnants are those of andesine (Ab_6An_4), but most of the plagioclase is much altered to feltlike aggregates of sericite, albite, and epidote and irregular and more sparsely scattered patches of calcite.

The quartz phenocrysts range from 1 to 4 millimeters in size. Measurements show that they make up only 8.6 per cent by volume of the rock from the Bazoo claim, although the total amount of quartz is considerably greater. Some of the phenocrysts are remarkably free from inclusions, and others contain many. In the rock from the Bazoo claim and Printer Boy Hill they are rounded and embayed by magmatic resorption, and none of them show crystal boundaries. In the rock from Little Ellen Hill they are much larger, many attaining a diameter of 10 millimeters or more, and are beautifully developed double pyramids with smaller prismatic faces.

The dark phenocrysts of the rock are biotite and in some places hornblende; they are numerous and conspicuous in some varieties and only sparsely scattered in others. The biotite is usually in plates, which range from 0.2 to 2 millimeters in diameter. Nearly all these plates are partly to thoroughly altered to mixtures of sericite, chlorite, epidote, and carbonate. Some of the biotite crystals are replaced by relatively coarse-grained aggregates of chlorite and muscovite. Extensively altered crystals are distorted, as if the cleavage plates had been pushed apart by the growth of the decomposition products.

In the rock from the Printer Boy mine the hornblende phenocrysts, short stout prisms, are comparatively abundant and are as conspicuous as the quartz phenocrysts, though smaller. Some of them form profusely scattered inclusions in the large orthoclase phenocrysts.

The groundmass in the rock, where least altered, is usually dove-colored and very fine grained to dense. Single grains range from 0.1 millimeter in diameter downward but on the whole are of rather uniform size and of roughly rectangular to circular outline. The recognizable minerals are usually untwinned feldspar (albite?) and quartz. Less sodic plagioclase can seldom be identified with certainty, but, to judge from the extensive development of sericite and calcite as decomposition products, it was probably present in considerable amount in the original groundmass. Apatite, zircon, magnetite, and titanite are invariably present in typical crystals, and allanite is also a fairly constant minor constituent.

Plate 37, *B*, shows the microscopic appearance of the freshest obtainable specimen of the rock, taken from the Yak tunnel, more than 1,000 feet below the surface. This does not show any of the large orthoclase phenocrysts.

CHEMICAL COMPOSITION AND CLASSIFICATION

A chemical analysis of the type rock from Mount Lincoln, quoted from the Leadville monograph, is given below, with the corresponding norm and mode.

Analysis of Lincoln porphyry from Mount Lincoln

Analysis			Norm	Mode
SiO_2	66.45	Quartz	29.10	29.8
Al_2O_3	15.84	Orthoclase	17.24	5.6
Fe_2O_3	2.59	Albite	33.12	33.1
FeO	1.43	Anorthite and		
MgO	1.21	epidote	3.34	3.3
CaO	2.90	Corundum	5.00	------
Na_2O	3.92	Sericite	--------	16.7
K_2O	2.89	Hypersthene	3.66	------
H_2O+	.84	Chlorite	--------	3.8
CO_2	1.35	Magnetite	3.71	3.7
TiO_2	.10	Apatite	1.01	1.0
P_2O_5	.36	Calcite	3.10	3.1
Cl	.05	Water	.84	------
MnO	.09	Rutile	--------	.1
BaO	None.			
Li_2O	Trace.		100.12	100.2
SrO	.07			
	100.09			

Specific gravity, 2.670.

According to the quantitative classification, the rock is lassenose (I.4.2.4).

The alteration of the rock, indicated by the quantities of corundum, calcite, and water in the norm, prevent a precise determination of the mineral composition or mode. If the excess alumina represented by the corundum is entirely due to sericite and chlorite, a recalculation would show 16.7 per cent of sericite, 3.8 per cent of chlorite, and only 5.6 per cent of the pure orthoclase molecule. The sericite is largely an alteration product of plagioclase and may be due mainly to the introduction of additional potash by mineralizing waters or to a recrystallization of original constituents during hydration. According to the first cause, the original orthoclase, even if it contained as much as 50 per cent of the albite molecule, would amount to only 10 or 12 per cent, whereas plagioclase, which would have a composition approximating Ab_5An_1, would amount to 30 per cent or more, and the rock would be classified as granodiorite. If, on the other hand, practically all the potash was originally present in orthoclase and all the lime originally in plagioclase, only 5 per cent of the albite molecule would be required by the orthoclase to place the rock in the quartz monzonite group. The feldspars would then have the following approximate composition: Orthoclase (Or_3Ab_1); plagioclase (Ab_1An_1). As the plagioclase identified optically was near Ab_3An_2, the rock appears to be intermediate between granodiorite and quartz monzonite.

Ransome,[8] who has made a comparative study of the intrusive rocks in the Leadville, Breckenridge, and neighboring districts, quotes the foregoing analysis and refers to the Lincoln porphyry as siliceous quartz monzonite. The prevailing monzonitic character of the intrusive rocks is a marked feature of the region in general.

JOHNSON GULCH PORPHYRY

DISTRIBUTION

The variety here called Johnson Gulch porphyry is the Gray porphyry of the Leadville monograph. Next to the White porphyry it is the most widespread intrusive rock within the Leadville district (pl. 13), but it is not definitely recognized elsewhere. It forms the extensive sheet that overlies the White porphyry in the northwestern quarter of the district and the intrusive sheets exposed in mine workings under Iron Hill, Carbonate Hill, and elsewhere. The stocklike mass at Breece Hill, where not too much altered, is closely similar to if not identical with the Johnson Gulch porphyry, and probably represents the conduit through which it rose; but the stock may include also one or more later intrusions.

PETROGRAPHY

The Johnson Gulch porphyry is very similar to the Lincoln porphyry, just described, but generally lacks the large phenocrysts of orthoclase and quartz. A few of these are present, but they are sporadic and not a distinctive feature of the rock. This rock, like the other porphyries, is considerably altered throughout the district, but some only slightly altered specimens have been found.

The color of the specimens ranges from greenish gray to dark green as the percentage of dark minerals increases. In the lighter-colored varieties biotite occurs with little or no hornblende; in the darker varieties hornblende or its alteration products are abundant. In the darkest facies the hornblende is chiefly in the groundmass. The darker varieties, which may correspond to the porphyries described by Cross in the original report, occur in small masses, but the lighter and intermediate varieties form large masses and are typically represented by the porphyry at Johnson Gulch.

The minerals of the Johnson Gulch porphyry are orthoclase, plagioclase, quartz, biotite, and hornblende, with accessory magnetite, apatite, titanite, and allanite. As alteration products sericite and chlorite are invariably present; pyrite, epidote, calcite, and siderite (?) are common; and quartz occurs here and there. Calcite is very abundant in the darker varieties. Kaolin appears to some extent in rocks near the surface but is entirely absent in the deeper-seated masses.

The phenocrysts are plagioclase, a few large orthoclase crystals, quartz, biotite, and hornblende. The large orthoclase phenocrysts are essentially identical in character with those in the Lincoln porphyry and contain inclusions of sericitized plagioclase and chloritized biotite, as well as impregnations of calcite. A chemical analysis of those from the Johnson Gulch porphyry, quoted from the Leadville monograph, is given below.

Chemical analysis of orthoclase phenocryst from Gray [Johnson Gulch] porphyry

[W. F. Hillebrand, analyst]

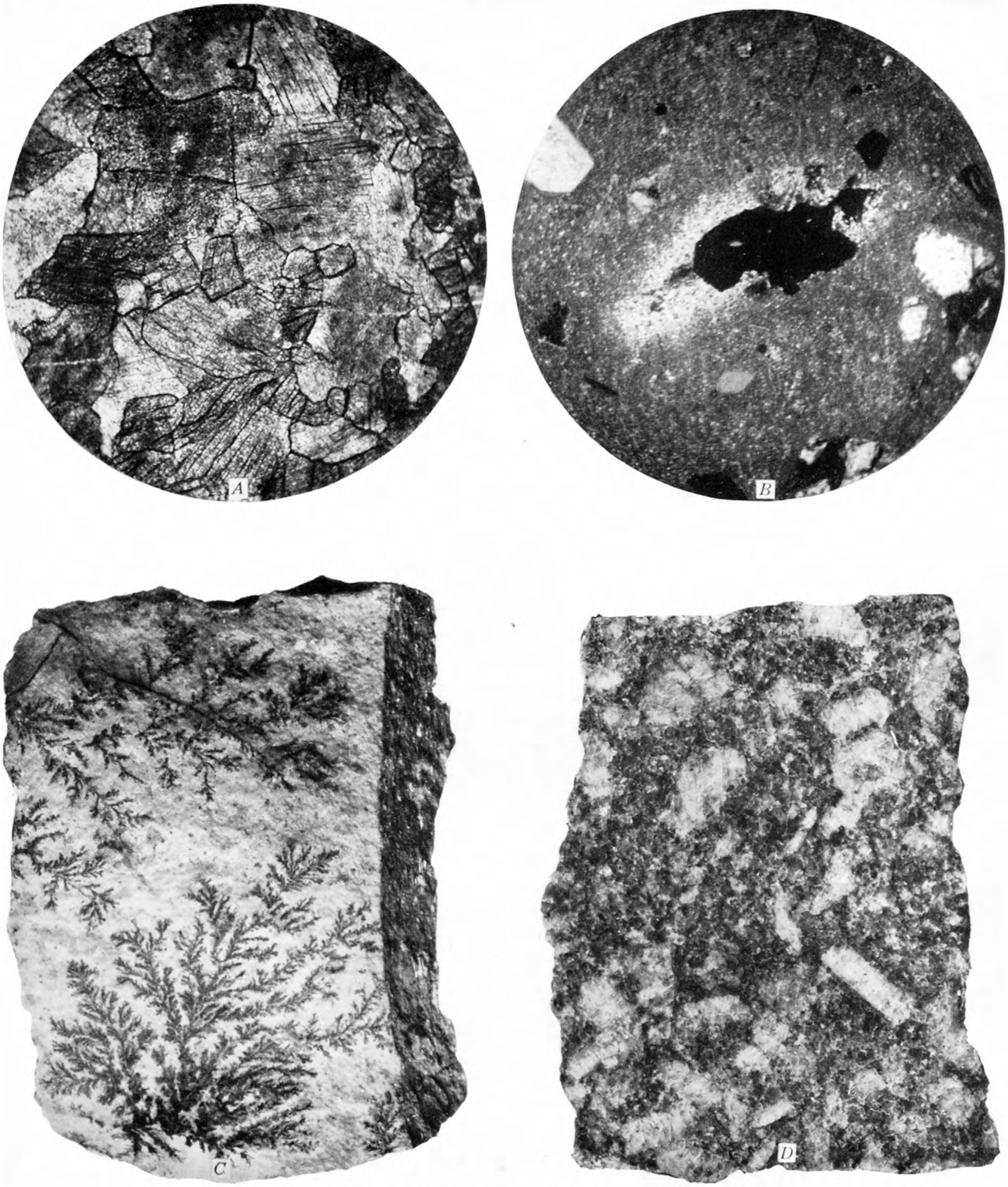
Analysis		Approximate mineral composition	
SiO_2	62.22	Orthoclase	38
Al_2O_3	20.33	Albite	29
CaO	2.95	Anorthite	8
Na_2O	3.45	Quartz	8
K_2O	8.31	Sericite	15
Loss on ignition	1.90	Calcite	2
	99.16		100

Without separate determinations of water and carbon dioxide, both included in "loss on ignition," only the above rough calculation of the composition of the mineral and its inclusions can be made. It serves, however, to indicate the sodic character of the orthoclase.

The plagioclase phenocrysts vary within wide limits in their abundance and size. Their length is usually between 0.5 and 5 millimeters. In the more salic varieties they are of nearly the same color as the groundmass and are not readily discernible, but in the more mafic varieties they form a striking contrast with the dark-green groundmass. They range from nearly 30 per cent by volume down to approximately 3 per cent, but plagioclase in the groundmass is abundant where the phenocrysts are scarce and absent where they are present in large numbers.

Quartz phenocrysts are invariably present. They are commonly much resorbed and of very irregular outline. Many of them are broken and their fragments separated by subsequently crystallized groundmass. They range from a maximum of 8 millimeters to a fraction of a millimeter in diameter. The larger ones are relatively few but are so prominent that they make

[8] Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colo.: U. S. Geol. Survey Prof. Paper 75, p. 44, 1911.



A. PHOTOMICROGRAPH OF LEADVILLE ("BLUE") LIMESTONE

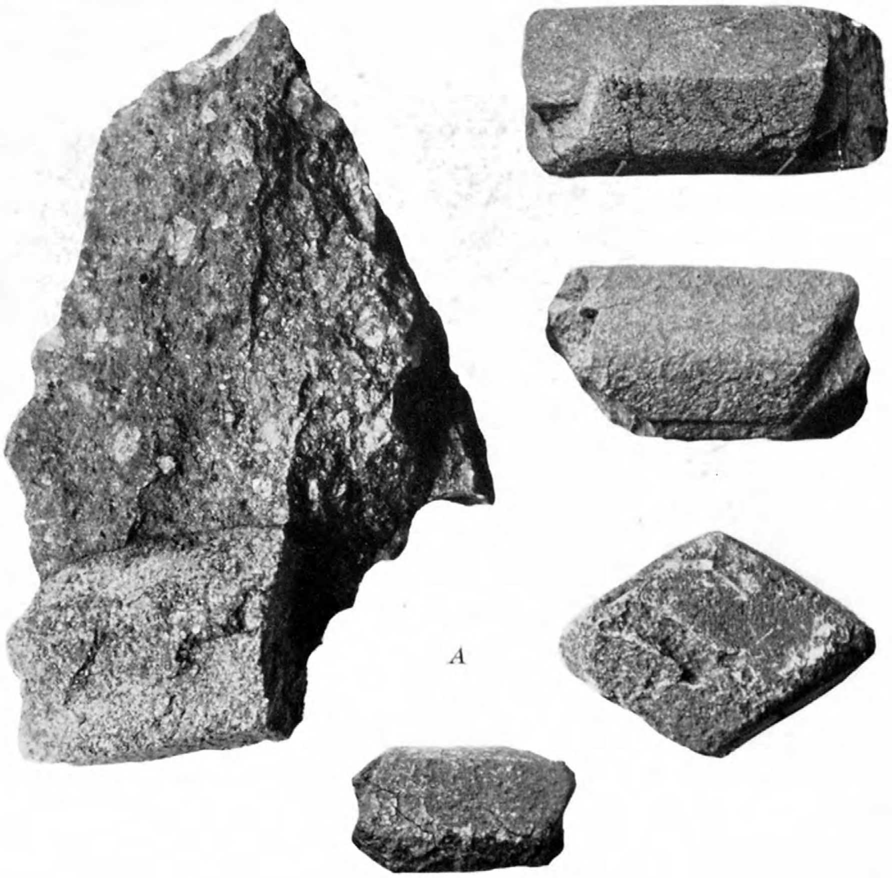
Showing characteristic texture formed by interlocking grains of dolomite, also dusty appearance due to presence of exceedingly minute inclusions

B. THIN SECTION OF SERICITIZED WHITE PORPHYRY

C. DENDRITIC STAINS OF MANGANESE OXIDE ON JOINT PLANE IN WHITE PORPHYRY

D. PRE-CAMBRIAN GRANITE IN LEADVILLE DISTRICT

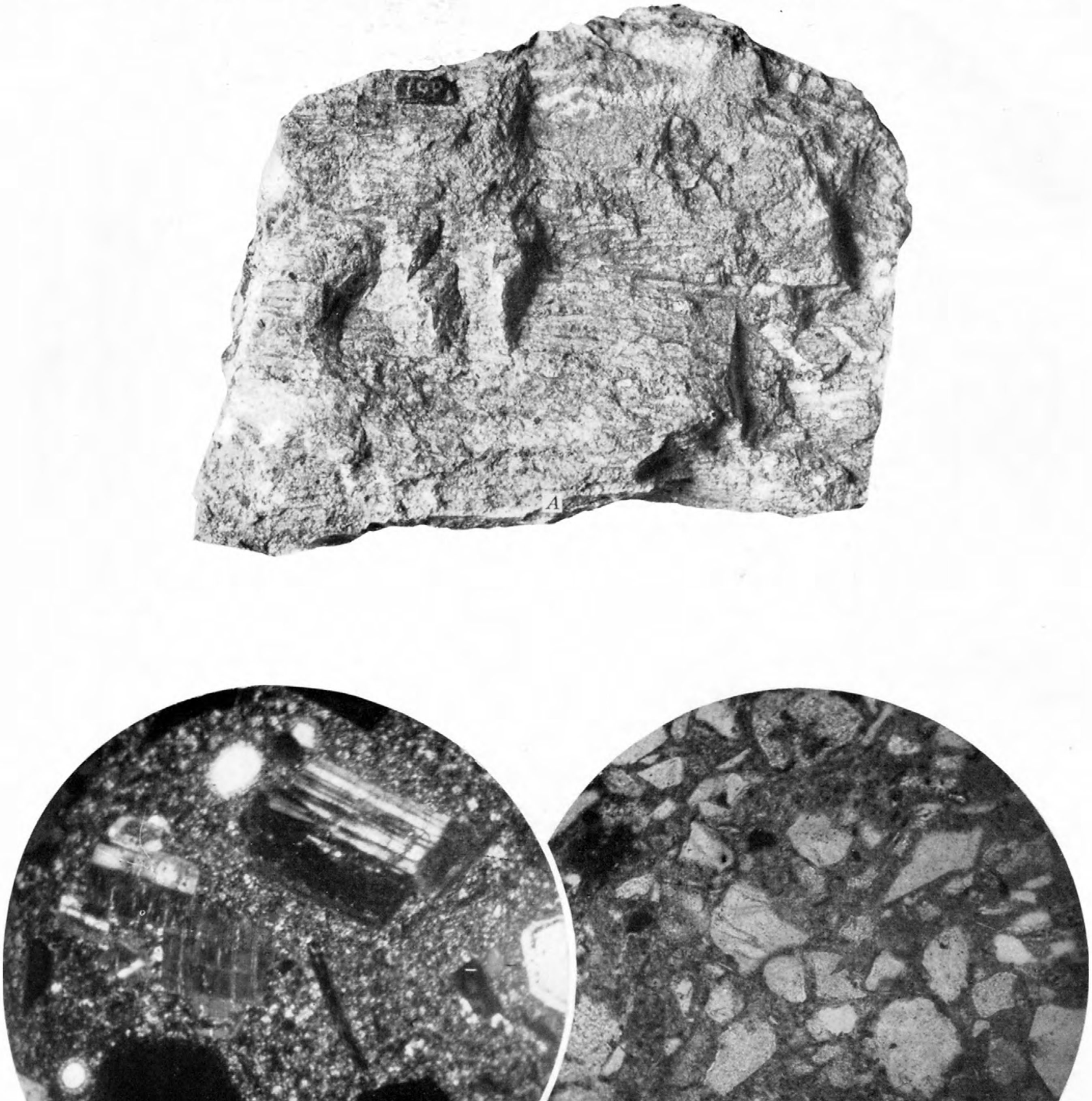
Showing marked tendency toward porphyritic texture



A. SPECIMENS OF LINCOLN PORPHYRY

Large phenocrysts of orthoclase in rock (at left) and weathered out of rock (at right). Natural size

B. SPECIMEN FROM "RED CAST" BEDS



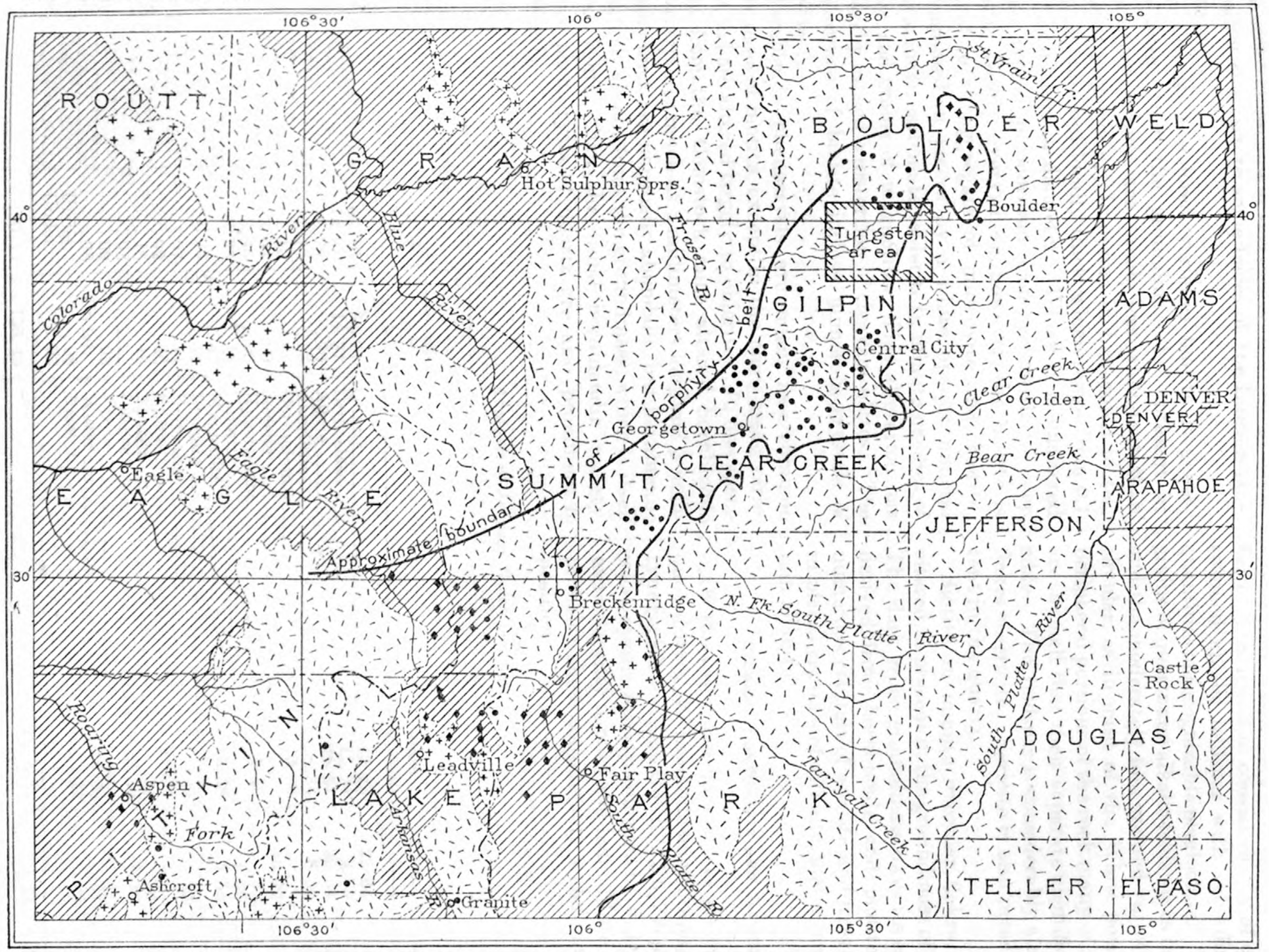
A. SPECIMEN OF RHYOLITE SHOWING FLOW LINES AND VESICULAR TEXTURE

B. PHOTOMICROGRAPH OF LINCOLN PORPHYRY

Showing phenocrysts of plagioclase and quartz in a finely granular groundmass. The quartz phenocrysts are surrounded by halos of quartz crowded with included grains of the groundmass

C. THIN SECTION OF AGGLOMERATE-BRECCIA MATRIX FROM JOSIE MINE

Showing fragments of quartz, unsericitized glass, and sericitized fragments of earlier porphyries



MAP OF CENTRAL COLORADO, SHOWING BELT OF INTRUSIVE PORPHYRIES

After S. H. Ball and J. E. Spurr, with modifications

EXPLANATION

the percentage of quartz appear larger than it really is. The smaller ones are more widely scattered. In number they are everwhere subordinate to the plagioclase phenocrysts, and in this respect the rock presents a marked contrast to some facies of the Lincoln porphyry.

In the lighter-colored varieties biotite is generally absent from the groundmass but present as phenocrysts, which are much less abundant than those of plagioclase. It occurs in hexagonal plates, generally thin but locally thick, which range from 0.1 to 2 millimeters in diameter. Where it is unaltered it has typical pleochroism from yellowish to deep brown. Nearly everywhere, however, the biotite is altered to an aggregate of muscovite and chlorite, accompanied in places by a white opaque mineral (leucoxene?), carbonate (siderite?), minute needles of rutile, and grains of magnetite. This alteration has generally caused a distortion of cleavage plates. The phenocrysts of biotite inclose numerous crystals of apatite.

Hornblende phenocrysts are much less common than those of biotite, except in the more mafic varieties, and are altered largely to chlorite. In one specimen from the Comstock mine altered hornblende phenocrysts as much as 5 millimeters long and 3 millimeters thick are unusually abundant, but hornblende is entirely absent from the groundmass, which is itself much lighter than the usual hornblendic variety. Large phenocrysts of quartz are also prominent in this rock.

In some varieties the hornblende has the form of small needlelike crystals about 3 millimeters long and 1 millimeter thick.

Under the microscope the groundmass of lighter varieties is found to consist chiefly of quartz and untwinned alkalic feldspar with subordinate, variable quantities of recognizable plagioclase. The individual grains of quartz and alkalic feldspar in both the coarser and the moderately fine grained varieties are roughly circular, as in most of the White porphyry. In the peripheral portions of the rock many of the individuals are so small that their separate identification is impossible. The feldspar is considerably altered to minute flakes of sericite. Sericite is also present to some extent in the quartz.

Biotite in minute irregular flakes, usually much altered, is present in the groundmass of some varieties. The dark-green groundmass owes its color to chlorite derived from hornblende and biotite. It contains numerous crystals of apatite and irregular grains and in places crystals of titanite, and a few sections contain allanite.

CHEMICAL COMPOSITION AND CLASSIFICATION

Of the two chemical analyses given below, No. 1, quoted from the Leadville monograph, represents the type rock in Johnson Gulch. No. 2 represents a somewhat pyritic variety collected by J. D. Irving, but its exact locality is not recorded. More analyses would probably show considerably wider variations in composition.

Analyses of Johnson Gulch porphyry

Analyses				1		2	
	1	2		Norm	Mode	Norm	Mode
SiO_2	68.10	68.91	Quartz	32.28	32.64	28.74	29.16
Al_2O_3	14.97	14.27	Orthoclase	17.24	9.73	42.26	35.00
Fe_2O_3	2.78	.90	Albite	29.34	29.34	16.77	16.77
FeO	1.10	.23	Anorthite	8.34	8.34	.56	.56
MgO	1.10	.67	Corundum	3.06		3.06	
CaO	3.04	.60	Sericite		10.72		10.67
Na_2O	3.46	1.96	Hypersthene	1.50		1.50	
K_2O	2.93	7.15	Chlorite		1.66		1.66
H_2O-	1.28	.43	Magnetite	3.38	3.38		
H_2O+		1.12	Ilmenite			.46	.46
TiO_2	.07	.41	Hematite	.32	.32	.96	.96
CO_2	.92	.26	Rutile			.16	.16
P_2O_5	.16	.16	Apatite	.34	.34	.34	.34
Cl	.03		Calcite	2.10	2.10	.60	.60
MnO	.09	.02	Pyrite			3.32	3.32
SrO	.08	Undet.	Water	1.28	.57		.38
BaO	Undet.	.08	Rest	.24	.24	1.81	.19
FeS_2	Undet.	3.32					
	100.11	100.49		99.41	99.38	100.49	100.14

Specific gravity of No. 1 at 16° C., 2.636.

99271—27†——5

According to the quantitative classification of igneous rocks the Johnson Gulch porphyry (No. 1) is, like the Lincoln porphyry, lassenose (I.4.2.4), and the other variety (No. 2) is omeose (I.4.1.2). The mode, or true mineral composition, of each rock is approximately shown above. In No. 1 the amount of orthoclase calculated to be present, even on the assumption that it contains considerable of the albite molecule generally present in orthoclase, leaves the ratio of feldspars well within the limits characteristic of granodiorite. If the potash in the sericite, however, is attributed to the alteration of orthoclase and biotite (in which the ratio $MgO: K_2O$ is assumed to be 3:1), the orthoclase molecule originally formed about 15 per cent of the rock, and the presence of only 3 per cent of the albite molecule in the orthoclase would be necessary to bring the feldspar ratio within the limits of quartz monzonite. The occurrence of the sericite principally as a result of the replacement of the plagioclase and the association with it of secondary albite, however, imply that the percentage of anorthite recorded above is less than that contained in the unaltered rock, which was evidently near the arbitrary boundary between granodiorite and quartz monzonite.

In the mode of No. 2 as recorded above the feldspar ratio places the rock on the border line between granite and quartz monzonite, but here also alteration obscures its original composition. To assume that the potash of the sericite was originally in orthoclase would place the rock well within the granite group, whereas restoration of the anorthite molecule replaced by sericite would place it well within the quartz monzonite group. The pyrite has replaced original biotite and perhaps ilmenite.

MAFIC VARIETIES

Comparatively little rock representing the mafic facies of the Gray porphyry and corresponding to the porphyrites described by Cross occurs within the Leadville district. In other words, the rocks on the east side of the Mosquito Range have in general a slightly more basic facies than those on the west side. A few rocks of which no analyses have been made but which appear to correspond to the more basic rocks described by Cross were observed in the district. Some of these are highly quartzose and much less basic than they appear.

EVANS GULCH PORPHYRY

During the first survey of the district the gray granular igneous rock that occupies a triangular area on the north slope of Evans Gulch was doubtfully correlated with the Mount Zion porphyry, which is present on Mount Zion and Prospect Mountain,[9] but the two rocks are so different in chemical composition that they are here classified separately, and the name Evans Gulch porphyry is applied to the rock on the north slope of Evans Gulch. This rock differs from other members of the Gray porphyry group in having a fine, almost even grained texture, and it resembles at first glance a fine-grained granite. On close inspection, however, its plagioclase appears as white roughly rectangular crystals 3 millimeters in maximum length embedded in a fine-grained groundmass, and therefore the term porphyry is somewhat justified. The plagioclase constitutes 25 to 30 per cent of the rock. Besides plagioclase minute black to dark-green irregular flakes of biotite and a few grains of colorless quartz can be detected without the aid of a lens. Many small pits on the weathered surface and the effervescence of the rock in dilute acid indicate the presence of calcite. The hand lens shows that the quartz in the groundmass is closely associated with a gray mineral which under the microscope proves to be orthoclase.

Under the microscope the plagioclase phenocrysts display a zonal structure. The crystals are clouded, except for the rims, by alteration to sericite. Their average composition is determinable as oligoclase-andesine, but the clear rims are albite, and the more altered crystals also contain secondary veinlets of albite. Small amounts of calcite and epidote accompany the sericite and albite. Besides the phenocrysts, plagioclase forms little rectangular crystals 0.1 millimeter or less in length in the groundmass. These small crystals are more sodic than the larger crystals.

Orthoclase occurs in irregular grains closely associated with quartz. It is most readily distinguished by its included dustlike particles of ferric oxide and kaolin and the scarcity of sericite. A few grains show micrographic intergrowths with quartz, and a few show poorly developed perthitic intergrowths with albite. Quartz forms typical interstitial grains rarely as much as 1 millimeter in diameter. A few have crystal boundaries in contact with irregular grains of calcite and appear to be secondary or perhaps secondarily enlarged. These calcite grains, the largest 1 millimeter in diameter, have impregnated the groundmass by replacing orthoclase. The biotite is entirely altered to chlorite, of which some preserves the original biotite structure and some forms diverging aggregates. Magnetite grains of irregular to crystalline outline are closely associated with the quartz and orthoclase, but few if any are inclosed in plagioclase or biotite. Apatite and zircon form typical minute crystals.

MOUNT ZION PORPHYRY

The Mount Zion porphyry also, where fresh and unaltered, is a fine-grained gray granitic rock with the same minerals as the Evans Gulch porphyry[10] but

[9] U. S. Geol. Survey Mon. 12, p. 76, 1886.

[10] Cross, Whitman, U. S. Geol. Survey Mon. 12, pp. 323-324, 1886.

contains more quartz and less biotite. It is rarely found unaltered, however, and in various stages of alteration it passes through a facies in which decomposed biotite produces a slightly spotted appearance into a white rock that glistens with fine lustrous particles of muscovite and can hardly be distinguished from the White porphyry. Emmons[11] stated that it is much decomposed on the south slopes of Prospect Mountain and apparently grades into the White porphyry. On Plate VI of the atlas accompanying the Leadville monograph, included in Plate 11 of this report, he represented the Mount Zion and White porphyries as parts of the same formation. As the Mount Zion porphyry was not studied during the resurvey, no further suggestion can be made on this question except that offered by comparison of the chemical analyses.

The chemical and calculated mineral composition of the Evans Gulch and Mount Zion porphyries are shown in the following table:

Analyses, norms, and modes of Evans Gulch and Mount Zion porphyries

Analyses	1	2		1 Norm	1 Mode	2 Norm	2 Mode
SiO_2	63.25	73.50	Quartz	23.64	25.0	34.68	35.2
Al_2O_3	16.16	14.87	Orthoclase	19.46	12.0	21.13	16.4
Fe_2O_3	2.60	.95	Sericite	----	[a] 11.5	----	4.4
FeO	2.44	.42	Albite	29.87	29.9	29.34	29.3
MgO	1.62	.29	Anorthite	7.78	[a] 7.8	10.56	[a] 10.6
CaO	2.99	2.14	Corundum	3.98	----	1.43	----
Na_2O	3.54	3.46	Chlorite (pennine)	----	[a] 5.9	----	[a] 3.0
K_2O	3.26	3.56	Hypersthene	5.55	----	.70	----
H_2O+	1.85	} .90	Magnetite	3.71	[a] 3.7	1.39	[a] 1.4
H_2O-	.63		Ilmenite	.91	.9	None.	----
CO_2	.88	----	Apatite	.62	.6	None.	----
TiO_2	.50	None.	Calcite	2.00	2.0	----	----
P_2O_5	.30	None.	Water	2.48	[a] .6	----	----
MnO	----	.03					
BaO	----	None.		100.00	99.9	99.23	100.3
SrO	----	Trace.					
	100.02	100.12					

[a] Sericite is subject to a slight correction for kaolin; anorthite and excess water for epidote; and chlorite and magnetite for epidote and hematite.

1. Evans Gulch porphyry from tunnel 200 feet east of Silver Spoon shaft. J. G. Fairchild, analyst.
2. Mount Zion porphyry. (Quoted from U. S. Geol. Survey Mon. 12.) W. F. Hillebrand, analyst.

According to the quantitative classification, both of these porphyries are toscanose (I.4.2.3), but the Evans Gulch porphyry is very near lassenose (I.4.2.4). The Evans Gulch porphyry is the more altered of the two, as indicated by the presence of sericite, chlorite, and calcite, but its original mineral composition is not greatly obscured. Allowance for the small amount of orthoclase replaced by calcite and for the minor amount of the albite molecule present in the orthoclase grains places the feldspar ratios within the range covered by monzonite but rather near that covered by granodiorite. The feldspar ratios place the Mount Zion porphyry in the same group, and both rocks may be classified as quartz monzonite near granodiorite; but the much higher percentage of quartz and lower percentages of dark constituents in the Mount Zion porphyry would classify it as granite porphyry. In this last respect it closely resembles the White porphyry (p. 45) and tends to justify Emmons in correlating the two rocks as parts of the same formation. The Evans Gulch porphyry bears no resemblance to the White porphyry and is so different from the Mount Zion porphyry in chemical composition that it is mapped separately on Plate 11.

[11] Idem, p. 76.

OTHER PORPHYRIES IN MOSQUITO RANGE REGION

The types above described include all the specimens collected within the Leadville district. Some variations would undoubtedly be found if a complete series of analyses were made, but the petrographic similarity of all the known varieties is too close to warrant the expense of additional analysis.

In the Mosquito Range region as a whole the composition of the porphyries varies a good deal more widely than it does within the Leadville district. These variations are briefly considered in the section on regional relationships of the intrusive porphyries (pp. 54–55).

AGE RELATIONS OF PORPHYRIES AT LEADVILLE

Although the White porphyry in most parts of the district is isolated from the different varieties of Gray porphyry, there are a few places in the Iron Hill and Fryer Hill areas where it is cut by dikelike apophyses from Gray porphyry sills. The Gray porphyry in the extensive sill that overlies the White porphyry in the northwest quarter of the district was evidently intruded from the conduit at Breece Hill, crosscutting the White porphyry and spreading along its top beneath a roof of the "Weber shales." The earlier age of the White porphyry is thus established in the western part of the district, but at Breece Hill, both on the surface and underground, there are places where the porphyries are so diverse in texture and so highly altered that the White porphyry can not be distinguished with certainty from the Gray porphyry. This is especially true where small masses of Gray porphyry, finer grained than the typical rock, have been bleached by alteration, and where White porphyry sills as well as Gray porphyry sills are present at the lower stratigraphic horizons. The two kinds of rock, however, can be distinguished under the microscope, except where alteration is extreme, and Irving's study of the Breece Hill area showed that the Gray porphyry was much the more abundant. For this reason all the porphyry in this area, where not positively identified as White porphyry, is mapped as Gray porphyry on Plates 13 and 27.

The relations of the different varieties of Gray porphyry to one another have not been determined, partly because of their isolation but largely because of their altered condition in the areas studied in detail. At a few places one intrusion of Gray porphyry has been found cut by another, but the two varieties are too much alike in their altered condition to be classed as different varieties. The evidence as a whole shows that although the Gray porphyry sills were not all intruded at quite the same time, the intrusions all took place within the interval between the intrusion of the White porphyry and the period of folding and reverse faulting described in the next chapter. Within this interval there was no conspicuous change in the composition of the Gray porphyry magma.

The local age relations considered in the preceding paragraphs do not represent the entire age relations of the igneous rocks of the region. Knopf has found that in the Aspen district sills of dioritic rock were intruded before an albite alaskite porphyry that resembles the White porphyry of Leadville, and that a stock of granodiorite was intruded later.[12] Crawford,[13] from studies at different places in Colorado, concludes that a widespread intrusion of porphyry, mainly as sills, antedated a period of folding and faulting, which was followed by small intrusions of quartz diorite and a batholithic invasion of quartz monzonite. These two recent statements agree with the findings of Cross and Spencer[14] several years earlier in the Rico Mountains.

The porphyry sills of the Leadville district belong to the earliest group recognized by Crawford. The stocks were supposed by Irving to be contemporaneous with the sills of Gray porphyry, and this supposition is supported by the larger structural features of the district; but owing to the complexity of the porphyries in and around the Breece Hill stock and the obscuring of their relations to each other, it may be that some of the rock in this stock is later than that in the sills and is to be correlated with the intrusions that followed the period of folding and reverse faulting. The intensity of mineralization in and around the Breece Hill stock suggests the presence of such a late intrusion, as mineralization in certain other districts in central Colorado is closely correlated with igneous stocks intruded subsequent to the period of folding.[15]

STRUCTURAL FEATURES OF PORPHYRIES AT LEADVILLE

FORMS OF INTRUSIVE BODIES

The forms assumed by the intrusive bodies have been largely determined by the structural features of the rocks which they have invaded. In the pre-Cambrian crystalline rocks the porphyries occur as vertical or nearly vertical dikes, but in the sedimentary cover, where the lines of least resistance lay parallel with the component layers, they have spread between the strata as sills or sheets. The few stocklike bodies penetrate both granite and overlying strata, but even the extensive underground development in Leadville has not fully outlined them.

SILLS OR SHEETS

The sill, or sheet, is by far the commonest form at Leadville. Sills occur at many horizons in the sedimentary layers, which at the period of injection were undoubtedly horizontal. The largest one is the main sill of White porphyry, which in some places attains a thickness of 1,500 feet, but the thickness and lateral extent of some of the Gray porphyry sills are also great.

The sills, especially those of the White porphyry, are for considerable distances fairly conformable to the bedding. Few of the large sills, however, are conformable throughout; nearly all break across here and there from one bed to another. The crosscutting contacts of the White porphyry sills are nearly all at small angles to the inclosing sedimentary layers. Such contacts of the White porphyry may be seen in sections N–N′ on Plate 17, and B–B′ and C–C′ on Plate 14. The Gray porphyry bodies, on the other hand, are very much more commonly crosscutting, transgress the layers at all angles, and in places terminate abruptly. They are accompanied by short, stumpy apophyses or offshoots, some of which form a maze of interconnected bodies.

The crosscutting and transgressing contacts of sills appear in general to slope upward, away from their conduits. This fact is illustrated by the main White porphyry sill of the Leadville district, whose magma appears to have entered the sediments in the neigh-

[12] Knopf, Adolph, Recent developments in the Aspen district, Colorado: U. S. Geol. Survey Bull. 785, pp. 6-14, 1926.

[13] Crawford, R. D., A contribution to the igneous geology of central Colorado: Am. Jour. Sci., 5th ser., vol. 7, pp. 365-388, 1925.

[14] Cross, Whitman, and Spencer, A. C., Geology of the Rico Mountains, Colo.: U. S. Geol. Survey Twenty-first Ann. Rept., pt. 2, pp. 96, 98-114, 1900.

[15] Crawford, R. D., op. cit., pp. 384-386.

borhood of Breece Hill, probably through the same conduit that later gave access to the Gray porphyry. At this conduit the two porphyries are closely associated and even appear to grade into each other. In this vicinity—that is, on Ball Mountain, in South Evans and Evans gulches, and at the head of California Gulch—many sills of the White porphyry lie between the Lower quartzite and the underlying granite.

Farther from Breece Hill they gradually rise to higher horizons until they spread in their maximum lateral development and greatest thickness in the fissile shales at the base of the Weber (?) formation. The large masses of Gray porphyry that have been extensively explored have a general sill-like form, but many of them are very irregular in detail. Dikelike apophyses extend upward from certain sills into the overlying strata and locally into White porphyry and gradually thin out (see sections E–E′ and Yak, pl. 15, and section M–M′, pl. 17); other sills are locally thickened or have knoblike protuberances (see sections Yak, pl. 15, and N–N′, pl. 17); others have more complex irregularities (see section J–J′, pl. 25). In general the Gray porphyry bodies are more regular the greater their distance from the principal conduits, whereas near the conduits they are least regular as well as most numerous. Thus in the Iron Hill region (see sections A–A′, C–C′, pl. 23; F–F′ and H–H′, pl. 24; M–M′, pl. 26) Gray porphyry bodies occur in greatest profusion in the White limestone and are very irregular. The same is true to a less degree in the Adelaide Park region, but on Carbonate Hill the masses of Gray porphyry are thinner and more regular, and in the western part of the Downtown district only one sheet is found in the Blue limestone.

The characteristic irregularity of the Gray porphyry sills may be attributed in part to structural conditions at the time of their intrusion and in part to their degree of viscosity. As already stated, the shaly beds, particularly the black shale of the Weber (?) formation just above the Blue limestone, afforded the easiest access to the intrusive porphyries. The White porphyry, rising first and in great quantity, was deflected along some of the lower and thinner shale beds, but for the most part reached the base of the Weber (?) formation, along which it spread as the largest intrusive sheet in the district. The Gray porphyry, rising later, found the shale contacts largely occupied by White porphyry, and doubtless also found the limestone and quartzite as well as the White porphyry locally fractured as a result of the White porphyry intrusion. The "Weber shales" were still an effective barrier, and the Gray porphyry magma was therefore deflected along available planes of weakness, whether bedding planes or fractures. Near the conduit, where the quantity of magma and the pressure exerted by it were greatest, room for the porphyry was made by the local thrusting aside of limestone, which resulted in the variations in thickness of both limestone and porphyry. Short branches or apophyses were sent out along fractures across the bedding, and where these were numerous and connected with other accessible bedding planes complex sheets were formed. Farther from the conduit, where the pressure of the magma was less, the intrusion became localized along one or two bedding planes that offered a minimum of resistance, particularly along the one in the Blue limestone known as the "second contact."

Only a part of the Gray porphyry magma is represented by these lower sills. A large part of it succeeded in penetrating the White porphyry and reaching the base of the "Weber shales," along which it spread as a great sheet, rivaling the main sheet of White porphyry in size. This sheet forms the bedrock surface west of the Weston fault and north of Breece, Iron, and Carbonate hills. Some of the Gray porphyry magma even penetrated the "Weber shales" and spread in sheets along beds of the overlying "grits" or sandstone of the Weber (?) formation, as shown on the western slope of Ball Mountain.

The difference in viscosity of the two magmas, which were similar in chemical composition, is indicated by their texture. The White porphyry, which is very finely porphyritic, was evidently intruded at a temperature above the crystallization points of feldspar and quartz, but after intrusion it was quickly chilled, so that even in the thickest sill these minerals had little time to crystallize. The Gray porphyry, on the other hand, had already begun to crystallize and contained feldspar, quartz, and biotite crystals of considerable size when it reached the sedimentary rocks. It was therefore intruded at a lower temperature and must have been more viscous and more likely to deform the strata locally rather than to follow bedding planes.

The relative quantities of gaseous matter or "mineralizers" present in each magma and the resulting relative increase in fluidity can not be estimated but were evidently small. The prominence of distinct muscovite crystals in the White porphyry suggests that volatile matter may have been rather abundant, but the small size of the quartz and feldspar crystals shows that it was not sufficient to affect crystallization materially before the magma solidified. The large size of quartz and feldspar crystals, especially orthoclase, in some of the Gray porphyry suggests that gaseous matter was present in sufficient quantity to promote fluidity and the growth of large crystals before intrusion. Dikes or veins of very coarse grained or pegmatitic material are absent from both porphyries. The influence of gaseous materials in rendering one porphyry more fluid than the other therefore appears negligible, and the greater regularity of the White porphyry is attributed to its intrusion at higher temperature and its more ready access to the shale beds.

DIKES

True dikes of porphyry—that is, dikes which are not merely the apophyses of sills—are rather scarce in the sedimentary rocks. Those found include both the White and the Gray porphyry. Besides these the structure sections show several dikes that are inferred to be present from structural data. (See sections on pls. 14–17 and 23–26.)

In the pre-Cambrian rocks, however, dikes of porphyry are more conspicuous and probably represent some of the conduits through which the porphyries reached the overlying sedimentary formations. East of the Mosquito Range dikes are numerous in the area mapped in detail by Patton and others (pl. 11). They may also be numerous in the pre-Cambrian areas concealed beneath "wash."

The Yak tunnel, which is the longest single opening in the district and has afforded a continuous series of accurate observations, cuts a great number of dikes in its passage through the granite—so many, in fact, that no attempt was made to map them individually. These are near the west edge of the Gray porphyry stock beneath Breece Hill.

STOCKS [16]

No typical stocks of porphyry are present in the Leadville district, but two and perhaps three irregular intrusive masses are included under this title. None of them are outlined on the ground surface, and their dimensions as represented in the sections on Plates 14–17 are based on underground observations.

The largest is a cylindrical mass beneath the Banker shaft, Breece Hill (sections D–D′, pl. 14; E–E′, and Yak, pl. 15; L–L′, pl. 16). Its contacts with the pre-Cambrian granite are about vertical, but in the overlying sedimentary rocks it branches into several sills, some so thick as to suggest a laccolithic form. The surface of Breece Hill consists of the thick sill-like mass that spreads out from the top of the cylindrical stock. This stock fills the main conduit through which the Gray porphyry was intruded, but it has not been determined whether the latest intrusion along the conduit was later than that which spread out to form the sills.

Between Printer Boy and Dome hills (section H–H′) the mass of Gray porphyry between the Pilot and Mike faults is part of a similarly shaped mass. Its outline has been obscured by faulting, and it may have been a southward continuation of the Breece Hill stock.

The third stock (section D–D′, pl. 14) underlies Adelaide Park, and although it reaches the bedrock surface its northern half is concealed beneath the south moraine of the Evans Gulch glacier and its southern half beneath "wash." In horizontal section it is like a broad lenticular dike, but in vertical cross section it is funnel shaped. It extends southward to the Adelaide fault, but as no trace of it has been found west of the fault its original outline must have been much the same as the present one.

[16] Irving's manuscript contained this heading, but the two pages which presumably contained a description of the stocks were missing. The writer has had no opportunity to study the stocks underground, and the text here given merely calls attention to the salient features shown in the maps and sections.—G. F. L.

REGIONAL RELATIONS OF THE INTRUSIVE PORPHYRIES

Cross[17] in 1894 called attention to the general similarity of the intrusive rocks of late Cretaceous or early Tertiary age in Colorado and neighboring parts of Utah and Arizona. He also noted their similarity in Wyoming and Montana. In 1889 he introduced the names monzonite, monzonite porphyry, and quartz monzonite porphyry in his descriptions of the igneous rocks in the Telluride district of the San Juan region.[18] Cross had intended eventually to publish a revision of the terminology of the porphyries at Leadville, but the report on the Alma district, to the east, by Patton,[19] who had been in correspondence with Cross, gave the necessary information. In 1908 Ball[20] correlated the intrusive rocks of central Colorado and showed them to lie mostly within a belt that extends southwestward from Boulder County and to be prevailingly of monzonitic character. The Leadville district lies near the center of the broadest part of this belt (pl. 30). Ransome,[21] who had worked in the San Juan region, later made a detailed study of the Breckenridge district and classified all the intrusive rocks there as quartz monzonite and monzonite. He compared them with the intrusive rocks of the Tenmile and Leadville districts and concluded that, although they varied considerably in certain details, the rocks of all three districts formed a generally continuous series.

As detailed reports [22] on some of the districts within this central Colorado belt were published subsequent to Ball's study, Irving reviewed these reports as well as the older reports and reclassified the rocks described in them according to the quantitative modal system

[17] Cross, Whitman, The laccolitic mountain groups of Colorado, Utah, and Arizona: U. S. Geol. Survey Fourteenth Ann. Rept., pt. 2, pp. 219–241, 1894.

[18] Cross, Whitman, U. S. Geol. Survey Geol. Atlas, Telluride folio (No. 57), p. 6, 1899.

[19] Patton, H. B., Hoskin, A. J., and Butler, G. M., Geology and ore deposits of the Alma district, Park County, Colo.: Colorado Geol. Survey Bull. 3, 284 pp., 1912.

[20] Spurr, J. E., and Garrey, G. H., Economic geology of the Georgetown quadrangle (together with the Empire district), Colo., with general geology by S. H. Ball: U. S. Geol. Survey Prof. Paper 63, pp. 67–71, 1908.

[21] Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colo.: U. S. Geol. Survey Prof. Paper 75, pp. 43, 60–62, 1911.

[22] 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, 379 pp., 1917. Crawford, R. D., Geology and petrography of the Sugar Loaf district, Boulder County: Colorado Univ. Studies, vol. 6, No. 2, pp. 97–131, 1909; Intrusive rocks of the main tungsten area of Boulder County: Colorado Geol. Survey First Rept., pp. 23–36, 1909. Fleck, Herman, Welfare of Colorado's rare-metal industry: Colorado School of Mines Bull., vol. 4, No. 4, pp. 234–242, 1909. George, R. D., The main tungsten area of Boulder County, Colo., with notes on the intrusive rocks by R. D. Crawford: Colorado Geol. Survey First Rept., pp. 7–103, 1909. Irving, J. D., and Bancroft, Howland, Geology and ore deposits near Lake City, Colo.: U. S. Geol. Survey Bull. 478, 128 pp., 1911. Patton, H. B., The Montezuma mining district of Summit County, Colo.: Colorado Geol. Survey First Rept., pp. 105–144, 1909.

proposed by Iddings.[23] Of 70 rocks considered 32 were classified by Irving as belonging to the granodiorite group, 30 as monzonite and quartz monzonite, 6 as diorite, and 2 (from the Georgetown quadrangle) as syenite. Some of the rocks were so altered or so incompletely described that the value of this reclassification is questionable. Some of the rocks placed in the granodiorite group are very close to the quartz monzonite group and the results as a whole tend to confirm Ball's statement that the rocks are of prevailingly monzonitic character. More recent descriptions by Bastin[24] of intrusive rocks in Gilpin County show that the principal masses belong to the quartz monzonite group accompanied by mafic differentiates, and that dikes in the region include monzonite porphyry and latite, diorite and andesite, granite porphyry, alkali syenite porphyry and bostonite, and basalt porphyry.

clined contacts through granite, sedimentary rocks, and intrusive porphyry and in places cut off ore bodies. Narrow offshoots extend from the pipes along faults or steeply inclined fissures, but offshoots along bedding planes are exceptional. The boundaries of the agglomerate are generally smooth or gently undulating, but some of the walls of narrow offshoots are angular. The known vertical extent of the pipes far exceeds their horizontal diameter, as is well shown in the Ollie Reed or South Evans pipe, which has been considerably explored along its north and southwest borders and has been crosscut at a depth of 850 feet by the Yak tunnel, where it is bounded on both sides by granite.

Outcrops of these pipes are very few, as they occupy low-lying areas deeply covered by glacial and other débris.

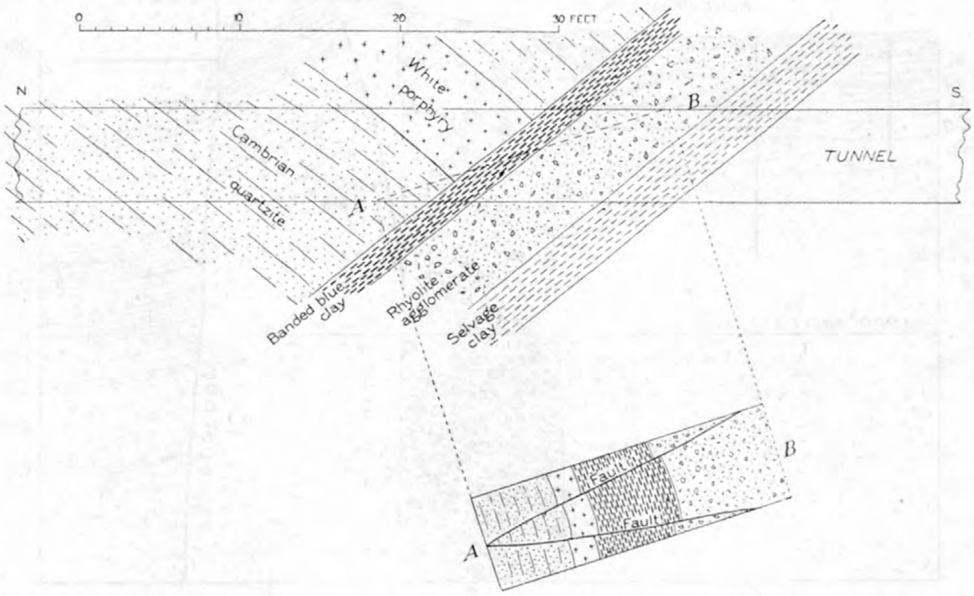


FIGURE 11.—Sketch of a portion of Miner Boy tunnel, looking east, showing how a dike of rhyolitic agglomerate has penetrated between the selvage surfaces of the Colorado Prince fault. The postagglomerate faulting is shown in a view of the roof of the drift, as seen in the projection

The altered condition of the White and Gray porphyries of the Leadville district, as shown on preceding pages, prevents their exact designation, but there is no question that the Gray porphyry includes some of the more common members of this series, and the White porphyry may be regarded as one of the less common members.

RHYOLITIC AGGLOMERATE

STRUCTURE AND DISTRIBUTION

Only one volcanic rock, a rhyolitic agglomerate, occurs within the Leadville district. This rock forms funnel-shaped necks or pipes of roughly elliptical cross section which extend upward with steeply in-

[23] Iddings, J. P., Igneous rocks, vol. 2, pp. 21–26, New York, John Wiley & Sons, 1913.

[24] 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. 37–57, 1917.

The agglomerates, though later than the major faults, are in a few places slightly fractured and faulted, owing to renewed movement along such faults. Where, for example, the Miner Boy tunnel, on the north slope of Breece Hill (fig. 11), cuts the Colorado Prince fault, 170 feet from its portal, the fault fissure contains a dike of agglomerate that has been thus fractured by movement along the old fault surface.

Four agglomerate pipes have been disclosed by mine workings. These are the Ollie Reed pipe, in South Evans Gulch; the Josie pipe, on the point of the divide between Evans and South Evans gulches; the St. Louis pipe, just west of the Ollie Reed pipe; and the Eureka pipe, at the head of Stray Horse Gulch, on the northwest slope of Breece Hill. A dikelike mass of agglomerate has been found in workings at the head of California Gulch.

The form and distribution of these pipes are shown in Plates 13 and 27. As they are not exposed at the surface, except here and there in a prospect pit, their surface outlines have been determined so far as possible by projection from below.

OLLIE REED PIPE

The Ollie Reed pipe, in South Evans Gulch, has been more fully exposed by mine workings than the others. It has a rudely elliptical plan, very irregular in detail, with long, dikelike branches extending along faults. Its longer diameter trends approximately northeast, nearly parallel to the Colorado Prince fault. It has a length of 2,000 feet and a width of 800 to 900 feet. The north wall of the mass has been extensively explored by the workings of the Ollie Reed mine, as shown on Plate 27 and in part in Figure 12. In these workings its position is shown both by the drifts of the first and second levels (altitude 10,725 and 10,625 feet) and by drill hole No. 4, which has been put down from the second level. This drill hole passed through the pipe for 178 feet and then entered quartzite, showing that the conduit narrowed downward. The Ollie Reed No. 2 shaft penetrated the mass for a depth of 350 feet, and a drift on the 10,650-foot level followed the contact for 100 feet. A dike of this material is reported to have been found by the Winnie workings a few feet to the east of the vein.

The pipe was probably reached in some of the more southerly drifts from the Favorite shaft, but those workings have not been examined. Its western boundary is shown in the Big Four and Gold Basin mines, but the pipe is so confused with the irregular blocks into which the Cambrian quartzite and porphyry intrusions have been broken in this neighborhood by both faults and veins that its exact boundaries can not be accurately projected to the surface. In these mines the agglomerate penetrates the veins and appears in some places along one wall of the vein filling, in some places on the other. It also crosses the workings at all angles, and the included masses of country rock may be regarded as exceptionally large fragments of the agglomerate.

The southern boundary of the mass appears to be a fault parallel to the Colorado Prince fault, although its true position is exposed only in the Yak tunnel. The tunnel penetrates the center of the mass at a depth of 800 to 900 feet. Both walls of the pipe are granite at this depth and are vertical, but they are nearer together than the corresponding contacts in the upper workings and therefore indicate the funnel shape of the vent. On the tunnel level they show a seam of clay selvage lined with a blackish shaly material.

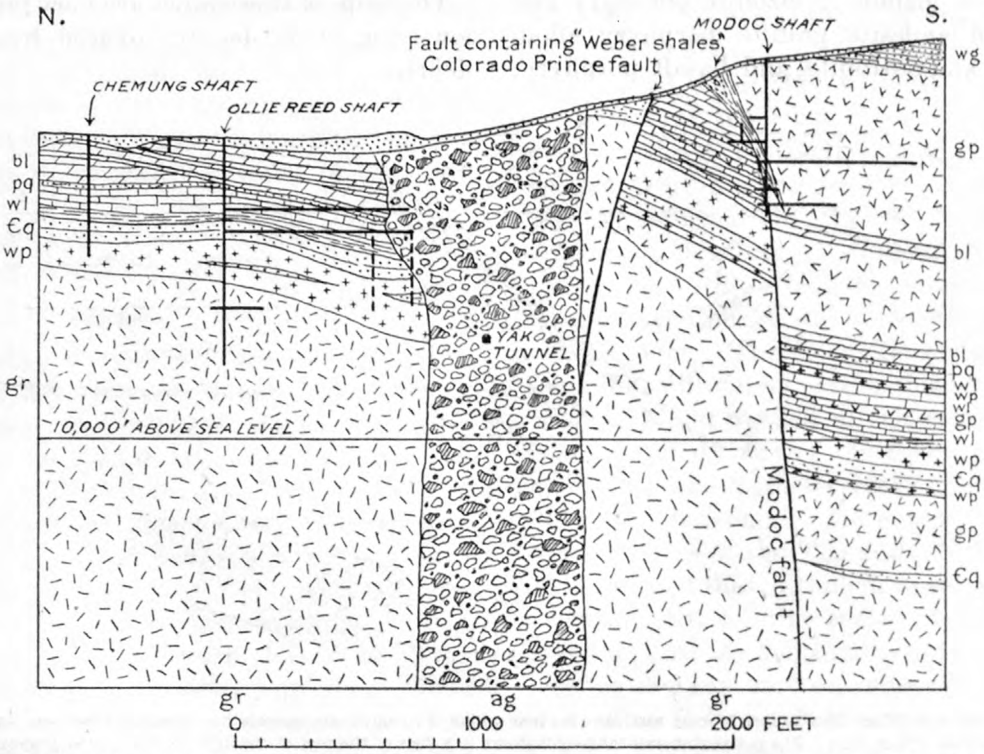


FIGURE 12.—North-south section through South Evans (Ollie Reed) body of agglomerate, looking east. wg, "Weber grits"; gp, Gray porphyry; bl, Blue limestone; pq, Parting quartzite; wl, White limestone; wp, White porphyry; cq, Cambrian quartzite; gr, granite

The eastern boundary of the mass is shown in the workings of the Howard shaft, where the east drift passes abruptly from agglomerate into fault selvage and thence into granite. The contact dips 60° W. The position of the northeast corner of the pipe is uncertain but is south of the workings of the Silent Friend mine.

From the southeast corner of the mass a long dike extends along the fault. This is shown in the Nevada tunnel,[25] where a grayish breccia occurs between the

[25] Field notes of J. E. Spurr.

two fault walls, and in a shallow prospect pit on the north spur of Ball Mountain that lies between "Weber grits" and the Gray porphyry along the Ball Mountain fault. The southern limit of this dike is not known.

It is probable that the Ollie Reed pipe represents a volcanic vent located on a vertical line of weakness at the intersection of the Ball Mountain, Colorado Prince, and minor faults. The eruption of the rhyolite was probably accompanied by additional faulting along existing fault planes, which were lubricated by previously developed selvage and comminuted rock.

JOSIE PIPE

The Josie pipe is exposed in the Josie shaft and in two shallow prospect holes 480 feet to the northwest. It is not known elsewhere at the surface and is only imperfectly outlined by mine workings. It is, however, well surrounded by mine workings and is thus restricted within fairly well defined limits. The Josie shaft was sunk to a depth of 500 feet entirely in the agglomerate. Drifts from it have exposed the southwest and northeast borders and indicate a funnel shape (fig. 13). The Midnight workings followed an ore body dipping north, with the inclosing sedimentary rocks, until it was cut off by the agglomerate, which is reported to have consisted at this point chiefly of granite boulders. Nothing is known of the Lida workings, on the south. On the west the workings in the Luema mine do not reach the agglomerate mass, but the 400-foot level of the Silver Spoon mine enters the agglomerate 80 feet east of the shaft and continues eastward in it for 170 feet. On the east the west workings of the Famous mine (altitude 10,664 feet) are

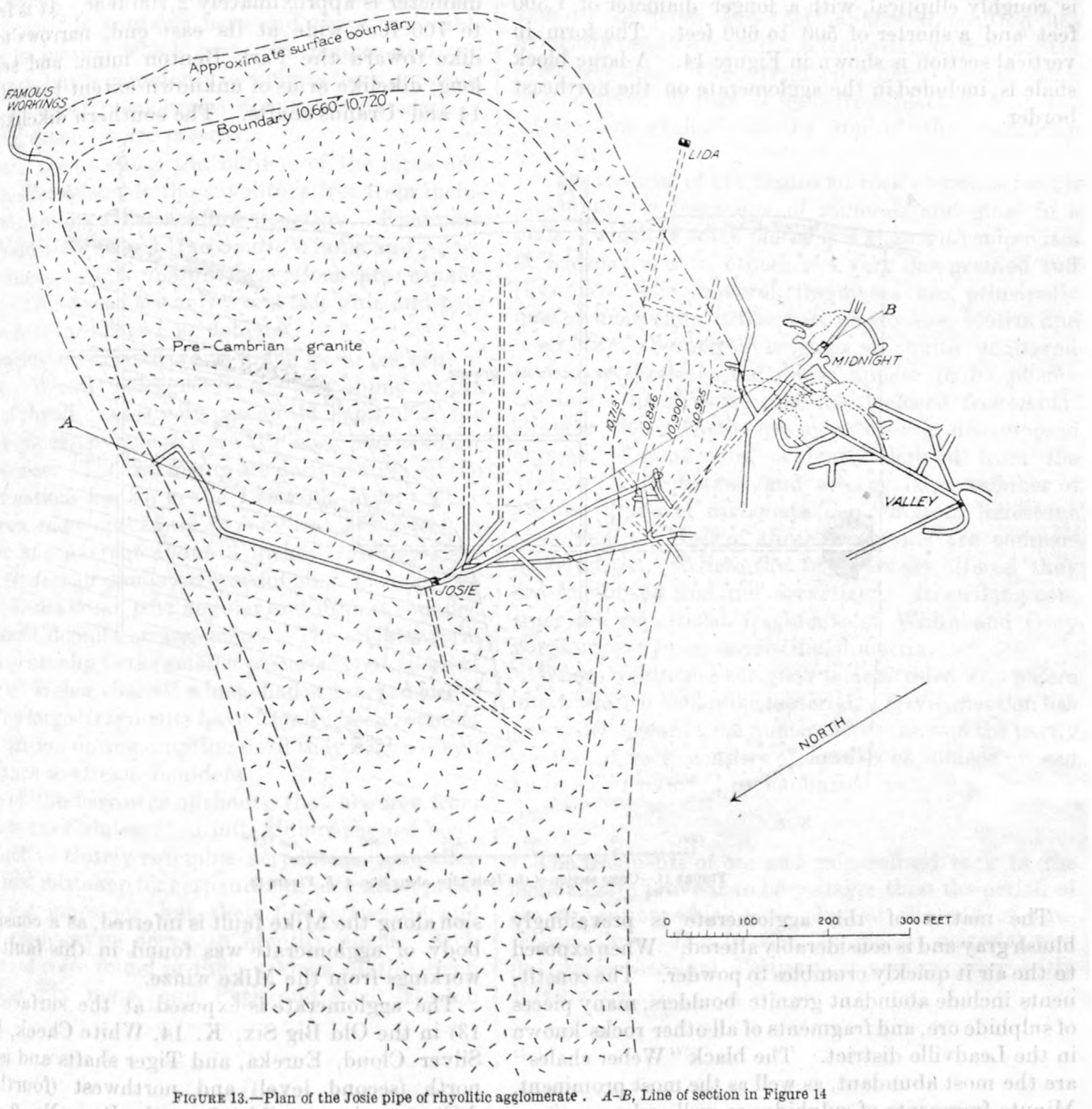


FIGURE 13.—Plan of the Josie pipe of rhyolitic agglomerate. *A-B*, Line of section in Figure 14

reported to have entered it for a distance of 8 feet. Between this point and the Midnight its border is unknown and is only roughly indicated on the map. Long west and southeast drifts from the Josie were entirely within the agglomerate body. On the north side of Evans Gulch its limit is defined by outcrops of Evans Gulch porphyry.

As nearly as can be determined the plan of the pipe is roughly elliptical, with a longer diameter of 1,300 feet and a shorter of 500 to 600 feet. The form in vertical section is shown in Figure 14. A large block shale is included in the agglomerate on the northeast border.

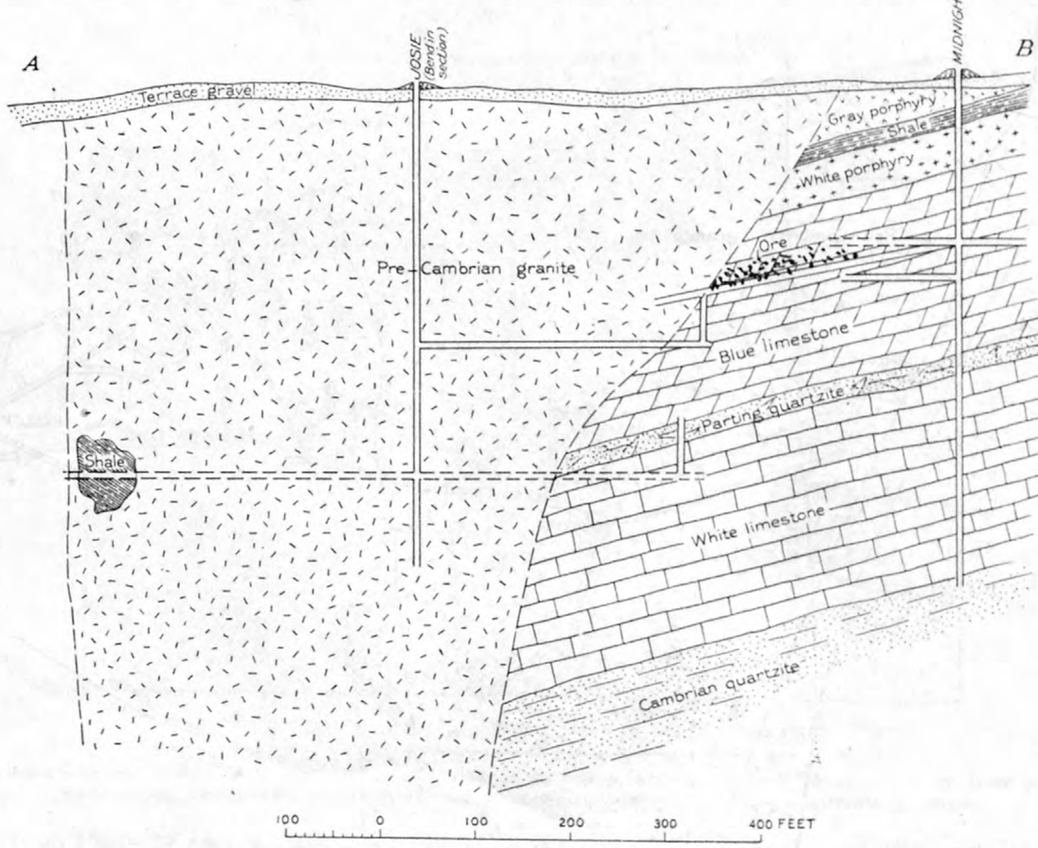


FIGURE 14.—Cross section of the Josie pipe along line *A–B*, Figure 13

The matrix of this agglomerate is prevailingly bluish gray and is considerably altered. When exposed to the air it quickly crumbles to powder. The constituents include abundant granite boulders, many pieces of sulphide ore, and fragments of all other rocks known in the Leadville district. The black "Weber shales" are the most abundant, as well as the most prominent. Minute fragments of sulphides as well as larger pieces of ore are disseminated sparsely through the mass. When the drifts were driven many assays were made of the agglomerate, and all showed small amounts of gold and silver in the included fragments of ore.

EUREKA PIPE

The Eureka pipe is on the northwest slope of Breece Hill at the head of Stray Horse Gulch. Owing to the small number of deep workings that penetrate it and their comparative inaccessibility its boundaries are very imperfectly known. Its area, however, is fairly well defined, as it is exposed in a number of small prospect shafts. These relations are fairly well shown on Plate 13.

The main mass has a roughly crescentic form with its concave side toward the southeast. Its longer diameter is approximately 2,700 feet. It is from 600 to 700 feet wide at its east end, narrows to a thin dike toward the Park Benton mine, and sends out long, dikelike arms of unknown extent toward the K. 14 and Uranus shafts. The southern dikelike extension along the Mike fault is inferred, as a considerable body of agglomerate was found in this fault in the workings from the Mike winze.

The agglomerate is exposed at the surface (see pl. 13) in the Old Big Six, K. 14, White Cheek, Uranus, Silver Cloud, Eureka, and Tiger shafts and is cut by north (second level) and northwest (fourth level) drifts (now inaccessible) from the Penn No. 2 shaft at depths of 155 and 709 feet below the surface. Southwest drifts from the Nettie Morgan also cut it at depths of 195 and 200 feet, where the adjacent limestone is much shattered. The rhyolite there is much more compact, has a more marked flow structure, and is freer from inclusions than in most occurrences. The central part of the pipe is generally softer and contains a greater number of fragments than the marginal part.

PETROGRAPHY

The rhyolite matrix of the agglomerate is light gray, mostly of medium to fine grain, and generally so much decomposed as to resemble a tuff and to crumble rapidly on exposure. In some places—for example, in the Big Six mine—it is glassy, without flow structure, and contains sufficient water to be classed as perlite or pitchstone. It rarely possesses a cellular or vesicular texture. It contains here and there noticeable crystals of biotite, which give it a pepper and salt appearance, but is commonly lacking in dark minerals. Scattered quartz phenocrysts about one-sixteenth of an inch in diameter are present.

In some places along the borders of the pipes and in the smaller offshoots the rhyolite is free from inclusions and exhibits a distinct flow structure. Examples of this kind were seen in the South Winnie and Silver Spoon mines. Such marginal portions are usually narrow. Those seen are only 3 or 4 feet wide and pass within a foot into coarse agglomerate.

The inclusions constitute as much as 60 per cent of the rock. Where the fragments are very abundant the matrix of rhyolite is scarcely perceptible, and offshoots from the pipes have nearly always been mistaken for fault breccias. The fragments are derived from all the rock formations known in the Leadville area. They range from mere specks up to boulders 2 or 3 feet in diameter and average about 3 inches. At one place a block 60 feet in diameter was found. (See fig. 14.) The fragments are in part angular and in part rounded and without definite arrangement. The angular form is confined usually to the smaller pieces, except those of the black "Weber shales" which had a marked cleavage. The larger fragments have usually been rounded off by attrition during eruption until they bear a rough resemblance to stream boulders.

Some of the narrower offshoots that are free from fragments are disintegrated into kidney-shaped boulders which so closely resemble serpentine that they were at first mistaken for serpentinous alteration products of the limestone, but their flow structure and minute phenocrysts serve to identify them. Such occurrences were found in the workings of the Penn mine, Big Six mine, and Park and Park Benton group of mines. Plate 37, *C*, shows the included fragments in this agglomerate, and Plate 37, *A*, shows fluidal texture in the Gray rhyolite.

In most places the fragments that are most abundant represent either the adjacent wall rock of the pipe or some underlying formation; but in some places fragments resembling "Weber shales" occur far below the horizons of the "Weber shales" adjacent to the pipes, and their abnormal position has evidently resulted from the settling of the agglomerate after eruption. These fragments, however, may have been derived, in part at least from black beds in the "transition shales" at the top of the Cambrian quartzite.

Thin sections of the unaltered rock commonly show many angular fragments of minerals and glass in a matrix which in some places is a glass with microlites of feldspar and in others is a very fine grained tuff (fig. 28). The mineral fragments are principally quartz microcline, orthoclase, plagioclase, biotite and magnetite. Scattered crystals of quite unaltered biotite, orthoclase, and albite appear to be phenocrysts of the rhyolite and not inclosed fragments Besides these there are more or less decomposed crystals of muscovite, evidently derived from the Weber (?) formation, and a very large number of angular grains of carbonate derived from limestone or dolomite. Most of these fragments are comparatively fresh. Where the feldspars are altered they are kaolinized and not sericitized. In striking contrast are sericitized fragments of White and Gray porphyry set in an unsericitized matrix.

Where weathered the glass is devitrified and passes into a whitish kaolinlike material. Devitrification has proceeded inward from numerous cracks, and the partly weathered rock consists of kernels of undecomposed material surrounded by kaolinized rock.

AGE

The fragments of ore and mineralized rock in the agglomerate prove it to be younger than the period of ore deposition, which took place at the end of Cretaceous time. It is overlain by glacial material, and its age is therefore Tertiary or perhaps very early Pleistocene.

CHAPTER 5. STRUCTURE

The principal structural features of the region that have not already been adequately considered in the chapters on sedimentary rocks and intrusive porphyries are folding and faulting. Folding is not pronounced within the Leadville district but is conspicuous in parts of the surrounding region and must be understood before the geologic structure of the district can be adequately appreciated. The faults of the district were for a long time believed to have been formed in a single period of disturbance and to be contemporaneous with the regional folding; but mining operations, especially since Emmons and Irving completed their field studies, have disclosed evidence pointing to at least three periods of faulting besides one or more periods of minor fissuring.

The earliest faults are reverse faults, which were formed at the same time as the folds and broke their western or southwestern limbs. Subsequently a system of fissures along which faulting is inconspicuous was formed transverse to the axes of the folds, also a system of more pronounced faults, several of which are radially arranged around the intrusive stock at Breece Hill. All the faults and fissures thus far mentioned are of premineral age. Subsequent to mineralization normal faulting on a much larger scale took place. The major faults shown in the atlas accompanying Monograph 12 are mostly normal and of postmineral age, but a few, originally mapped as normal, have since been found to be reverse and contemporaneous with folding.

The relation of intrusive porphyry sheets to folding and faulting within the Leadville district is simple, as all the sheets were intruded before any appreciable amount of folding or faulting took place, but in parts of the surrounding region, notably the Monarch and Tomichi districts, 45 miles south of Leadville, batholithic intrusions of similar rocks occurred later.[1] The relations of these intrusions to folding and faulting are suggested in connection with the origin of folding (p. 96).

FOLDING

The maps and cross sections on Plates 11 and 13 show at a glance that all the sedimentary formations except glacial deposits and all the intrusive sheets of porphyry are equally affected by folding. The distribution and trends of folds are shown on Plate 11. The average trend of the major folds is about N. 30° W., though some trend north. These folds are mostly unsymmetrical, the anticlines having steep or even slightly overturned west limbs, which are broken by steeply dipping reverse faults of premineral age. Local monoclinal folds also associated with faulting are present in or close by the Leadville district but are believed to have formed later, at the time of postmineral faulting. Other local monoclines are due to pronounced bulging or thinning of intrusive sheets. Several minor folds parallel to the major folds and other minor folds transverse to these may be noted in the sections on Plate 11, but no description or enumeration of them is essential here. The Weston and Sheep Ridge or London anticlines are the largest major folds and will be described first.

WESTON ANTICLINE

The south end of the Mosquito Range is described by Emmons as a simple monoclinal fold, but at the south edge of the area shown on Plate 11 an anticline of north-northwestward trend is present, and it can be traced northward as far as Iowa Gulch. It is closely associated with the Weston fault and is therefore called the Weston anticline. The east limb of this anticline dips at a moderate angle, but its west limb, where not obscured by erosion, dips steeply or vertically along the east side of the Weston fault. For the most part, however, the strata have been eroded from the crest and west limb of the anticline. A remnant of Cambrian quartzite remains at the summit of Weston Peak, and vertical beds of quartzite are exposed to the west of it. To the south of Weston Peak the southeastward pitch of the anticline brings the Cambrian quartzite of the two limbs together at the edge of the mapped area.

About 13 miles to the north the axis of the anticline is shown at the summit of Long & Derry Hill, and there again the west limb of Cambrian quartzite ends abruptly against the Weston fault. At the north base of Long & Derry Hill the anticlinal structure is cut off by the Iowa Gulch fault, which marks the south end of a down-faulted block where the exposed strata dip eastward and southeastward. The small domelike anticline in Evans Gulch is almost in line with the axis of the Weston anticline and is bounded on the west by the Weston fault, but it is more closely associated with the Colorado Prince fault and is believed to be independent of the Weston anticline, which evidently dies out a short distance north of Iowa Gulch. The east limb of the syncline to the

[1] Crawford, R. D., Geology and ore deposits of the Monarch-Tomichi districts, Colo.: Colorado Geol. Survey Bull. 4, p. 99, 1913.

west of the Weston anticline has been cut off by the Weston fault, and only eastward-dipping beds are shown on the map, although Emmons[2] refers to a compressed syncline at Weston Pass.

SHEEP RIDGE OR LONDON ANTICLINE

The other major anticline within the area shown by Plate 11 extends from a point near its southeast corner north-northwestward along Round Hill, Sheep Ridge, Sacramento Arch, and Pennsylvania Hill, beyond which all strata above the pre-Cambrian complex have been removed by erosion. Emmons refers to this as the Sheep Ridge anticline, but owing to its close association with the London fault it may be conveniently referred to as the London anticline. This anticline also pitches south-southeastward and dies out beyond Round Hill, where both limbs consist of the Weber (?) formation and no faulting is evident. Toward the north along Sheep Ridge and the long south slope of Sheep Mountain the west limb has been concealed or destroyed by the London fault. From Sheep Mountain to Pennsylvania Hill, however, the upper part of the west limb is present with steep to vertical dips. Although the axis of the anticline can not be traced any farther, the steeply dipping to slightly overturned beds along the southwest side of the London fault indicate the continuation of the structure almost to the Mosquito fault. There is little evidence in Plate 11 of a continuation of this anticline beyond the Mosquito fault. Some anticlinal folds are indicated, but they are hardly pronounced enough to be correlated with the London anticline.

MIKE ANTICLINE

The Mike anticline, whose west limb is cut by the Mike fault, is parallel to the Weston anticline and more than a mile west of it. This anticline, which pitches northward at a low angle, is best defined on the spur south of Empire Gulch and can also be recognized on the north slope of Iowa Gulch. It is also indicated in the vicinity of California Gulch (Pl. 15, sections F–F′ and G–G′), but farther north it is lost in the faulted mass of Gray porphyry beneath Breece Hill. On the south the anticline is cut off by the Union fault, beyond which the strata along the axis of the fold are entirely eroded. West of the junction of the Mike and Union faults there is a small basinlike syncline. Its east limb is steeper than its west limb but is still at so low an angle (15°–25° W.) as to suggest that the intensity of the folding decreases southward.

COLORADO PRINCE ANTICLINE

The anticline that lies along the Colorado Prince fault forms a domelike uplift at the junction of Evans and South Evans gulches and extends southeastward to the north slope of Ball Mountain. Its northwestward continuation beyond the Weston fault is concealed by the extensive sheet of Gray porphyry and the overlying glacial deposits. The domelike appearance on Plate 13 is exaggerated, as the concentric arrangement of outcrops of White porphyry and Cambrian quartzite around the southeast boundary of the granite is due partly to the southeastward rise of the bedrock surface. The anticlinal structure southeastward from the Gold Basin shaft is much obscured by the Ollie Reed mass of agglomerate and by dislocation along the Winnie-Luema and Ball Mountain faults. East of the Ball Mountain fault the position of the anticlinal axis is shown by the pre-Cambrian granite in small prospect pits, and the east limb is well defined.

The steeply dipping southwest limb of the anticline, broken by the Colorado Prince fault, is well defined and of uniform character from the Weston fault southeastward to the Modoc fault and borders a syncline that has a nearly horizontal west limb which is clearly indicated in the mine workings beneath Idaho Park. South of the Modoc fault the Blue limestone and lower rocks have dropped below the surface, and the uniform character of the "Weber grits" and the shallowness and scarcity of mine workings afford no opportunity to determine the details of structure. A remnant of the west limb apparently lies on the west side of the granite close to the Ball Mountain fault, but the anticlinal form has been destroyed by the local complex of faults, which is considered on page 76. The anticline evidently dies out along the south slope of Ball Mountain opposite the north end of the Weston anticline.

MOSQUITO GULCH FOLD-FAULT

Perhaps the most clearly defined exposure of an overturned anticline broken by a reverse fault is that described by Patton[3] as the Mosquito Gulch fold-fault, about 2 miles east of the London fault. Its trend is nearly north, and therefore it tends to converge toward the south with the London anticline and fault; but it has not been traced in that direction beyond the north wall of Sacramento Gulch. It has been traced northward only to the southwest slope of Buckskin Gulch, beyond which only pre-Cambrian rocks are exposed along the continuation of the anticlinal axis.

Emmons[4] noted the exposure of this fault on the north side of Mosquito Gulch but did not recognize its reverse or overthrust character. According to Patton's description, the structure exposed on the north side of Mosquito Gulch is a recumbent fold with a nearly horizontal axial plane and with its lower limb parallel to the fault. On the south side of the

[2] Op. cit., p. 36.

[3] Patton, H. B., Colorado Geol. Survey Bull. 3, pp. 121–127, 1912.

[4] U. S. Geol. Survey Mon. 12, p. 131, 1886.

gulch it is a double recumbent fold each part of it broken by an overthrust, as shown diagrammatically in Figure 15. These overthrusts converge downward

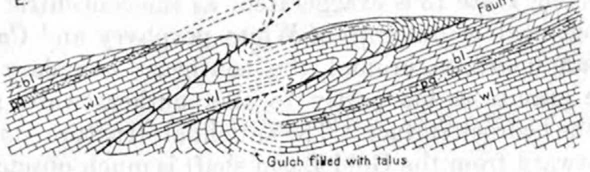


FIGURE 15.—Double recumbent fold, broken by overthrusts, on south side of Mosquito Gulch. bl, Blue limestone; pq, Parting quartzite; wl, White limestone. (After Patton)

and are interpreted as forks of the main fault. The dip of the fault is estimated by Patton to be 23° E. or somewhat steeper. The fault has not been traced northward across Loveland Mountain, but a reverse fault in line with it is exposed on the north slope. Two nearly parallel fold-faults are exposed nearly a mile to the east, just southwest of Buckskin Joe. They are similar to the double fold-fault just described but can not be proved to connect with it.

KOKOMO SYNCLINE

The largest fold in the region represented by Plate 11 is a northward-pitching syncline that extends from a point between Fremont Pass and Bartlett Mountain northward beyond the north boundary of the Tenmile quadrangle and includes on its east limb a few subordinate anticlines and synclines. Its west limb has a normal dip of 25°–40° E., but its east limb dips 70°–90° W. and is broken for its entire length by the Mosquito fault, which has a very irregular outcrop in the vicinity of Copper Mountain. Emmons[5] inferred that this irregularity was due to overthrust faulting but noted that the fault south of the point where it crosses Tenmile Creek is normal, in spite of its irregularity across Mayflower Hill. Here, however, the steep and locally overturned dips of the strata and their generally crumpled character indicate a considerable compressive strain. Emmons also concluded that this compressive movement, with its accompanying folding and faulting, may have antedated ore deposition. Recent disclosures within the Leadville district suggest that possibly the Mosquito fault fissure as shown on the map is the site of one or more reverse fault movements that originated at the time of folding and before ore deposition, and one or more normal fault movements that occurred after ore deposition. Further field study is necessary to settle this question, but provisional correlation on the basis of Emmons's observation may associate the reverse parts of the Mosquito fault with the Kokomo syncline on the west and a corresponding anticline on the east, now entirely eroded except for remnants of Cambrian quartzite on Little Bartlett Mountain and on Quandary Peak, which is east of Fletcher Mountain and 2 miles beyond the limits of the mapped area.

[5] U. S. Geol. Survey Geol. Atlas, Tenmile district folio (No. 48), p. 3, 1898.

FRYER HILL FOLDS

The shallow anticline and syncline shown by the mine workings beneath Fryer and East Fryer hills differ from the folds previously described in that their axes trend east of north and they are associated with irregular intrusive sheets and not with reverse faults. They are in line with the Carbonate and Niles normal faults, which die out a short distance to the south, and are believed to be in minor part related to them—that is, the forces that produced the complex faulting to the south were sufficient at Fryer Hill to warp but not to break the strata except along major normal faults, the Pendery and Mikado faults. The folding is pronounced, however, only in that part of the Blue limestone that lies between porphyry sheets. These sheets thin abruptly northward, and the folding of the limestone parallels their changing thickness. The folds are due mainly to the intrusions and are not to be classified with the other folds here described.

WARPING AND DRAG ALONG NORMAL FAULTS

The cross sections on Plates 14–17 show considerable warping or dragging of strata along the major normal postmineral faults. The prevailing eastward dip of the strata has been locally changed to a westward dip to such a degree that distinct anticlines have been produced along the eastern or footwall sides of the faults and synclines on the western or hanging-wall sides. Some interfault blocks contain both an anticline and a syncline. In some places minor folds or warps due to intrusive sheets or to the forces that produced regional folding have been modified by local warping along postmineral faults, and it is difficult or impossible to interpret their origin with certainty.

FAULTS AND FISSURES

PERIODS OF FAULTING

Faults, as well as large fissures without noteworthy displacement of their walls, were formed at three or more different periods in the Leadville region, all subsequent to the local disturbances caused by the intrusion of the Gray porphyry sills. Movements along the same fault may have taken place during more than one period, and some faults or fissures formed at different times may have similar strikes and dips. It is not possible, therefore, to assign every fault or fissure definitely to a certain period, although many of them can be so assigned, and certain faults that were originally mapped as continuous are evidently in part reverse faults of relatively early origin and in part normal faults of later origin. Complete resurvey of these faults would extend far beyond the limits of the Leadville district and has not been attempted. The faults as originally mapped with few exceptions, are represented on Plate 11. Owing to the importance of the question whether certain faults were formed before or after the period of ore deposition, the different periods of faulting must be kept in mind in interpreting the significance of faults and fissures during mine development. Faults classified according to relative age are shown in Plate 39.

Fissuring and minor faulting may have taken place in Paleozoic time during the periods of elevation and subsidence noted in chapter 3 (pp. 26–42), but none of any great extent can be correlated with these periods. The general absence of White porphyry dikes in the sedimentary rocks and their scattered distribution in the pre-Cambrian rocks indicate that up to the beginning of igneous activity in late Cretaceous or early Tertiary time fissuring was of little consequence. The fissures containing these dikes trend for the most part northeastward (pl. 11), approximately at right angles to the folds just described, which were formed later. The White porphyry dike on the south slope of Mount Lincoln fills a minor fault fissure. The greater abundance and continuity of the dikes of Gray porphyry show that some profound fissuring had taken place before their intrusion, but the predominance of sills over dikes and the fact that several of the dikes discovered by mining operations proved to be offshoots from sills show that up to the time of intrusion fissuring was a subordinate process. The fissures and faults that call for more detailed consideration may be grouped as follows:

1. Fissures and local faults caused by the intrusion of Gray porphyry sills.
2. Reverse faults and auxiliary faults and fissures accompanying regional folding. These include a few of the main faults of the region, which are in part reverse and in part normal. The normal movements were later than the reverse movements, and the normal portions are equivalent to one of the later groups.
3. Normal faults and fissures formed subsequent to folding but prior to ore deposition.
4. Normal faults formed subsequent to ore deposition, including most of the major faults of the region.

A fifth group, including small faults parallel to the bedding of the strata, may be added, but their time relations to the other faults differs in different places, and they are best considered in connection with the four main groups.

MINOR FISSURES AND FAULTS CAUSED BY INTRUSION OF GRAY PORPHYRY

The irregularity of the Gray porphyry sills and the local deformation that accompanied their intrusion has been considered on page 53. No attempt has been made by Emmons or Irving to indicate or describe type fissures of this group. It is evident from the kind of deformation that occurred that in some places the rocks adjoining the sills were stretched or domed, with the development of fractures normal to the direction of stretching; and that in other places they were thrust forward or aside, with the development of fractures and small faults oblique to the bedding and along the bedding. Local shattering as well as simple fissuring must have taken place. Shattered zones and fissures across the bedding are likely to terminate against shale beds and to extend for comparatively short distances horizontally. Their importance as local channels for ore-forming solutions is obvious, and it is unfortunate that more attention was not given to them when the structure of the ore bodies was being studied in detail. From a review of the available maps and sections, however, it appears that this group of fissures may account for certain irregularities in ore bodies and offshoots from them rather than for the position and trend of the main ore bodies.

The roughly radial arrangement of veins (mineralized faults and fissures) and elongate replacement ore bodies with respect to the stocklike intrusion beneath Breece Hill suggests that they were formed by tensional stresses due to the intrusion; but Gray porphyry sills are offset by the mineralized faults, and a few of the mineralized fissures along which there is little or no displacement are later than the reverse faults that were formed subsequent to the intrusion of the sills. There was doubtless a tendency toward radial fissuring at the time of the intrusion that formed the sills; but the larger mineralized fissures were developed later than the sills and may be associated with a later stocklike intrusion, the existence of which has been suggested on page 54.

MAJOR FAULTS AND FISSURES

FEATURES COMMON TO ALL

The distribution and trends of the major faults of the region are shown in Plates 11 and 39. From information at hand they appear to be limited to the area represented by Plate 11, which is traversed by the few longest faults, whereas the west-central part of this area, which includes the Leadville district, is cut by a number of smaller but important faults. The faults represented, however, are only those made evident by discontinuity of rocks at the surface or revealed by extensive mining developments. Were the rest of the region to be studied as thoroughly above and under ground as the Leadville district has been, more faults would undoubtedly be found. Plate 39 shows in what a small part of the area faults can be readily detected and in what a large part they are concealed beneath glacial deposits.

The faults belong to three classes—earlier reverse faults of regional and local extent trending N. 20°–55° W.; normal mineralized faults of intermediate age, principally confined to the eastern part of the Leadville district and trending in various directions; and later normal faults of regional and local extent with prevailing trends of N. 10°–30° E. The average trend of the longer reverse faults is N. 25° W., and that of the longer normal faults is N. 11° E., but the normal faults undulate considerably and trend north-northwest for short distances, and some of their branches and auxiliary faults trend northeast. Some of the apparent irregularities of trend are due to the intersection of a fault of moderate dip with the undulating ground surface; but many of the faults have irregular strikes and dips. These irregularities are illustrated so far as practicable in the geologic sections, but where the scale is too small or the details are not sufficiently known the dips of the faults are diagrammatically represented by straight lines.

The larger faults in all three classes have certain features in common. They are fault zones rather than simple faults and are characterized by parallel fissures filled with tough clay gouge or selvage and by intervening or bordering masses of distorted, broken, or crushed rock. The crushed zones reach 100 feet in thickness.

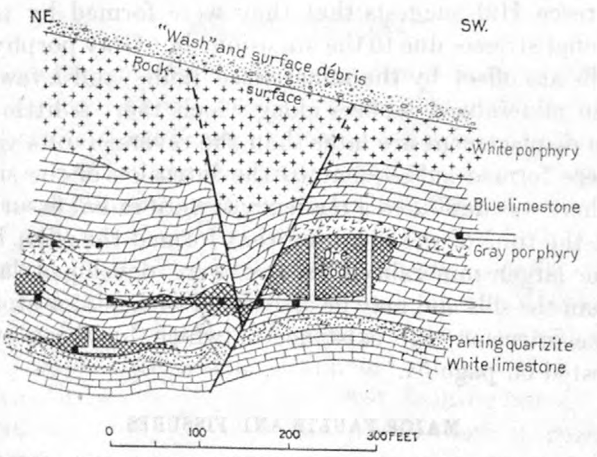


FIGURE 16.—Section looking southeast through Coronado-Sixth Street workings, showing auxiliary wedge faulting

Besides containing several fissures along which slipping has been distributed, the main fault zones of all three classes have branches or closely related auxiliary faults and fissures formed during and as a result of movement along the main zones. These auxiliary faults and fissures lie at different angles to the main faults, but those connected with any one main fault commonly show systematic relations to it and are closely related to the distortion of interfault blocks. Displacement along the auxiliary faults is commonly small, and few of them have been discovered on the surface. Many of them, especially in the eastern part of the district, die out upward at the base of the "Weber shales," and those which penetrated upward into the White porphyry in the western part of the district can not be traced on the surface. They also may die out downward in the shaly beds near the Parting quartzite or at the top of the Cambrian quartzite or may dip downward to connect with a major fault or another auxiliary fault. Where two auxiliary faults meet on the dip they usually bound a down-faulted wedge (fig. 16), but the more prominent auxiliary faults in any group dip parallel and bound steplike displacements transverse to the main fault zone.

Distortion is also expressed by drag along fault walls, as shown in several of the geologic sections. Where drag has been considerable along the major normal faults, the strata of the adjacent fault blocks have been distorted into synclinal and anticlinal form, as stated on page 62. Where exploration has been thorough the dragged parts of blocks are commonly found to be complicated by auxiliary faulting.

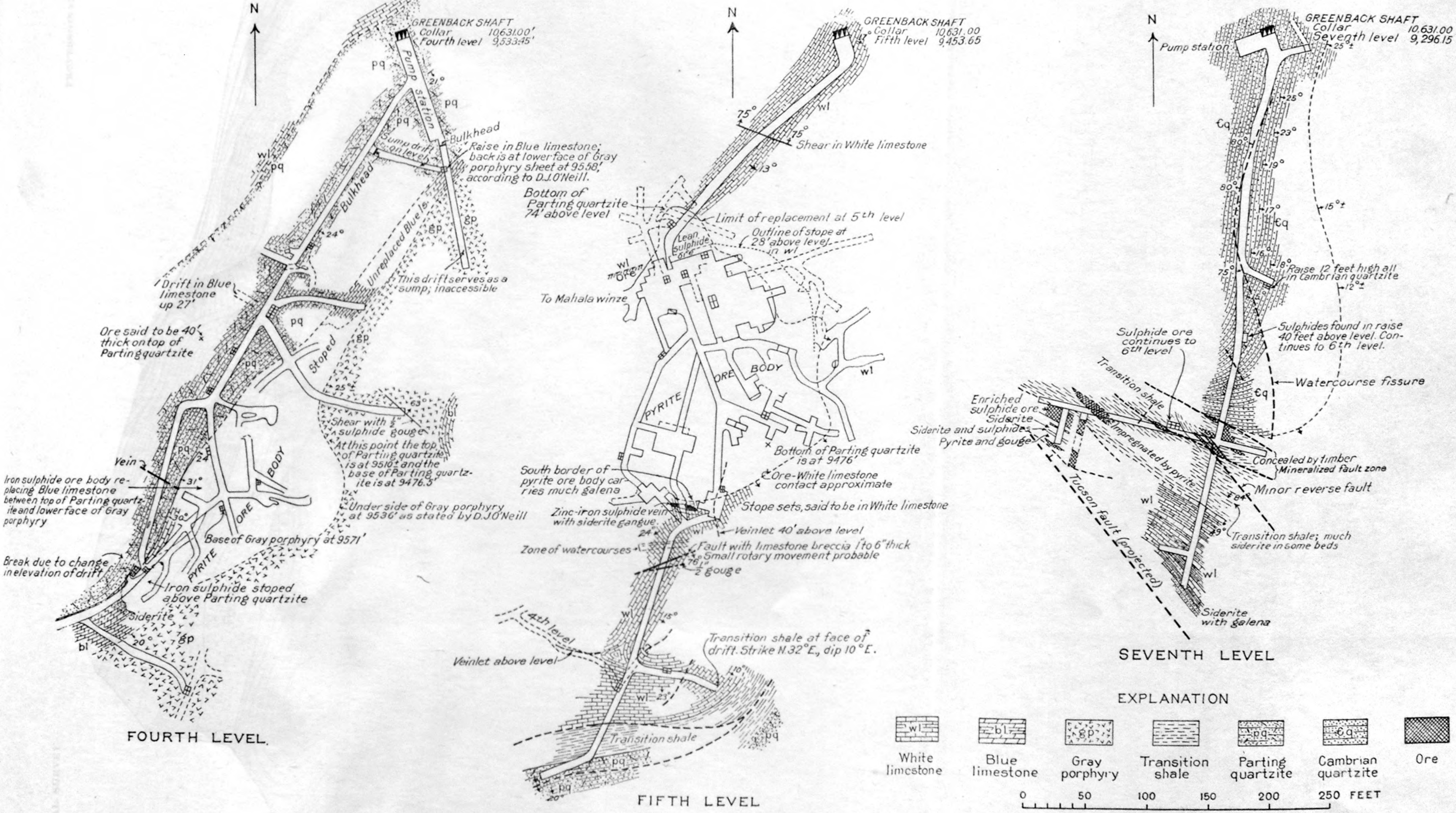
Some faults in each class die out along the strike, either in folds or by feathering out into a number of branches along which the diminishing displacement is distributed. Where faults of different classes intersect, the older ones are offset, as has been proved at one place and is strongly suggested at others; or displacement along the later fault may continue along the earlier fault, and the later fault therefore appears to terminate against the earlier. Intersections outside of the Leadville district, however, are in part conjectural, and they have received no attention since they were mapped by Emmons during the first survey of the district. Where junctions of faults have been approached in mine workings the rock is extremely shattered. Renewal of movement along faults should be constantly considered in the interpretation of the geologic structure. Later movement along a reverse fault, for example, may have been opposite to the earlier movement, as is evident along the northern part of the Mike fault, or it may have been in the same direction, as is probable along the southern part of the same fault. Comparatively recent faulting in the same direction as the principal movement is indicated at several places in the Downtown district.

Besides drag and auxiliary faults that cut across the strata, the fault blocks are further distorted by small faults or slips along bedding planes. Some, at least, of these bedding faults have been found to offset auxiliary faults of steep dip and are therefore attributed to adjustments within the blocks after the main faults and their principal auxiliaries have been initiated. This adjustment is believed to be due to curvature of the major faults along the strike and especially along the dip and is illustrated in Figure 17. Were the fault block to move without distortion (fig. 17, A) there would be a large open space in the fault fissure, which is not found in nature. This space is taken up by slipping distributed along all the beds (fig. 17, B), which may be modified by drag (fig. 17, C) or by slipping along only one or two beds and crushing and dragging along the main fault (fig. 17, D). The last case is the most conspicuous and doubtless the most common, as movement tended to concen-

SKETCH MAP SHOWING FAULTS IN MOSQUITO RANGE

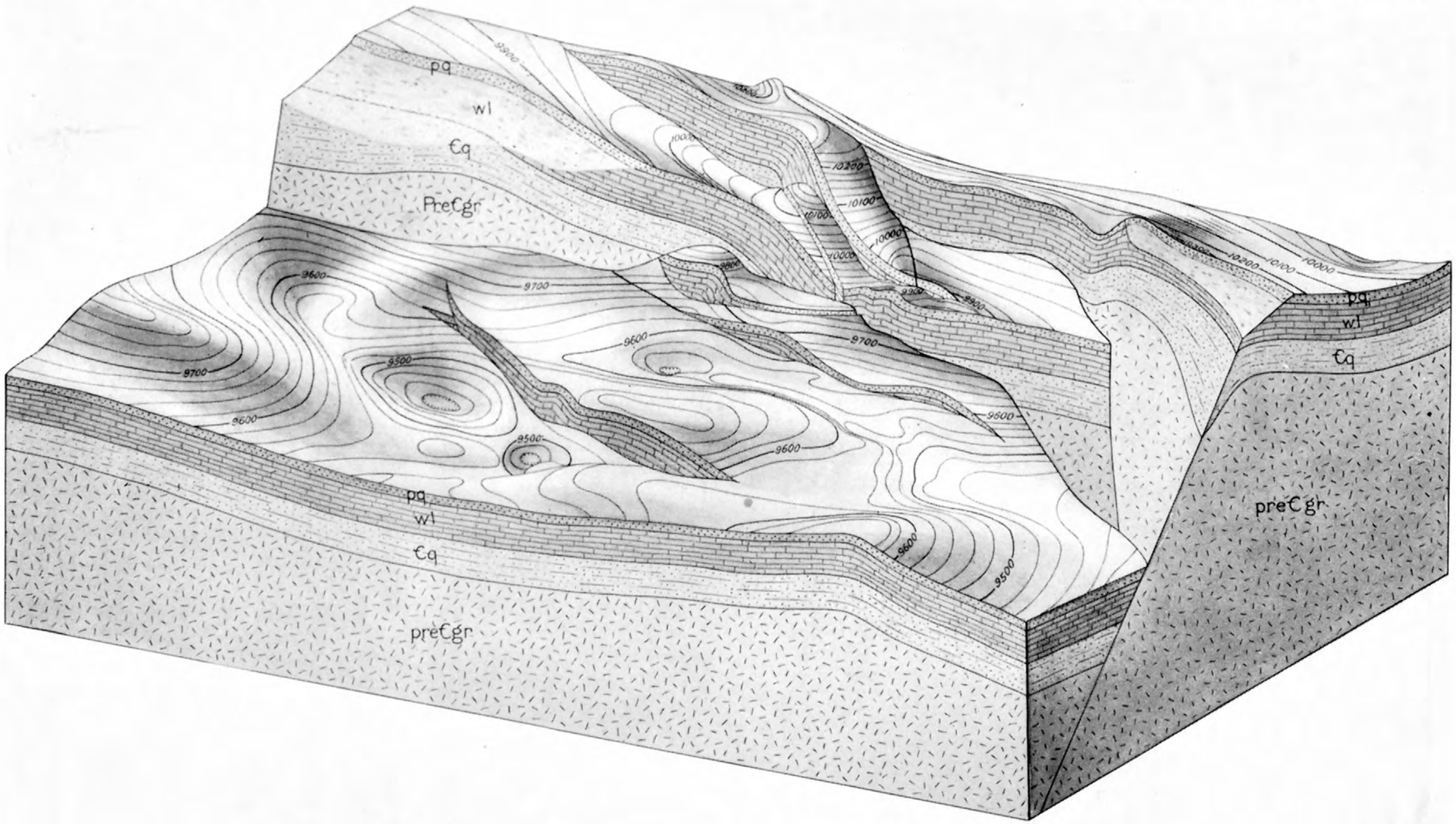
0 1 2 3 4 5 MILES

1927



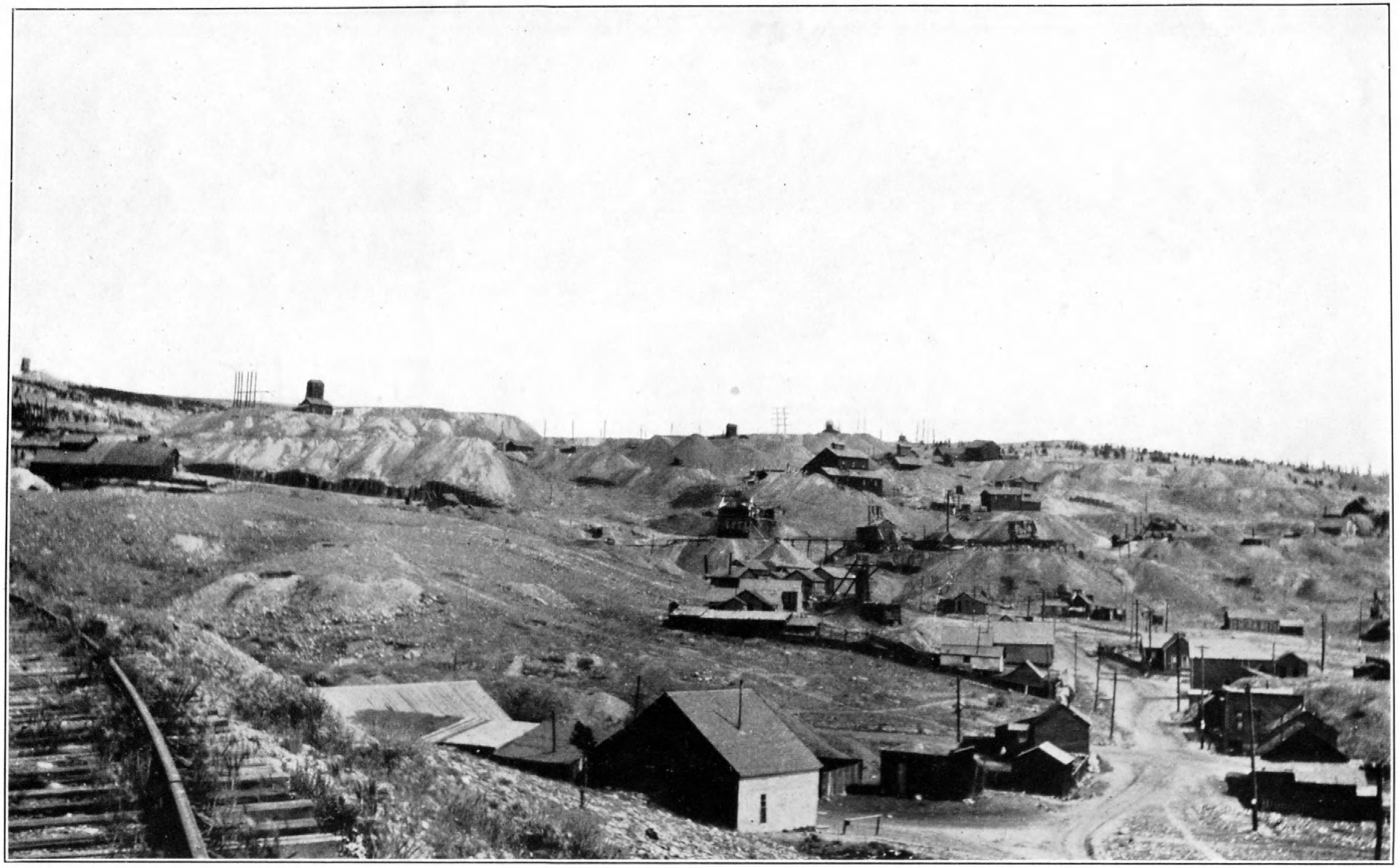
PLANS OF FOURTH, FIFTH, AND SEVENTH LEVELS OF GREENBACK MINE

By F. A. Aicher



ISOMETRIC PROJECTION OF DOWNTOWN DISTRICT, LEADVILLE

Showing curvature of fault surfaces, differential distortion of the rocks on the several sides of the faults, and lateral termination of the faults. The shaded surface is that of the Parting quartzite, with all upper rocks removed so as to show the effects of the faults where unaffected by erosion



WOLFTONE AND OTHER MINES ON NORTHWEST SLOPE OF CARBONATE HILL

Showing extent to which surface is covered by dumps. View looking south from point near north end of Seventh Street trate along shaly layers and contacts between limestone and altered porphyry sheets. Where bedding planes are closely spaced and in uniform materials the slipping movement may be so evenly distributed as not to be recognizable. These bedding faults, as would be expected, are found even at considerable distances from the main faults.

Bedding faults are conspicuous along the contact between the Blue limestone and the overlying White porphyry, the basal part of which is thinly sheeted parallel to the contact; but the amount of faulting is likely to be overestimated owing to the abundance of plastic claylike material with chert inclusions along the contact. This material has been interpreted by some as a thick selvage into which fragments of black chert have been dragged from the uppermost beds of the limestone; but it is more likely that the clayey material has been deposited by descending waters mainly as a replacement of the limestone (see p. 261), and that the chert inclosed in the clay is the only mate-

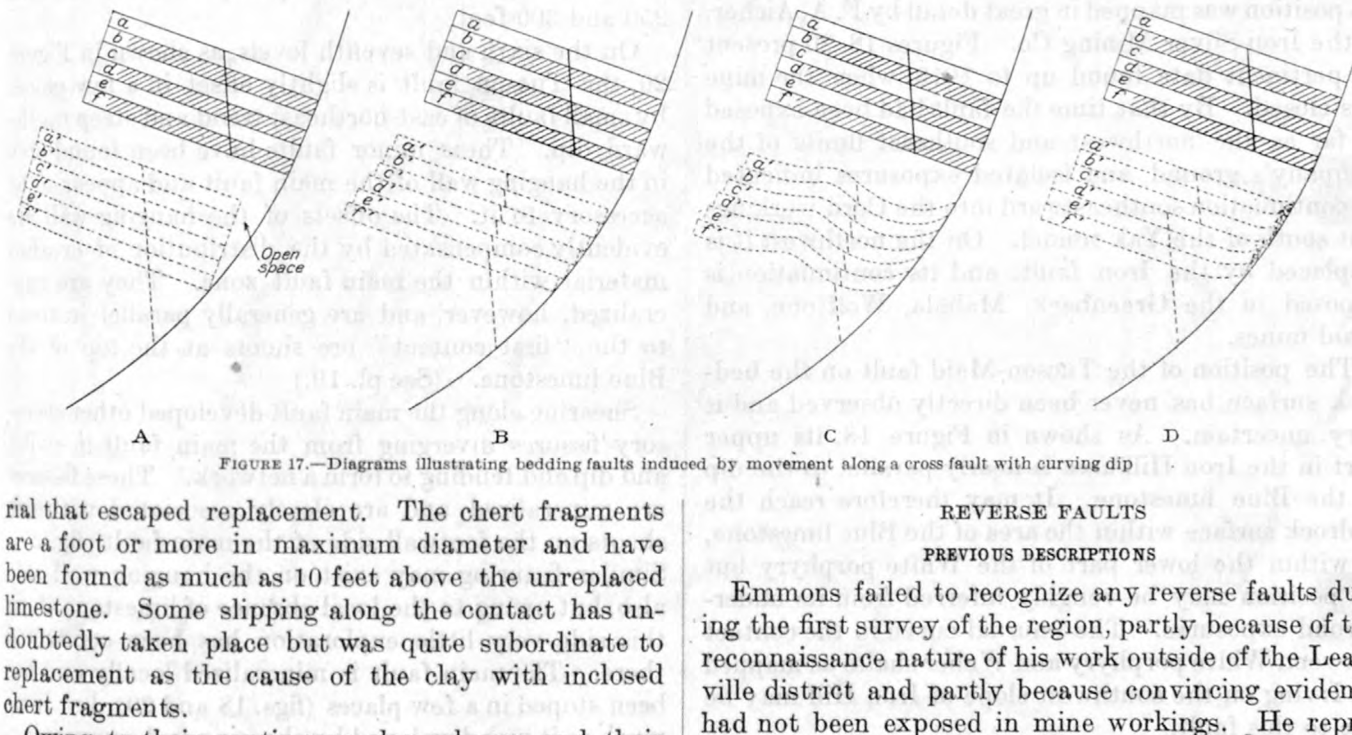


FIGURE 17.—Diagrams illustrating bedding faults induced by movement along a cross fault with curving dip

rial that escaped replacement. The chert fragments are a foot or more in maximum diameter and have been found as much as 10 feet above the unreplaced limestone. Some slipping along the contact has undoubtedly taken place but was quite subordinate to replacement as the cause of the clay with inclosed chert fragments.

Owing to their continuous clay selvages and their contained broken rock the larger fault zones have been local reservoirs of ground water and have acted as barriers between reservoirs of water in adjacent fault blocks. This has been an important factor in the oxidation of ore bodies and particularly in mining operations; for although faults may be approached rather closely without noteworthy change in the quantity of ground water, if the fault zone is entered water rushes into the workings, carrying mud and crushed rock and often seriously endangering lives. If the entire width of the fault zone is penetrated not only the water within the zone but the reservoir on the opposite fault block must be drained, involving an expense that may be prohibitive.

The early history of Leadville is full of instances in which the unwise penetration of fault zones has caused expensive and dangerous accidents. The Columbia No. 2 shaft, sunk 200 feet west of the Iron fault, penetrated the Iron fault zone at a depth of a little more than 600 feet. An inrush of water occurred at once and was so rapid that although the men jumped immediately into the bucket, by the time they had given the signal to hoist the water was up to their necks. The water rose 72 feet in the shaft in the first hour after the fault was penetrated and to a height of 125 feet in the second hour. This danger is now less common, because many of the larger faults have been penetrated and drained and hence are prevailingly dry. In deeper workings, however, miners have learned to avoid approaching faults any more closely than is necessary, both because of the water and the difficulty of maintaining openings in "heavy" ground.

REVERSE FAULTS

PREVIOUS DESCRIPTIONS

Emmons failed to recognize any reverse faults during the first survey of the region, partly because of the reconnaissance nature of his work outside of the Leadville district and partly because convincing evidence had not been exposed in mine workings. He represented the Mike fault south of its junction with the Pilot fault to be in reverse position but made no mention of this fact in his description of the fault. In 1898, as already shown on page 62, he recognized the northern part of the Mosquito fault in the Tenmile quadrangle as an overthrust.

In 1913 Moore[6] described the London fault at the London mine as a reverse fault, and about the same time Patton[7] gave a more complete description of it and presented cross sections prepared by Moore. Irving during the second survey of the Leadville district proved the reverse character of the Colorado Prince

[6] Moore, C. J., London mine, Mosquito mining district, Colo.: Am. Inst. Min. Eng. Trans., vol. 45, pp. 244–246, 1913.

[7] Op. cit., pp. 102–121.

fault, and Emmons and he recognized that the Weston fault in places was reverse. They also noted a reverse fault in the Yak tunnel a short distance east of the Iron fault. A reverse fault in the Maid mine was described by Spurr in a private report and was evidently noted by others. In 1908 a reverse fault in the Tucson mine was discovered and described by G. O. Argall[8] after Emmons and Irving had completed their field work. Because of its significance, this fault will be described first.

TUCSON-MAID FAULT

IRON HILL

Tucson mine.—During the next three years after the discovery of a reverse fault in the Tucson mine in 1910 it was opened from the fourth to the tenth levels of the mine and became known as the Tucson fault. Development work under the direction of Philip and George Argall proved it to have an important influence on the local distribution of ore bodies. Its position was mapped in great detail by F. A. Aicher, of the Iron-Silver Mining Co. Figures 18–20 present all pertinent data found up to 1919, when the mine was closed. By that time the fault had been exposed as far as the northwest and southeast limits of the company's ground, and isolated exposures indicated its continuation southeastward into the Cord workings just south of the Yak tunnel. On the northwest it is displaced by the Iron fault, and its continuation is exposed in the Greenback, Mahala, Wolftone, and Maid mines.

The position of the Tucson-Maid fault on the bedrock surface has never been directly observed and is very uncertain. As shown in Figure 18, its upper part in the Iron Hill area is nearly parallel to the dip of the Blue limestone. It may therefore reach the bedrock surface within the area of the Blue limestone, or within the lower part of the White porphyry but its position may be roughly inferred from its underground exposures. The unusual curve in the contact between White porphyry and Weber shales as mapped by Irving on the southwest slope of Iron Hill may be due to this fault.

In the Tucson mine the fault is undulating and splits locally into two or more parts, which inclose lenticular rock masses as much as 400 feet in length. Its strike ranges from N. 20° W. to N. 45° W., and its dip from 35° to 60° NE. It steepens downward and approaches the dip of the strata upward. At the second level it is about parallel to the strata but its position is indicated by the disturbed condition of the Blue limestone. Careful search by Mr. Aicher at higher levels failed to disclose the fault, and he concluded that it must continue parallel to the dip of the Blue limestone, as shown in figure 18. If the fault is projected from this position to the outcrop of the Blue limestone on the southwest slope of Iron Hill it apparently coincides with the upward projection of "fault G," which is shown east of the Iron fault in the sections along the Yak tunnel on Plates 15 and 26. Workings that might have shown the relations between fault G and the Tucson fault are inaccessible.

Below the second level and southeast of the Tucson shaft (fig. 18) the fault splits into three branches, and the total dip slip is about 150 feet. The presence of White limestone between Parting quartzite and Gray porphyry on the hanging wall and its absence within the fault zone and along the footwall indicate that horizontal movement or strike slip along the fault was also considerable. Between the third and fifth levels the fault is within a thick irregular sill of Gray porphyry and is less conspicuous. Below the fifth level, however, it is clearly marked by the discordance between the rocks in its footwall and hanging wall, as shown in Figure 18. The dip slip is there between 250 and 300 feet.

On the sixth and seventh levels, as shown in Figure 20, the Tucson fault is slightly offset in a few places by small faults of east-northeast trend and steep northward dip. These minor faults have been found only in the hanging wall of the main fault and appear to be accessory to it. The offsets of the hanging wall are evidently compensated by the distribution of crushed material within the main fault zone. They are mineralized, however, and are generally parallel in trend to the "first contact" ore shoots at the top of the Blue limestone. (See pl. 19.)

Shearing along the main fault developed other accessory fissures diverging from the main fault in strike and dip and tending to form a network. These fissures are mineralized and are closely associated with ore shoots on the footwall side of the main fault (fig. 20). Similar fissuring may exist on the hanging wall side also, but owing to the local absence of limestone along this side very little exploration has been conducted there. The main fault is mineralized locally and has been stoped in a few places (figs. 18 and 20), but inasmuch as it was developed by shearing and compression and contains a large quantity of gouge derived from the siliceous rocks, it has been relatively impervious to ore-forming solutions and has tended to deflect them along the more open accessory fissures. Where limestone forms a considerable part of the hanging wall ore shoots may be found, provided the ore-forming solutions were able to penetrate the main fault and follow the transverse or other accessory fissures.

Yak tunnel and its branches.—Aicher has traced the Tucson fault southeastward to the Gold raise, which connects with the Louisville lateral of the Yak tunnel, and Pendery found it a short distance farther southeast, where it is cut by the Louisville lateral.

[8] Argall, G. O., Eng. and Min. Jour., vol. 89, p. 265, 1910.

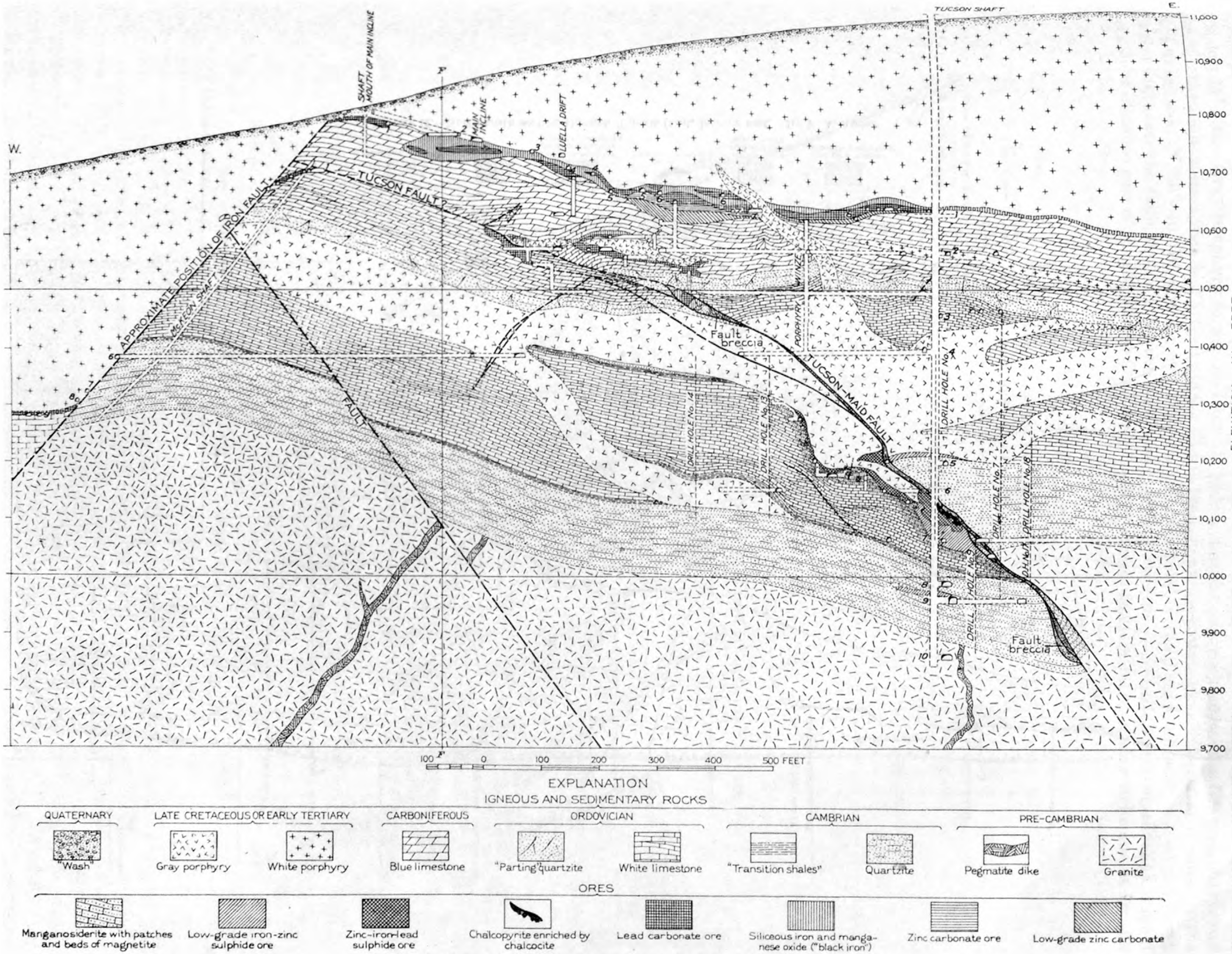


FIGURE 18.—Section N. 63° E. through Tucson fault, looking northwest. By F. A. Aicher

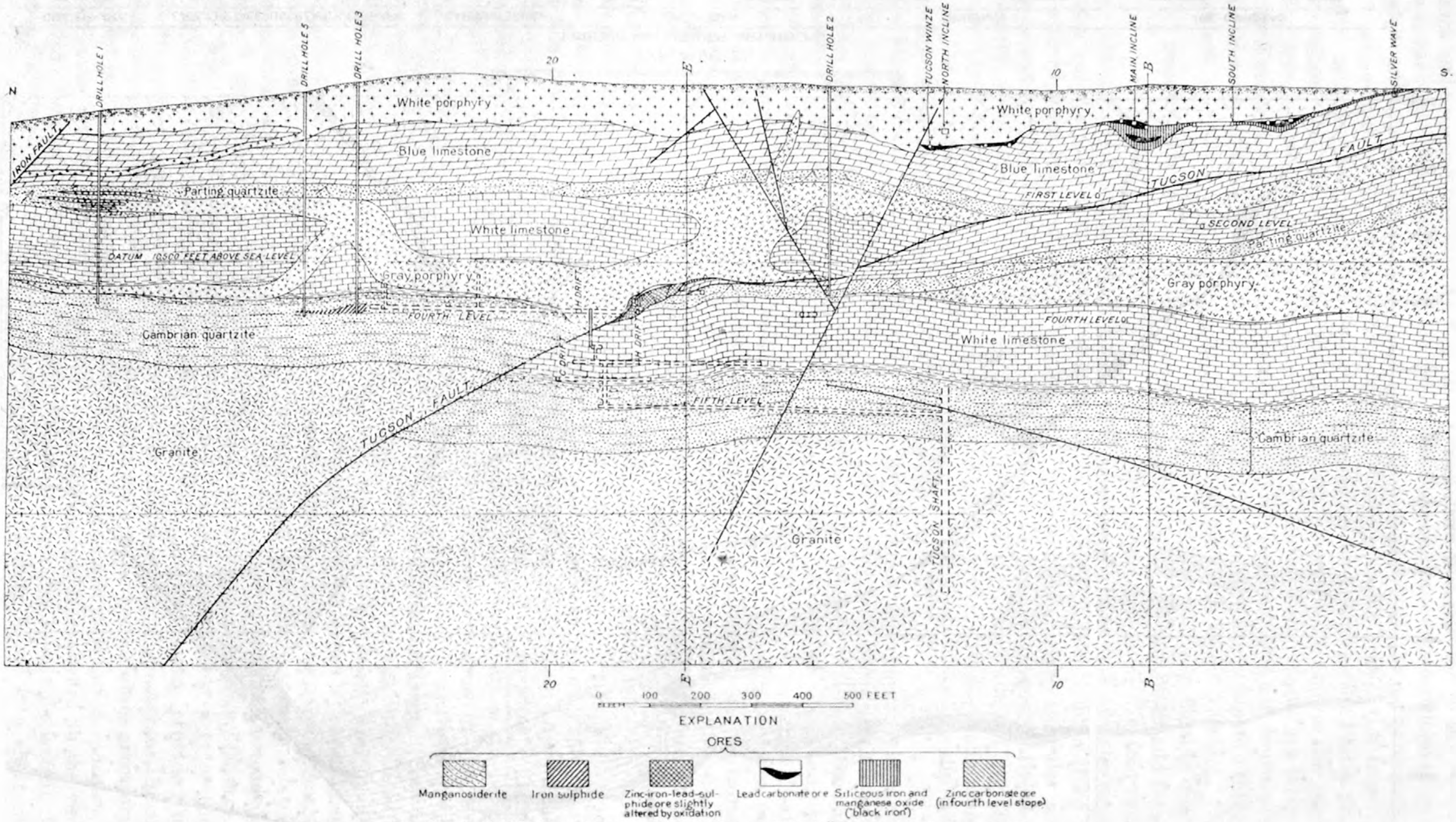


FIGURE 19.—North-south section through Tucson fault, looking east. By F. A. Aicher

At this place Parting quartzite forms the hanging wall and dips 35° NE. Gray porphyry forms the footwall and fills the fault zone, which is 75 feet wide. The fault walls strike N. 30°–40° W. and dip 50°–57° NE. Farther southeast the fault should cross the Yak tunnel a short distance east of the foot of the Cord incline (pl. 22). Fissures of proper dip and strike are present there, but the only rock exposed is Gray porphyry, and faulting appears inconspicuous, just as it does on the Fourth level of the Tucson mine.

Cord workings.—A little south of the Yak tunnel the Tucson fault is cut at nearly right angles by the

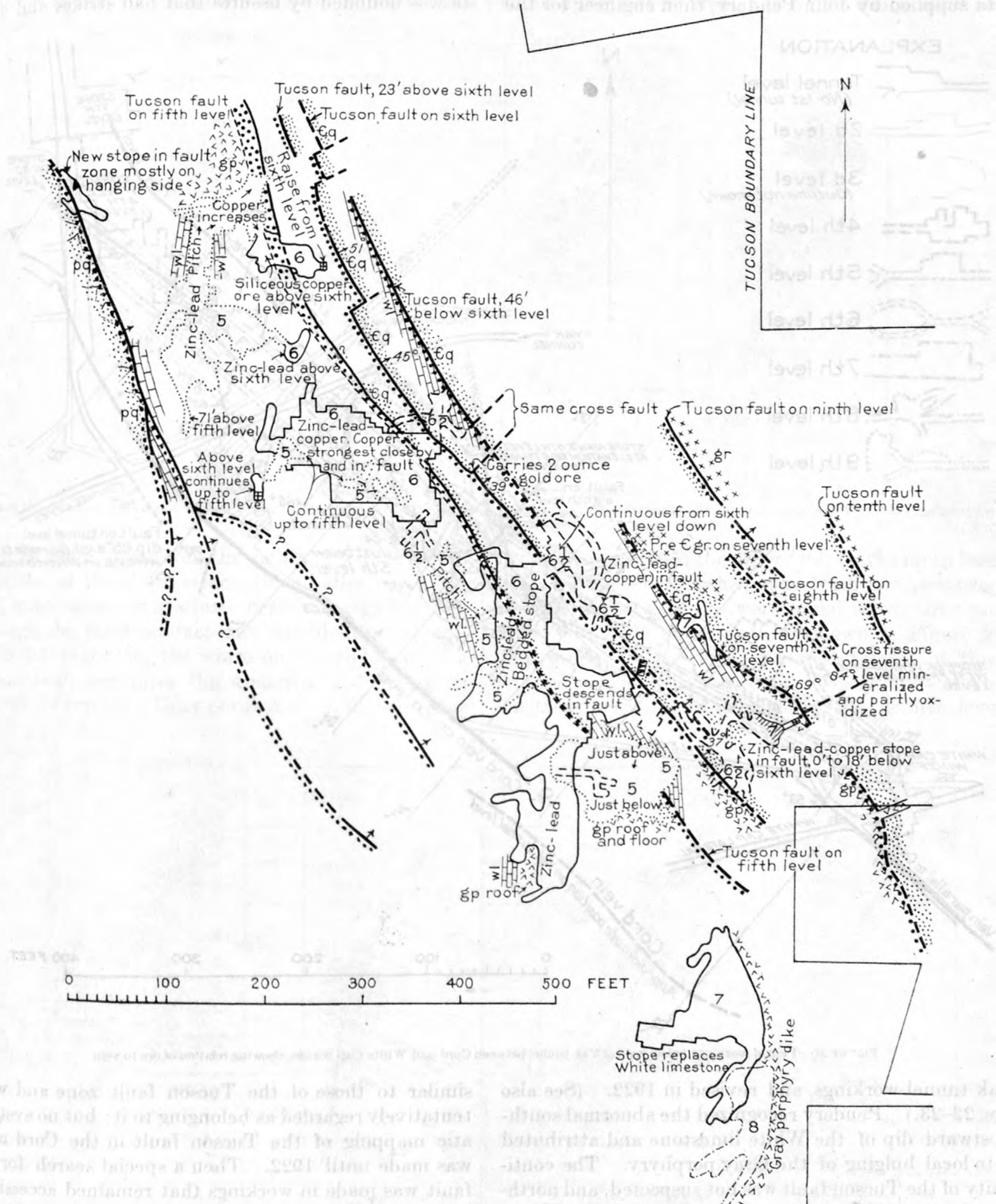


FIGURE 20.—Plan of fourth, sixth, and seventh levels of Tucson mine, showing relation of Tucson fault to ore bodies. By F. A. Aicher, Iron-Silver Mining Co. Numbers in stopes refer to levels. pq, Parting quartzite; wl, White limestone; Єq, Cambrian quartzite; gp, Gray porphyry; Pre-Є gr, pre-Cambrian granite

Cord vein and its associated replacement ore bodies, but the displacement of the Tucson fault zone is comparatively small, and such evidence as is obtainable suggests that the fault is dying out in a series of diverging branches. This evidence is shown in Figures 21 and 24, which were at first compiled in 1913 from data supplied by John Pendery, then engineer for the Yak tunnel workings, and revised in 1922. (See also figs. 22–23.) Pendery recognized the abnormal southwestward dip of the White limestone and attributed it to local bulging of the Gray porphyry. The continuity of the Tucson fault was not suspected, and northwestward-trending fissures in porphyry gave no evidence of considerable displacement. No faulting of northwestward trend was recognized in the stopes, presumably because within the White limestone they were obliterated by ore deposition, and crosscutting contacts between porphyry and limestone were regarded as some of the many irregularities that are characteristic of the Gray porphyry. In 1920 an ore shoot opened on the ninth level in Cambrian quartzite was bounded by fissures that had strikes and dips similar to those of the Tucson fault zone and were tentatively regarded as belonging to it; but no systematic mapping of the Tucson fault in the Cord mine was made until 1922. Then a special search for the fault was made in workings that remained accessible, and the faults found are represented by solid lines in Figure 24. The outlines of stopes shown in this figure are profiles furnished by the Yak Co. in 1922 and

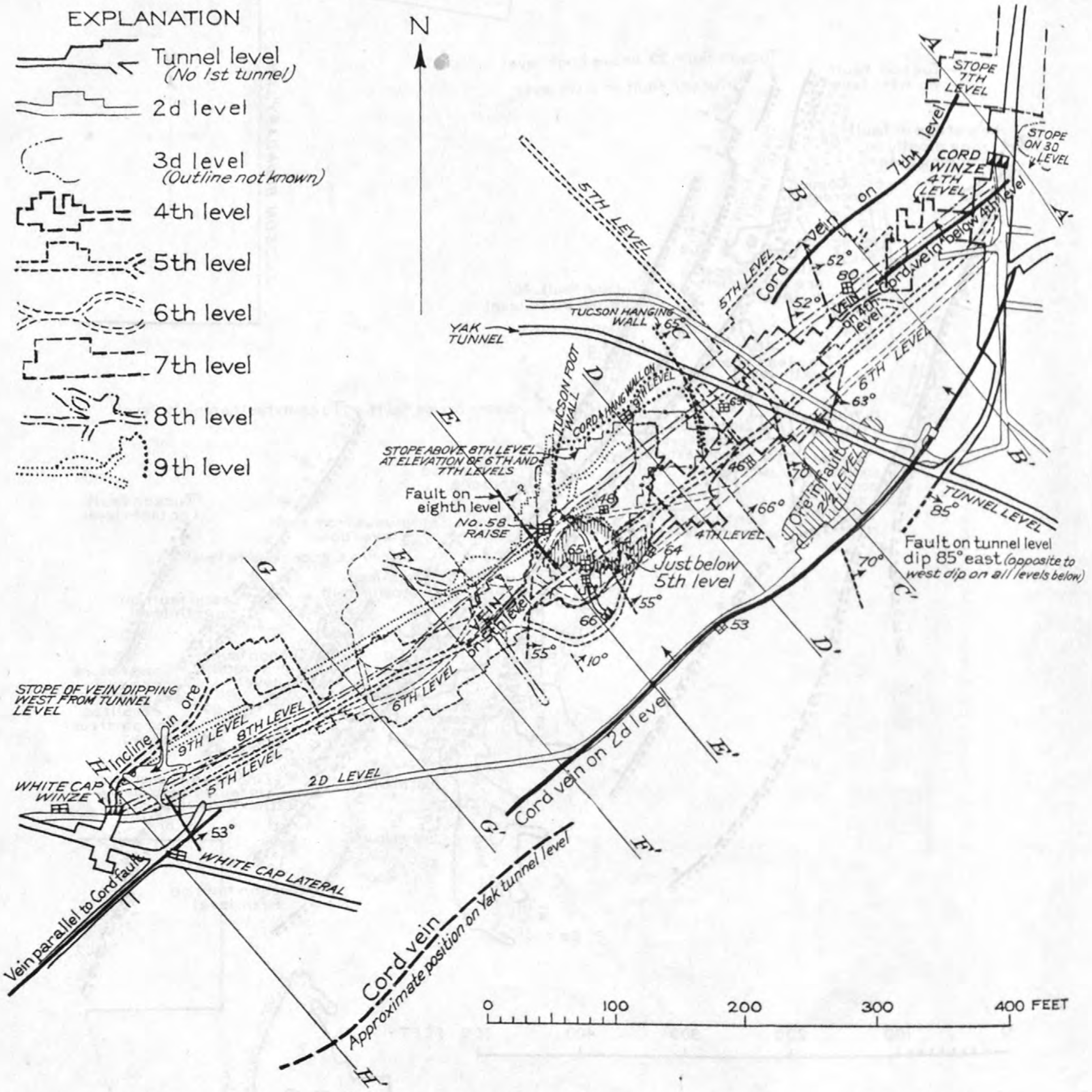


FIGURE 21.—Plan of workings below level of Yak tunnel between Cord and White Cap winzes, showing relation of ore to vein

included work done since Pendery's death in 1919. As access to stopes could not be gained in places of critical importance, the relation of faults to stopes is only roughly indicated.

Pendery had found that the top of the Cambrian quartzite was cut by the Cord winze at the seventh level. The top of the quartzite, dipping northeastward, is again found on the eighth level 125 feet southwest of the shaft, a fact which indicates a fault that must cross the winze near the eighth level, although the fault contact was not identified there. About 200 feet from the winze on the eighth level a reverse fault separates the quartzite and transition shale at its top from Gray porphyry. A little ore was found on the hanging wall along one of the transition beds. At a point 150 feet farther southwest the eighth level passes through stoped and timbered ground above one of the faults on the ninth level already mentioned, and evidence of faulting is concealed. Farther west another fault striking N. 40° W. and dipping 50°–60° NE. was found which must connect downward with the other fault on the ninth level. On the sixth level crushed zones with northwestward strike and eastward dip were found in the Gray porphyry along the main drift, as shown in Figure 24. The stope in line with the westernmost of these crushed zones was inaccessible. Three faults of similar trend were found in porphyry on the fifth level.

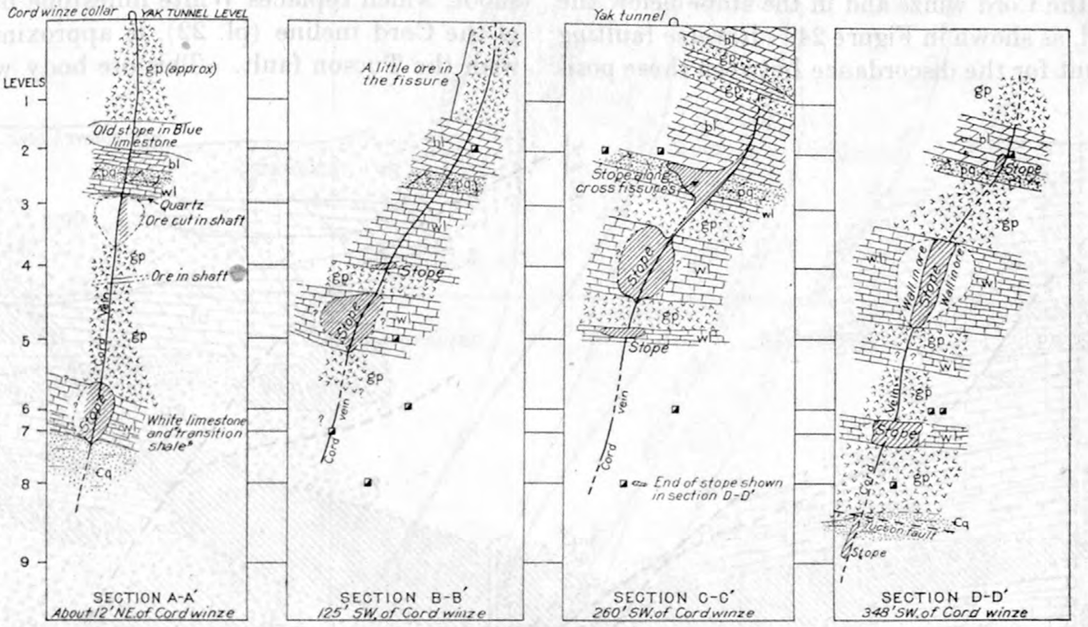


FIGURE 22.—Northwest-southeast sections through Cord winze workings. gp, Gray Porphyry; bl, Blue limestone; Pq, Parting quartzite, Wl, white limestone; €q. Cambrian quartzite; gr, granite

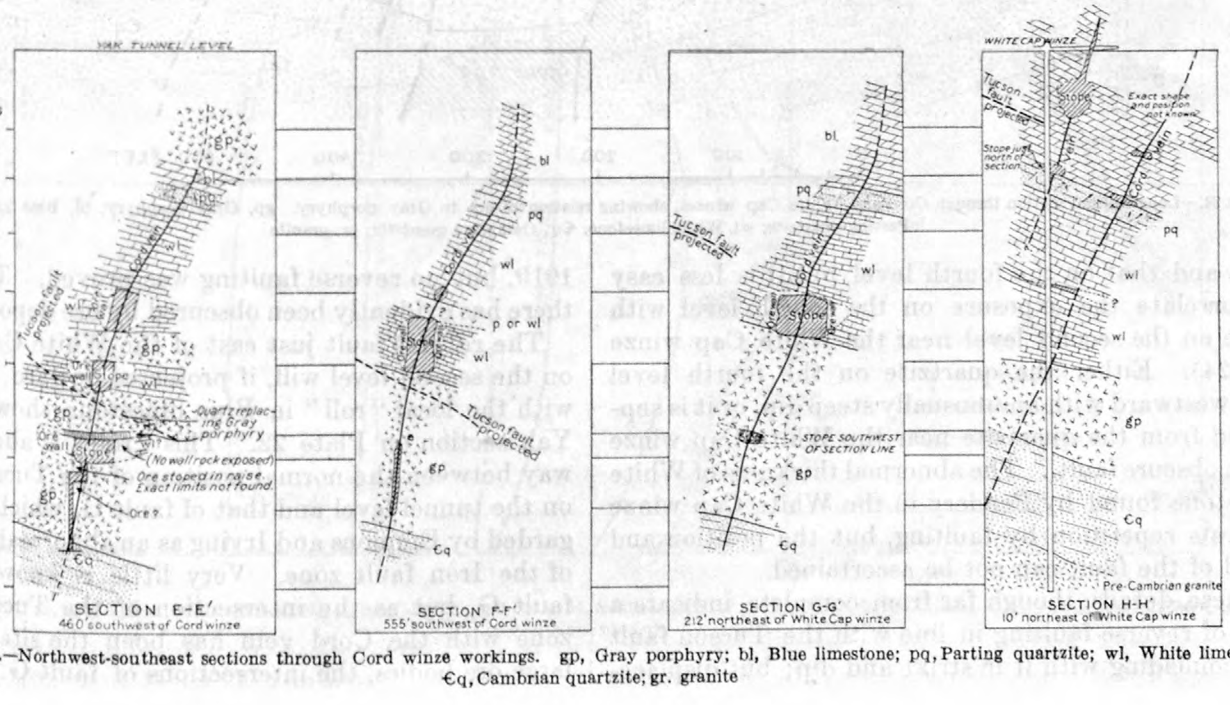


FIGURE 23.—Northwest-southeast sections through Cord winze workings. gp, Gray porphyry; bl, Blue limestone; pq, Parting quartzite; wl, White limestone; €q, Cambrian quartzite; gr. granite

No faults were located where the fourth level was accessible, but the westward dip indicated in Figure 24 was verified. Quartzite resembling the Parting quartzite formed the walls of the main drift for 270 to 300 feet or more from the shaft. Beyond this place the drift is caved. The structural relations of this quartzite are not clear. Parting quartzite was found by Pendery in the Cord winze and in the stope below the second level, as shown in Figure 24. Reverse faulting could account for the discordance between these positions and that on the fourth level, but it is less easy to correlate the exposure on the fourth level with those on the second level near the White Cap winze (fig. 24). Either the quartzite on the fourth level rises westward with an unusually steep dip, or it is separated from the quartzite near the White Cap winze by an obscure fault. The abnormal thickness of White limestone found by Pendery in the White Cap winze suggests repetition by faulting, but the position and trend of the fault can not be ascertained.

These details, though far from complete, indicate a zone of reverse faulting in line with the Tucson fault and coinciding with it in strike and dip; but displacement along single faults in the zone is small, and the aggregate displacement is much less than in the Tucson mine. Furthermore, the thickness of the zone in the Cord mine is greater than in the Tucson mine, and it appears that the fault zone is feathering out southeastward.

The short southeast branch of the south Cord ore shoot, which replaces White limestone below the foot of the Cord incline (pl. 22), is approximately in line with the Tucson fault. This ore body was visited in 1919, but no reverse faulting was proved. The fault there has evidently been obscured by ore deposition.

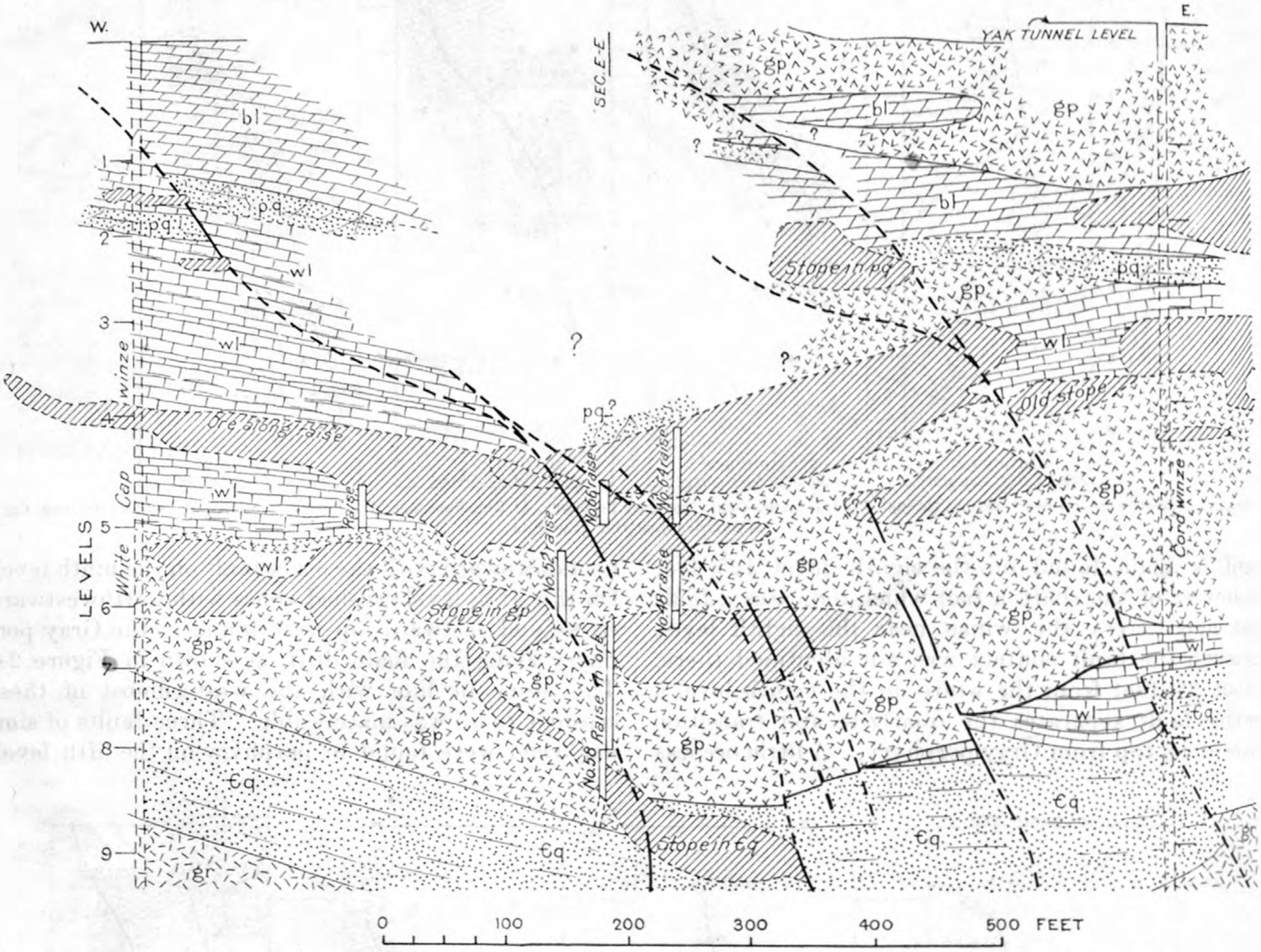


FIGURE 24.—Longitudinal section through Cord and White Cap winzes, showing relation of ore to Gray porphyry. gp, Gray porphyry; bl, Blue limestone; pq, Parting quartzite; wl, White limestone; €q, Cambrian quartzite; gr, granite

The reverse fault just east of the White Cap winze on the second level will, if projected upward, coincide with the local "roll" in Blue limestone shown in the Yak section on Plate 22. This "roll" is about midway between the normal position of the Tucson fault on the tunnel level and that of fault G, which was regarded by Emmons and Irving as an abnormal member of the Iron fault zone. Very little is known about fault G, but as the intersection of the Tucson fault zone with the Cord vein has been the site of some large ore bodies, the intersections of fault G with the

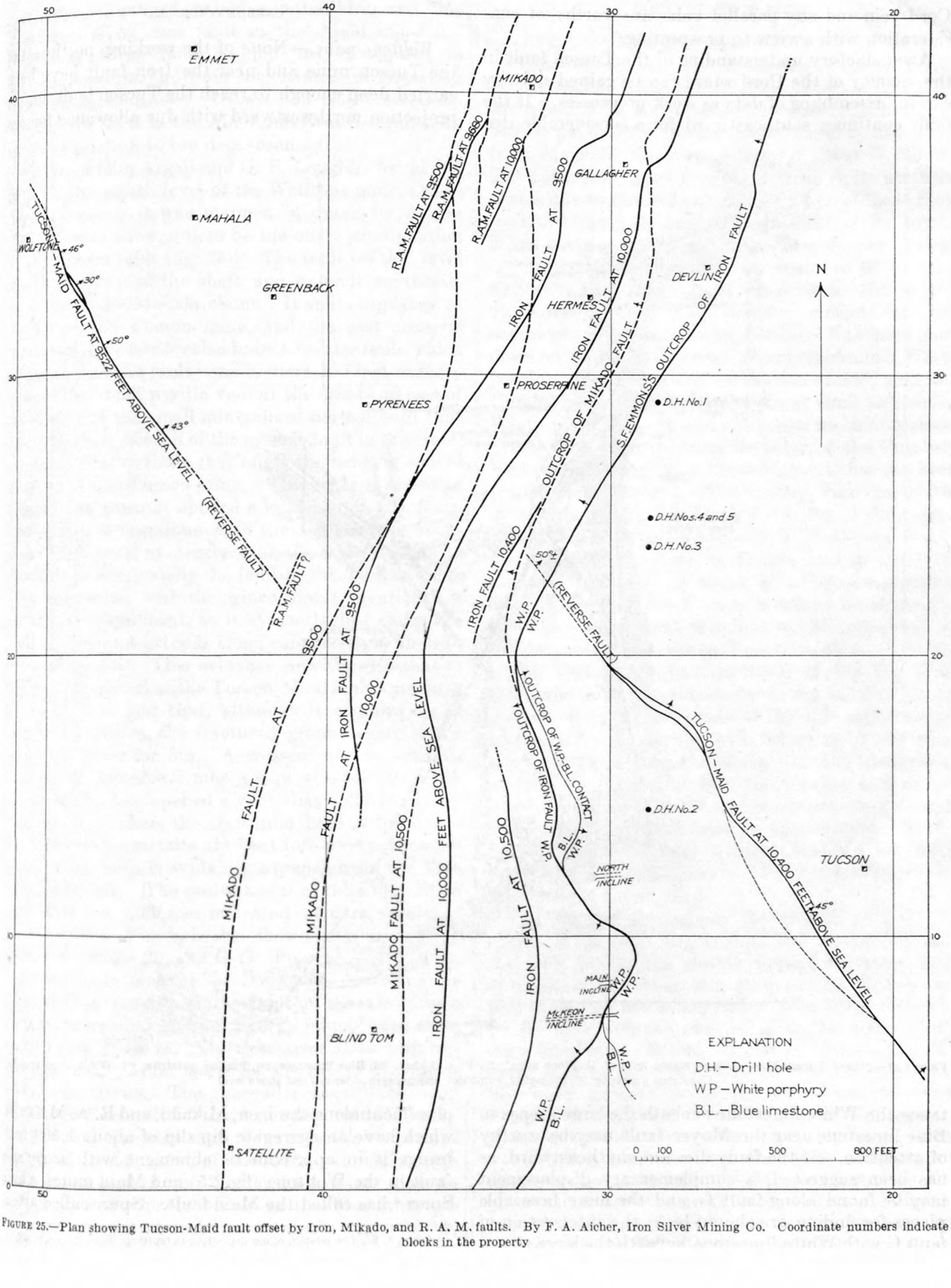


FIGURE 25.—Plan showing Tucson-Maid fault offset by Iron, Mikado, and R. A. M. faults. By F. A. Aicher, Iron Silver Mining Co. Coordinate numbers indicate blocks in the property

Cord vein and any parallel veins are worthy of consideration with a view to prospecting.

A satisfactory understanding of the Tucson fault in the vicinity of the Cord winze can be gained only by careful assembling of data as work progresses. If the fault continues southeastward for a considerable distance the White limestone beneath the large stopes in Blue limestone near the Moyer fault may be worthy of attention. If the fault dies out southeastward, as has been suggested, a complementary displacement may be found along fault G, and the more favorable places for finding ore should be at the intersection of fault G with White limestone beneath the large stopes in the Blue limestone.

CARBONATE HILL

Wolftone mine.—None of the workings northwest of the Tucson mine and near the Iron fault have been carried deep enough to reach the Tucson fault, but its projection northwestward with due allowance for displacement along the Iron, Mikado, and R. A. M. faults, which have an aggregate dip slip of about 1,000 feet, brings it in approximate alinement with a reverse fault in the Wolftone (fig. 25) and Maid mines, which Spurr [9] has called the Maid fault. Spurr called atten-

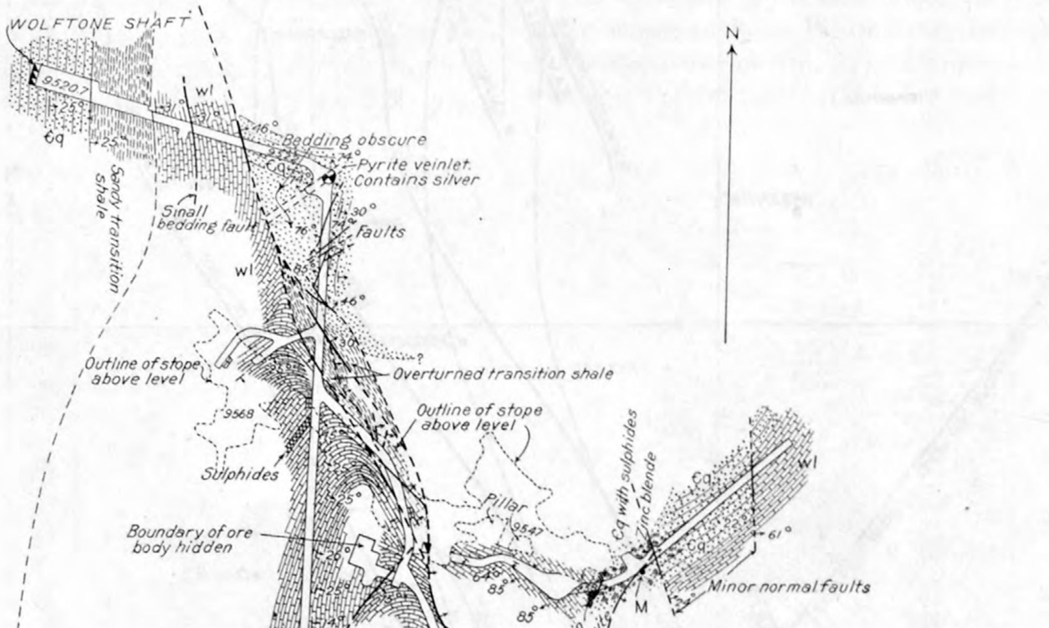


FIGURE 26.—Plan of Tucson-Maid fault on eighth level of Wolftone mine. By F. A. Aicher. bl, Blue limestone; pq, Parting quartzite; wl, White limestone; Єq, Cambrian quartzite; M, magnetite, sulphides, and manganosiderite 4 feet above level

[9] Spurr, J. E., The relation of ore deposition to faulting: Econ. Geology, vol. 11, p. 606, 1916; unpublished report to Western Mining Co.; Ore magmas, pp. 351-353 1923.

tion to the grouping of ore bodies in the White and Blue limestones along this fault in the Maid mine and inferred that the fault, formed just subsequent to igneous intrusion, had been the channel for ascending mineralizing solutions. Others had called attention to a reverse fault in the Maid mine but had not indicated its relation to ore deposition.

In 1919 Philip Argall and G. F. Loughlin found this fault on the eighth level of the Wolftone mine, and at Argall's request it was mapped in detail by Aicher (fig. 26), who showed it to be the offset continuation of the Tucson fault (fig. 25). The fault on this level lies 80 feet east of the shaft and extends southeastward across the Mahala claim. It splits in places, as it does in the Tucson mine, and the east crosscut shown in Figure 26 reveals a branch reverse fault, which indicates that the fault zone is there 100 feet or more wide. The small pyritic vein at the first bend east of the shaft and the small mineralized normal fault that offsets the east branch of the reverse fault in the crosscut are similar to those that offset the hanging wall of the fault of the Tucson mine. The winze in the main fault at this crosscut opened a local vein in the fault. The stopes in limestone near the fault on the Wolftone eighth level evidently bear the same relation to the fault as those along the fault in the Tucson mine. That connected with the winze above mentioned is particularly significant, as it evidently lies along the fault in part and extends along connected channels to both sides of it. This evidence accords with that in the Tucson mine that the Tucson-Maid fault antedates ore deposition and that, although it contains ore at only a few places, the fractured ground along it is a favorable place for ore. A crosscut on the seventh level of the Greenback mine (see pl. 40), 340 feet south of the shaft, has opened a vein that follows a small vertical fault where the transition beds at the top of the Cambrian quartzite are bent into a vertical monocline. This fault is evidently a branch from the Tucson-Maid fault. The position of the fault in the Maid and Wolftone mines, as indicated by data furnished by Spurr and Aicher, is also shown in sections C–C′ and D–D′, Plate 20, and G–G′, Plate 21.

Probable continuation in Downtown district.—The approximate outcrop of the fault in the Downtown district, taken mainly from Spurr's unpublished map, is shown in Plate 18. Its close association with certain ore bodies as far north as the Lower Henrietta shaft is apparent. The "second contact" ore body at the Old Hussey No. 2 shaft and the "third contact" body at the Hibschle shaft have boundaries parallel and close to the course of the fault. It is also possible that a part of the Tucson-Maid fault may be associated with the ore bodies in the Blue limestone near the Midas and Coronado shafts west of the Pendery fault, but an attempt to represent it so far from its known position would be inadvisable.

COLORADO PRINCE FAULT

The outcrop of the Colorado Prince fault extends southeastward along the southwest slope of South Evans Gulch from the Weston fault to the Ball Mountain fault, a distance of 1.2 miles. As nearly as can be determined from the few points at which the fault is visible, the average trend is about N. 53° W. The apparently more northward trend in its northern part is due to the steep northward slope of the surface toward Lincoln Gulch. Through most of its course it has a dip of about 45° NE. This steepens to 64° in the Archer tunnel, flattens again to 40° in the Kentucky Boy tunnel, and steepens to 70° in the St. Louis tunnel. The Boulder incline near its northwest end, is stated by Emmons[10] to have gone down on the fault between a granite roof and a White porphyry footwall, at an inclination of 45°, and the Cumberland shaft just east of it was sunk 150 feet in White porphyry. One of the faults in the Colorado Prince zone must therefore lie north of the Cumberland shafts, as shown on Plate 27, but it has not been traced southeastward. The underground exposures of the fault are represented in the Yak tunnel section, Plate 15, and sections B–B′, C–C′, and D–D′, Plate 14, and in several of the sections on Plate 28, the most instructive of which is the section trending 60° 33′, through the Fannie Rawlings mine (A–A′). Elsewhere its position is approximately indicated by the discrepancies in the geologic formations.

The fault passes just northeast of the Big Four shaft, and down its northeastward dip in this vicinity it is cut off by the large mass of rhyolitic agglomerate. In the Archer tunnel the fault fissure is 10 feet wide and is filled with the agglomerate. It contains agglomerate in the Kentucky Boy tunnel also, and in the Antelope tunnel it is said to contain breccia of considerable thickness which may be agglomerate. In the St. Louis tunnel the exposed fault zone is 5 feet thick but contains no agglomerate. Farther northwest the fault zone is not exposed.

The dip slip throughout the greater part of the course of the fault ranges from 100 to 120 feet, and the fault breaks the steeply dipping southwest limb of the local anticline; but between the Modoc and Ball Mountain faults both the position of the Colorado Prince fault and the amount of displacement along it are uncertain. It may extend eastward along the south edge of the small body of White porphyry, as this body appears to overlie Cambrian quartzite, whereas White porphyry elsewhere in the vicinity underlies Cambrian quartzite. A more normal course would be southeastward up the slope between the Cambrian quartzite and "Weber grits," but the displacement there is so much greater than it is northwest of the Modoc fault that it is more properly correlated with the Ball Mountain fault.

[10] U. S. Geol. Survey Mon. 12, p. 225, 1886

The most reasonable interpretation of the facts observed at this place is that the Colorado Prince fault is offset by the northward-trending fault along the Nevada tunnel and continues along the southwest side of the small granite exposure and southward up the slope, between Cambrian quartzite and White porphyry, until it is cut off by the Ball Mountain fault. It may be present along one of the contacts between Cambrian quartzite and White porphyry on the southeast slope of Ball Mountain, but as the anticlinal structure is not in evidence the Colorado Prince fault may have died out before reaching this place. As the dip slip along the Ball Mountain fault in this vicinity may be as much as 2,000 feet, any down-faulted part of the Colorado Prince fault must be well below any of the local mine workings. Its approximate position is indicated on sections E–E′ and F–F′, Plate 15.

The evidence on the west side of the Weston fault is even more obscure, as the only rock at the surface is Gray porphyry, and this is largely covered by a thin layer of glacial débris. The northwestward extension of the Colorado Prince fault is of importance, however, because of its possible influence on the distribution of ore bodies, and for this reason it has been roughly indicated on Plates 13 and 27. The tendency for reverse faults to develop auxiliary fissures that may serve as local feeders to replacement ore bodies and the presence of ore in old mines a short distance southwest of the fault tend to encourage prospecting along the northwest continuation of the Colorado Prince fault. The continuation, however, can be located only by drilling or drifting, and a large quantity of ground water must be expected, so prospecting will necessarily be expensive.

REVERSE FAULT IN RESURRECTION MINE

Section A–A′, Plate 14, shows a dike of Gray porphyry filling the fissure of a reverse fault which displaces Cambrian quartzite and rocks below it but does not extend upward through the White limestone. In a section only 300 feet to the south no faulting along the dike is represented. This apparent discrepancy can not be explained without more evidence than is now obtainable. If a fault is present as indicated in section B it is older than the porphyry intrusion and therefore not to be correlated with the other reverse faults here described, but the existence of two periods of reverse faulting can not be considered proved. Should further work to the west of the Resurrection shaft succeed in proving the upward extension of the fault, the fissured limestones along the fault may be found productive, especially if they are reached by some of the veins of the Resurrection group.

LONDON FAULT

The London fault is wholly outside of the Leadville district, but it is one of the largest reverse faults in the region represented by Plate 11 and is of added interest because of its association with ore bodies in the London mine. Emmons, although recognizing the close association of the fault with an unsymmetrical anticline, regarded it as normal with a southwestward dip and so represented it in the atlas accompanying his monograph; but later detailed work by Moore,[11] Patton,[12] Irving, and Aicher[13] proved the fault to be reverse. According to Plate 11 the London fault terminates against the Mosquito fault, with which it was at first believed to be contemporaneous, but the displacement of the Tucson (reverse) fault by the Iron (normal) fault suggests that the London fault may be similarly displaced by the Mosquito fault. There is little, however, in Plate 11 to indicate a northwestward continuation of the London fault, or the anticline with which it is associated.

The London fault extends from the Mosquito fault in a general direction S. 35° E. for 15 miles, along the west limb of the London or Sheep Ridge anticline, and finally dies out at Round Hill. South of Pennsylvania Hill and north of Mosquito Peak no later study of it than that of Emmons has been reported. Between these two places it has been mapped in detail by Patton, whose work is represented on Plate 11. Its dip, according to Patton, ranges from 65°–70° NE. Irving, who studied the fault only in the London mine, recorded dips of 74°–82° NE., and Aicher found a dip of 80° NE. where the fault is cut by the New London tunnel. Several planes of slipping are present in the fault zone, and their wide range in dip is not surprising. The total displacement, according to Irving, ranges from 1,700 to 2,540 feet, but the dip slip can not be closely estimated, as the fault for a considerable distance is parallel to the upturned strata of the broken anticline, and apparent displacement is largely due to folding.[14] Patton estimates the total apparent displacement as 2,500 to 3,000 feet. Patton's cross sections indicate a steep northeastward dip of the strata just west of the London fault, but Aicher, who made a detailed map of the North London mine and the Oliver Twist tunnel, northwest of it, records only southwestward dips, steep close to the fault and diminishing southwestward.

At the London mine the main London fault separates pre-Cambrian rocks from upturned Blue limestone and White and Gray porphyry. The fault zone is broad and complex. The ore bodies include replacement deposits along the bedding in Blue limestone and also veins in the South London mine, but only veins have been found in the North London mine. The main London fault has not been found to

[11] Moore, C. J., The London mine, Mosquito mining district, Park County Colo.: Am. Inst. Min. Eng. Trans., vol. 45, 1913.

[12] Patton, H. B., and others, Geology and ore deposits of the Alma district, Park County, Colo.: Colorado Geol. Survey Bull. 3, pp. 102–113, 191–204, 1912.

[13] Aicher, F. A., written communication dated April 24, 1924.

[14] Patton, H. B. op., cit., p. 103.

contain ore, but four veins, with strikes about parallel to the London fault, are present in the North London mine. These, named from west to east, are the London, McDonald, Hard to Beat, and East. The London vein is about 370 feet and the East vein 70 feet from the London fault. The McDonald and the Hard to Beat, which probably joins the McDonald toward the south, are midway between the other two. The dips of these veins, which approximately follow bedding planes of the upturned strata and their contacts with porphyry sills, are steep northeast in the upper levels but curve to steep southwest in the lower levels. The veins evidently fill or partly replace shear zones formed at the time of folding and reverse faulting. They range from mere streaks to veins 4 feet thick. The London and McDonald veins are said each to have a proved length of nearly 3,000 feet. They pass through the North London and South London mines and probably continue southeastward. They have been worked from points near the surface for several hundred feet down the dip.

In the North London mine the London vein is principally within Gray porphyry and locally cuts White porphyry and basal quartzite beds of the Weber (?) formation. The McDonald vein for the most part closely follows the contact between the Blue limestone and Weber (?) formation. The Hard to Beat vein follows bedding planes in the basal quartzite of the Weber (?) formation but passes into the Blue limestone at the lower levels. The East vein has been developed for 200 feet along a narrow sheeted zone in Blue limestone and locally along a contact between limestone and White porphyry. A small vein was also found in a minor reverse fault with east dip between the Hard to Beat and McDonald veins, below the level of the Blanchard tunnel.

Moore's sections indicate a continuous fault, which he calls the West London fault, with strike parallel to the main London fault and dip for the most part westward but curving upward with the dip of the strata until at the outcrop its dip also parallels that of the main London fault. Aicher shows a steep reverse fault dipping 60°–90° NE. on the Blanchard tunnel level of the North London mine, which corresponds to the northern part of Moore's West London fault; but he doubts the continuity indicated by Moore.

Between this fault and the main London fault Moore has shown some minor reverse faults with approximate dips of 45° E., along which there has been considerable strike slip. One of these in the South London mine contains a vein that is called the East vein but is not necessarily continuous with the East vein of the North London mine. These minor reverse faults and the shear zones that contain the veins are auxiliary to the main London fault.

The main London fault, the veins, and the West London fault as mapped by Moore are offset for short horizontal and vertical distances by several transverse minor normal faults of north-northeat to east-northeast trend. Most of these minor faults dip 65°–85° SE., but some of them dip northwestward at similar angles.

These features are similar in several respects to those of the reverse faults already described, and it is interesting to note that here, as at most places along the other reverse faults, ore has not formed in the principal faults of the zone where compression shearing was most pronounced but in openings that may be regarded as accessory to the main fault. The structure may have been complicated by movement during more than one period in the fault zone, as well as by the postmineral transverse faulting.

MOSQUITO GULCH FAULT

The reverse or overthrust fault associated with the overturned fold at Mosquito Gulch (p. 61) is the easternmost reverse fault recognized in the Mosquito Range region. No mining has been done along it, and it has no apparent association with ore bodies.

COMPOSITE REVERSE AND NORMAL FAULTS

When Emmons made his original survey of the Leadville district and Mosquito Range region there were no mine workings in which reverse faults were exposed, and the short time available for covering so great an area did not permit the detailed observations that have since been possible in the Leadville and Alma districts. He accordingly regarded all the faults as equal in age and gave a single name to faults which, though continuous and in line with one another, have been found in the light of further investigation to be of different character and to have been formed at different times. The Mosquito fault was later recognized by Emmons to be complex and possibly to represent two periods of faulting. The other two in this class, the Weston and Mike, were regarded by him as normal throughout, although he noted the complex relations between the Mike and Pilot faults. As these faults have been known so long by the names which Emmons gave them, they are described as composite faults instead of being described in part with the early reverse faults and in part with the later normal faults.

WESTON FAULT

The Weston fault, as shown on Plate 11, is one of the largest in the region, extending for more than 12 miles; but its variable character leads to the suspicion that its northern and southern parts represent different movements that were distinct in age. Underground exposures of the fault as mapped show displacement in different directions, but they are so few that only a tentative interpretation of the fault can be made.

From the south end of the region near Weston Peak to Iowa Gulch the Weston fault flanks the Weston anticline and has the appearance of a reverse fault.

This southern part of the fault has a maximum dip slip of 5,600 feet at Empire Hill. The amount of slip decreases gradually southward and more rapidly though less regularly northward. The average strike is N. 24° W. In the working of the Clear Grit mine, on the south slope of Iowa Gulch, its reverse character is shown according to sections by the late Charles J. Moore, which represent its dip as 60°–70° ENE. There is a complex of faults and veins here, as shown in Figure 27, and it is significant that the reverse Weston fault zone contains two parallel veins. The steep east-northeasterly dip shown in this figure is not apparent on Plate 11, which is based on Emmons's earlier work, and it may be that the reverse fault is obscured by auxiliary or later normal faults and by slide rock and that the mapped position of the fault north of Iowa Gulch is that of an associated normal fault. North of Iowa Gulch any evidence of anticlinal structure has been deeply buried in the down-faulted block that forms the west half of Ball Mountain, and the reverse fault, which is closely related to the anticline in origin, is evidently deeply buried also.

Northward from the Iowa fault as far as the Ibex No. 4 fault vein, the downthrow along the Weston fault, as represented on Plates 13 and 27, is on the east instead of the west. Within the Leadville district the fault is exposed in the Garibaldi tunnel, the northward branch of the Agwalt tunnel (known as the Tribune tunnel), the Yak tunnel, and the Forest Queen mine. In these places it has a very steep westward dip and is therefore reverse, but the movement was opposite to that south of the Iowa fault. In the Garibaldi tunnel both walls are porphyry and the amount and direction of dip slip can not be determined, although the fault zone is 100 feet wide; but drill holes put down from the Tribune tunnel appear to show down slip on the east side. According to the geologic sections the dip slip ranges from 420 feet at the Yak tunnel, where the fault zone is only 8 feet wide, to 800 feet or more at the point marked by section F-F', Plate 15, and is due to the relative drop of a block bounded by the Ball Mountain, Iowa Gulch, Weston, Ibex No. 4, and Modoc faults. This movement was subsequent to the period of folding and associated reverse faulting, and the part of the Weston fault here considered is therefore regarded as later than the southern part; but the period to which it should be assigned is somewhat uncertain. Most parts of it here described are regarded as formed subsequent to ore deposition, but the pyritic vein in the Forest Queen mine may be in a member of the Weston fault zone. As both premineral and postmineral faults are present in this part of the district, the Weston fault as represented may include closely parallel faults of two ages, or one fault along which movement has taken place at two different times. In the Garibaldi tunnel, according to Cross, it forms a very wide broken zone between two shattered and slickensided walls of Gray porphyry. From this point northward it bends toward the west and is again exposed just east of the quarry of the Antioch mine. In the Tribune tunnel it appears as a well-marked wall with a very steep westward dip. Another fault, which is regarded by some as the main Weston fault, is cut by the Agwalt tunnel about 250 feet farther west, but as the walls of both faults are porphyry the correlation with the Weston remains in doubt. The fault in the Tribune tunnel extends northward for more than 1,000 feet, then leaves this tunnel on the west, and is exposed again in the Yak tunnel.

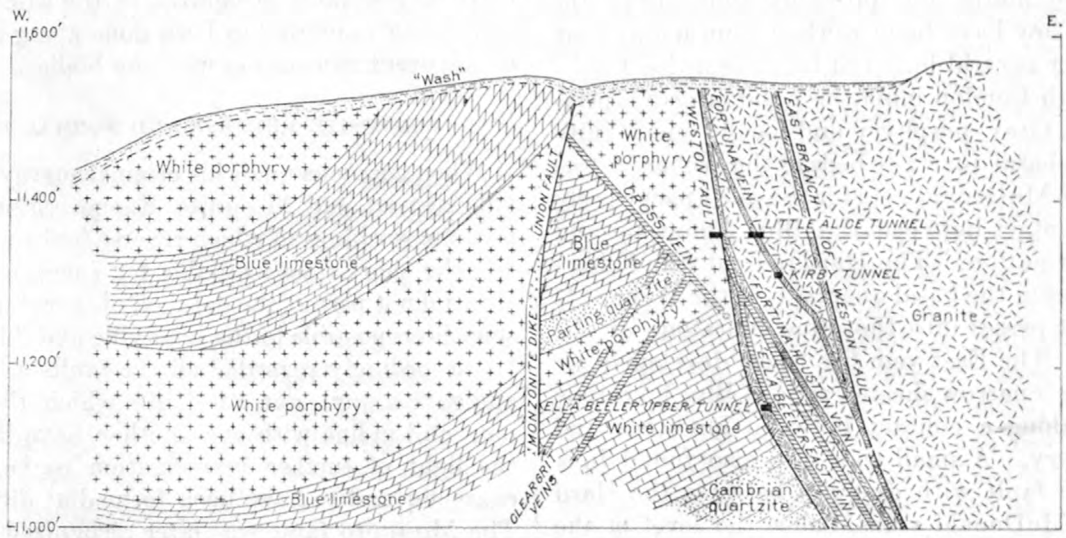


FIGURE 27.—Section through Clear Grit mine, on south slope of Iowa Gulch, showing reverse character of Weston fault and its relations to other faults and veins. After Charles J. Moore

In the Tribune tunnel the fault forms a narrow broken zone between two very sharp and distinct walls of Gray porphyry. In the Yak tunnel the fault is comparatively narrow with a zone of 8 feet of broken rock, lined on both sides by clay selvage. Where found the west wall is composed of the Lower or

Cambrian quartzite and the east wall of Gray porphyry. Above the level of the Yak tunnel the fault is exposed in the Forest Queen mine, and, as will be seen from its position on the Yak tunnel section (pl. 15), it has the irregular curvature which is so common a feature of those faults that have been extensively explored.

North of the Ibex No. 4 fault (section D–D′, pl. 14) the direction of movement again changes, and the dip slip is 450 feet downward on the west. The fault itself has not been cut in this part of its course, but the positions of the adjacent formations have been determined by rather extensive mine workings. The dip is represented by Emmons and Irving as steep to the west, and the fault here appears to be normal. At the point marked by section C–C′ the down slip has increased to 480 feet, but it decreases again northward, and somewhere beyond the intersection with the Colorado Prince fault the direction of down slip changes once more. In section A–A′ the down slip is represented as 60 feet on the east. The di tphere has also changed to very steep eastward and the fault again appears to be normal. Beyond this point the Weston fault is lost in the thick series of "Weber grits" which forms Prospect Mountain and in which the detection of displacement is impossible. It is probable, however, from the absence of this fault on the opposite side of the East Fork of Arkansas River, that it has died out completely in this direction.

The similarity in strike and direction of slip between this northernmost part of the Weston fault and the Winnie-Luema fault vein is noteworthy. No evidence of mineralization has been found along this part of the Weston fault, but the concealment of the fault beneath glacial débris has prevented its exploration. On the whole the Weston fault must be regarded as one of the most complex and least understood faults in this region.

MIKE, PILOT, AND WHITE PRINCE FAULTS

The Mike fault as represented on Plate 11 is 2.4 miles long. It is similar to the Weston fault in its changing character, though it is much shorter and its displacement is much less. Its southern part, between Empire Gulch and the Pilot fault, strikes N. 24° W. and lies along the west limb of an anticline, a relation which suggests a reverse fault. The suggestion is confirmed by the fact that the trace of the fault on the slopes of Long & Derry Hill, indicates an eastward dip. The amount of displacement is greatest on the south slope of Long & Derry Hill, where the east wall is pre-Cambrian granite and the west wall is Blue limestone. At the Kenosha tunnel, farther north on Long & Derry Hill, the east wall is formed by a mass of greenish Gray porphyry that underlies the White limestone and the west wall by a mass of White porphyry that overlies the Blue limestone. The throw here is about 1,000 feet. Southward toward Empire Gulch the throw decreases so rapidly that the fault has not been detected beyond the gulch.

North of Iowa Gulch most of the displacement of the Mike fault continues along the Pilot fault, which strikes nearly north for 1.1 miles and dips steeply west. The character of faulting therefore changes from reverse to normal. The Pilot fault is well defined by outcrops on both sides of California Gulch and has been exposed in the Printer Boy mine and the Yak tunnel. Its fissure zone is wide. A drift 500 feet below the surface was driven eastward from the Lower Printer Boy shaft for 300 feet along a zone of selvage clay and breccia material having a total width of 40 feet. In the Yak tunnel a broken zone fully 860 feet in width occurs to the east of the western wall of the fault. The larger portion of the tunnel walls at this point is necessarily obscured by lagging. It is probable that the fault, being one of considerable magnitude, is distributed along a number of nearly parallel fissures. The maximum dip slip, from evidence in the Yak tunnel, may be as much as 2,000 feet, but there is little opportunity to estimate it. (See sections on pl. 15.) The slip evidently decreases northward from the Yak tunnel and may die out within the Gray porphyry mass of western Breece Hill; but the fault may continue farther north than is indicated on the map and be represented by the White Prince fault, which is similar in strike, dip, and slip. The White Prince fault is not exposed either at the surface or underground, but its position and throw are approximately indicated by a difference of fully 400 feet in the altitude of corresponding strata in the White Prince and Across the Ocean shafts.

From its junction with the Pilot fault the Mike fault extends N. 17° W. as far as the Mike shaft, then curves to the north and northeast until it is lost in the Eureka mass of rhyolitic agglomerate at the northwest base of Breece Hill. Its dip is still eastward, ranging from 45° to 80°, but the dip slip is downward to the east and is relatively small, at few places exceeding 30 feet.

The fault has been explored by the workings of the Mike winze, the Yak tunnel, the north and south Mike shafts, and the Lady Alice, Morning Glory, and Park Benton mines on the northwest slope of Breece Hill. Throughout its extent the fault is characterized by a wide zone of shattered material. It is bounded in the Mike workings by prominent selvages of clay, the black color of which suggests derivation from the "Weber shales," although none of these shales have been found in place near the fault. In the workings from the Yak tunnel and Mike shafts the fault is marked by a selvage-lined zone of crushed rock 40 feet in width just west of a 100-foot zone of shattered rock within which the fragments have been comparatively little moved from their original position.

The fault zone is crossed by the Lady Alice shaft and is represented in the Park Benton mine by a number of small faults of general northerly trend, along each of which a small amount of movement has taken place.

The fault zone is occupied in portions of the workings of the Mike winze by a large dike of rhyolitic agglomerate containing fragments of all sorts of rock. A dike of the same material is found in the workings of the Park Benton mine. There can be no question that these isolated occurrences are connected along the fault zone by a greater or less thickness of agglomerate which has extended southward from the Eureka stock of agglomerate.

In view of the great width of the fault zone the relatively small displacement is remarkable. There is reason, however, to believe that the displacement along this fault was once greater than at present and that the movement has been now in one direction, now in the other. The wide zone of broken material is a rough index of the whole amount of movement without regard to direction; the present relative position of the two walls measures the algebraic sum of these movements. The main fault zone in places contains large fragments of pre-Cambrian granite and black shale between walls of Blue limestone. These fragments are not part of the rhyolitic agglomerate. The granite fragments are 400 to 500 feet above the top of the granite in place. The shale fragments may represent the transition beds at the top of the Cambrian quartzite or, less probably, the "Weber shales," a small part of which probably lies at the top of the Blue limestone beneath the White porphyry. No definite significance can be attached to the shale, but the granite fragments constitute proof that one of the walls of the fault must have been much higher than at present. The suggestion is plausible, therefore, that after reverse movement along the Mike fault had taken place the wedge-shaped block between the northern Mike and Pilot faults was dropped, and the small displacement along the northern Mike fault is the net result of two opposite movements.

MOSQUITO FAULT

The northern part of the Mosquito fault, north of Tenmile River (pl. 11), is an overthrust, but south of that stream the fault is normal, according to Emmons,[15] who describes it as follows:

In the southeastern portion of the area the position of the fault is readily seen on the hills by the sharp contrast between the rugged slopes afforded by the Archean rocks to the east and the softly rounded forms of the sandstone hills to the west. As represented on the map its line of outcrop has been most carefully traced by surface exposures and underground workings.

On the steep slope of Copper Mountain, where this line is so remarkably curved and broken, it is unusually distinct, as, owing to the steepness of the slopes, there is but little covering of loose material. Although several prospect holes have helped to define the line here, by showing the juxtaposition of different rock varieties, none have exposed the fault plane sufficiently to afford means of determining its hade by actual observation. The variations in the line of outcrop of the fault plane as it crosses depressions indicate that this plane hades to the east, and from this fact and the form of the outcrops on the south spur of the mountain it is assumed that the peculiar outline of the fault in this region is due to overthrust faulting, which has actually carried a portion of the Archean over the Carboniferous beds. On the other hand, south of the point where it crosses Tenmile River the fault is a normal fault and hades to the west. This is proved not only by the tracing of its outcrops as it crosses ridges and valleys but by actual demonstration in the underground workings of mines, especially the Treasure Vault on Mayflower Hill and the Boston in Mayflower Gulch. The limestone beds in the latter mine stand nearly vertical, and in the Old Mast tunnel, near the former, they have a reverse dip of 65° E. These facts and the general crumpling of the mass of the sedimentary beds show that the faulting was accompanied by a compressive strain on the region to the west, even where the upward movement produced a normal fault. Copper Mountain lies within the point of the angle made by the fault plane as it changes from a northerly to a northwesterly direction, and in this angle the westward push of the rising block would be greater than anywhere else and might have caused a change of hade in its plane and local overthrust.

Beyond the west fork of Tenmile River it appears that the fault plane separating Carboniferous from Archean extends about 25 miles in a general northwesterly direction. It may be that this is not simply a continuation of the Mosquito fault, as has been assumed above, but a distinct northwest-branching fault, like the London fault in the Leadville area, and that the Mosquito fault proper continues its northerly direction into the Archean area along the general line of the narrow gorge of Tenmile River. As regards the peculiar baylike intrusion of Archean to the east and south of Copper Mountain, it can only be said that it appears to be in the nature of an overthrust but that sufficient detailed and accurate data are not available to explain satisfactorily the mechanism by which it was produced.

According to Emmons's sections in the Tenmile district folio, the dip slip of the Mosquito fault north of Tenmile River is at least 1½ miles. It decreases southward and may be distributed over different surfaces. The results of exploration along the smaller reverse faults of the region strongly suggest that the Mosquito fault is even more complicated than Emmons's opportunity for observation indicated. What is shown on the map as one fault may prove to be one or more reverse faults modified by closely associated auxiliary faults and by nearly parallel subsequent faults. Emmons[16] realized that the northern part of the fault might be of premineral origin, although its southern part, near Leadville, was of postmineral origin.

The southern part is normal, and at no place adjoining it do the adjacent rocks show evidence of compressive strain. It cuts off the London reverse fault northwest of Mosquito Peak and is there evidently one of the postmineral faults. The dip slip

[15] U. S. Geol. Survey Geol. Atlas, Tenmile district folio (No. 48), p. 3, 1898.

[16] Idem, p. 4.

there is indicated by Emmons as about 4,000 feet, but it decreases southward, and beyond the Ball Mountain fault on the south slope of Long & Derry Hill it is only 500 or 600 feet.

NORMAL FAULTS AND FISSURES FORMED SUBSEQUENT TO REVERSE FAULTING AND PRIOR TO ORE DEPOSITION

In order that a given fracture may be assigned with absolute certainty to the second of the main groups above defined it must be shown to be mineralized, be traced across some of the reverse faults already described, and be found to be offset by the postmineral faults. None of the faults or veins classified in this group present all these criteria, but as their mineral contents are similar they are grouped together. Moore[17] and Irving felt that the ore in these veins was deposited later than that in the blankets and that the faults were to be grouped as auxiliary to the major postmineral faults. Irving, however, recognized that faulting took place at intervals through a long period, and that some of the veins had been affected by later movements. This question of correlation can not yet be satisfactorily answered, although evidence obtained since Irving's field work was completed points to simultaneous deposition of the veins and blanket ore bodies and therefore to difference in age between fissures that contain the veins and those that offset ore bodies. The veins thus far found are nearly all in the eastern part of the district, in Breece Hill and vicinity, and their structural features are described at some length in chapter 9 (pp. 178–184); but one of the most instructive from the present standpoint is that in the Cord mine, in southern Iron Hill.

CORD FISSURE

The Cord fissure, also referred to as the Cord fault, extends in a general northeasterly direction and has been exposed between the White Cap and Cord winzes, from the second to the ninth level below the Yak tunnel. Its general trend may be realized from Figure 21, and cross sections of it are shown in Figures 22 and 23. John Pendery, on whose work these figures are based, stated orally that at one place a displacement of 4 feet along this fissure appeared to be indicated by the bottom contact of an ore body with Gray porphyry but that no appreciable displacement was found elsewhere. The fissure undulates considerably along both strike and dip. At the Yak tunnel level near the Cord winze it strikes a little east of north and dips 80° E. Directly below, on the second level, the dip is 80° W. About 100 feet south of the winze the strike changes to southwest and the dip changes to 60° NW. The southwest strike is maintained on the lower levels. Between the second and fourth levels the dip decreases to about 45° NW. in places, but between the fifth and ninth levels it steepens to 75° and even 85° NW.

The degree of mineralization along the fissure varies. At some places where the fissure cuts Cambrian quartzite and Gray porphyry it has been stoped, and the ore body has proved to be of distinct veinlike form; in the shattered rock at intersections with members of the Tucson fault zone the ore body has the form of a stockwork containing what is locally called brecciated ore. At one place just below the seventh level a veinlike body in porphyry passed upward into a replacement body in White limestone. The ore in the Cambrian quartzite and porphyry and the ore body in Parting quartzite below the second level are mostly pyritic and relatively high in gold and copper contents. The replacement deposits in limestone, however, contain relatively large amounts of zinc blende and galena and are identical in mineral composition with blanket ore bodies that have been displaced by such major postmineral faults as the Iron, Mikado, and Pendery faults. The Cord fissure crosses the Tucson fault zone without deflection. It has not been followed to an intersection with any postmineral faults.

ST. LOUIS AND BIG FOUR FISSURES

The vein worked in the St. Louis or Colorado Prince mine is of special interest because it crosses the Colorado Prince reverse fault nearly at right angles and sends short branches along the reverse fault. There is no perceptible suggestion of faulting along the vein fissure, and so far as obtainable evidence indicates it is to be regarded as of the same character and age as the Cord fissure just described. The Big Four vein has been developed to the south of the Colorado Prince fault, but its intersection with the fault, so far as shown, has not been exposed. (See p. 306 for detailed description.)

WINNIE-LUEMA FAULT

The Winnie-Luema fault has not been followed to an intersection with either a reverse fault or a major postmineral fault, but it contains the longest lode that has been mined in the district. It has been explored from the Winnie shaft northward through the Luema and Silver Spoon workings, a distance of 2,600 feet, and its east wall is broken by branch faults of east-northeast trend. Its average dip is nearly vertical. The downthrow along it is on the east in the southern part and on the west in the northern part, and the change is accounted for by movement along the branch faults. Its southernmost part may have been cut off by the Ollie Reed mass of agglomerate. Its strike varies very little from north in its southern third, but near the Luema shaft it curves gradually westward, and in the northern part of the Silver Spoon mine it strikes N. 25° W. The fault zone ranges from 4 to 40 feet

[17] Moore, C. J., Am. Inst. Min. Eng. Trans., vol. 45, p. 247, 1913; Econ. Geology, vol. 7, pp. 590–592, 1912.

in thickness, and the position of most intense fissuring varies, being on the west side of the fault zone in the southern part of the Luema and on the east side in the Silver Spoon.

Near the Winnie shaft the displacement is 140 feet downward to the east; 700 feet to the north it has increased to 200 feet. The east wall in the Winnie ground is cut by three branch fissures or faults of northeastward trend with downthrow to the northwest. The increase in displacement along the main fault is evidently accounted for by these branch faults. Along all of them replacement (blanket) ore bodies in the lower part of the White limestone have been mined. Two of these ore bodies connect with the main vein. At the north end of the Winnie mine the vein is said to be offset a short distance by a minor postmineral fault of east-northeasterly trend.

The character of this fault in the Luema and Silver Spoon mines is represented by Figures 104–107. At the Luema shaft the displacement has changed to 50 feet downward on the west. A minor northeast vein is present a short distance to the east above the third level, but the amount of faulting along it could not be determined. Near the Silver Spoon shaft the displacement on the main vein is 90 feet, still downward on the west, but is compensated by displacement along a parallel vein on the east, which has been followed only a short distance. About 700 feet north of the Silver Spoon shaft a mineralized branch fault of east-northeasterly trend has been cut on the fifth level. It is similar to the eastward branch faults in the Winnie mine but has been exposed only between granite and Cambrian quartzite, where it is not productive. Its intersection with the White limestone has not been prospected. This branch fault dips steeply northward, and its dip slip is about 30 feet downward on the north. About 300 feet farther north two similar branch faults of more northeastward trend and less displacement are cut on the fifth level. Beyond these faults the main fault either dies out in a number of fissures or changes its down slip to east again. At the northernmost workings, reached through the Silver Spoon tunnel, the strata lie in an eastward monoclinal fold, along which there may be some faulting, as shown in Figure 106.

The diminution of slip along the main fault in the Silver Spoon mine is compensated by the northward down slips along the eastward branch faults. This relation suggests that differences in amount of slip all along the main fault may be due to compensating slips along branch faults that have not been exposed. As exploration has been largely confined to the productive part of a main vein and the short veins to the east, there may be more branch faults than have thus far been discovered. The importance of branch faults as guides to prospecting in the limestone is obvious. All the branch faults exposed are on the east side of the main fault and may be confined to that side; but the west side has not been explored, and the rather rapid changes in altitude of the boundaries of the Cambrian quartzite suggest the presence of similar faults on the west side also, as indicated in Figure 107.

MINOR FAULTS IN THE RESURRECTION MINE

A group of nearly parallel mineralized faults with north-northeasterly trend and dip slips of 10 to 40 feet connects upward with the blanket ore bodies in Blue limestone in the Resurrection mine. They terminate upward against the "Weber shales," which were too flexible to be ruptured by the faulting. They have been little explored, and it is not known whether or not there is appreciable displacement along all of them. The one that is best exposed is cut by the Yak tunnel and has a small down slip to the east. These minor faults are in alinement with a branch fault that extends northeastward from the Silent Friend fault.

SILENT FRIEND FAULT

The Silent Friend fault strikes N. 6°–10° W. and dips 60°–70° W. It is exposed in the Silent Friend and Howard workings and in the Yak tunnel. In the Yak tunnel the down slip is about 60 feet to the west. The fault has not been explored south of the Yak tunnel but evidently forms the east boundary of the Ollie Reed mass of agglomerate, as shown in the Howard workings. Farther south its probable continuation is followed for 400 feet by the Nevada tunnel, where its dip is 70° E. and its down slip has also changed to the east. Still farther south it reaches the Colorado Prince reverse fault and the Ball Mountain fault, but its relations to both of them are obscure.

In the Nevada tunnel the fault zone consists principally of breccia containing fragments of quartzite, porphyry, and other rocks embedded in a rhyolitic matrix and evidently represents a dikelike offshoot from the agglomerate mass to the north. It is also occupied by a vein 2 to 3 feet thick which was mined nearly the whole length of the tunnel. The vein is older than the agglomerate, which lies on the east side of the vein most of the way but crosses to the west side at a few places. The breccia is also found in a prospect hole 300 feet north of the tunnel.

The Howard shaft was sunk 755 feet entirely in agglomerate, and the fault was cut by an east drift from it at a depth of 450 feet. The fault here was found to dip 60° W. and to contain a black selvage full of fragments of White porphyry. Between this and another fault plane with black selvage broken coarse-grained granite was found. A raise along the main selvage disclosed many fragments of sulphide ore.

In the Yak tunnel the fault dips 70° W. and contains a vein of sulphide ore that has been explored both northward and southward. The entire fault zone here is 40 feet wide. It consists of an outer zone of broken material averaging about 18 feet in width on each side of the vein filling. The filling material consists of sulphide ore with more or less banding, bounded on the west side by a well-marked selvage. There are indications of considerable movement subsequent to deposition of the ore.

This vein is reported to have been worked upward as far as the workings of the Silent Friend mine, but these workings were not accessible at the time of Irving's and Loughlin's visits.

MODOC, GARBUTT, AND IBEX FAULTS

The Modoc fault and vein have been developed in the Modoc, Donovan, and Elk mines, in the lower northwest part of Ball Mountain, east of the Ibex mine. The fault extends S. 73° W. from the Colorado Prince fault for 900 feet but has not been followed any farther. It dips steeply southward and has a dip slip of 800 feet downward on the the south. It forms part of the north boundary of the large depressed fault block that constitutes the west half of Ball Mountain. It has not been followed into the Ibex workings, but its position at the bottom of the Elk shaft is in line with and at about the same altitude (10,890 feet) as vein No. 14 on the seventh level of the Ibex (10,900 feet), east of shaft No. 4. (See pl. 57.) No displacement nearly as great as that along the Modoc fault has been recognized toward the west through the Ibex ground, but there is a considerable displacement along the Garbutt fault, which should meet the No. 14 vein east of the Ibex No. 4 shaft. It is therefore probable that a local block bounded on the north by the Modoc fault and on the west by the Garbutt fault has dropped, as indicated diagrammatically in Figure 28.

The Garbutt vein has been worked northward and southward from the Garbutt shaft down to the Ibex thirteenth level. On the lowest levels it occupies a fault fissure with eastward dip along which porphyry and Cambrian "transition shales" on the east lie opposite Cambrian quartzite on the west. The amount of dip slip may be as much as 200 feet, but, as shown in Figure 29, it can not be closely estimated owing to intrusions of Gray porphyry and the absence of limestone in workings on the east side of the fault. The eastward dip continues up to the thirteenth level (altitude 10,670 feet), where the vein pinches and assumes a horizontal position for a few feet westward before continuing upward with a western dip. Only the lower part of the vein is diagrammatically represented in Figure 28. The upper part of the vein also fills a fault fissure, but the amount of dip slip along it has not been closely determined, as the accessible parts of it, showing porphyry faulted against "Weber grits" do not permit correlation of beds in the opposite walls. The accessible workings expose only Weber (?) formation, Gray porphyry, Cambrian shale and quartzite, and pre-Cambrian granite. No limestone has been reported from any part of the Garbutt workings, and the geologic structure is therefore obscure.

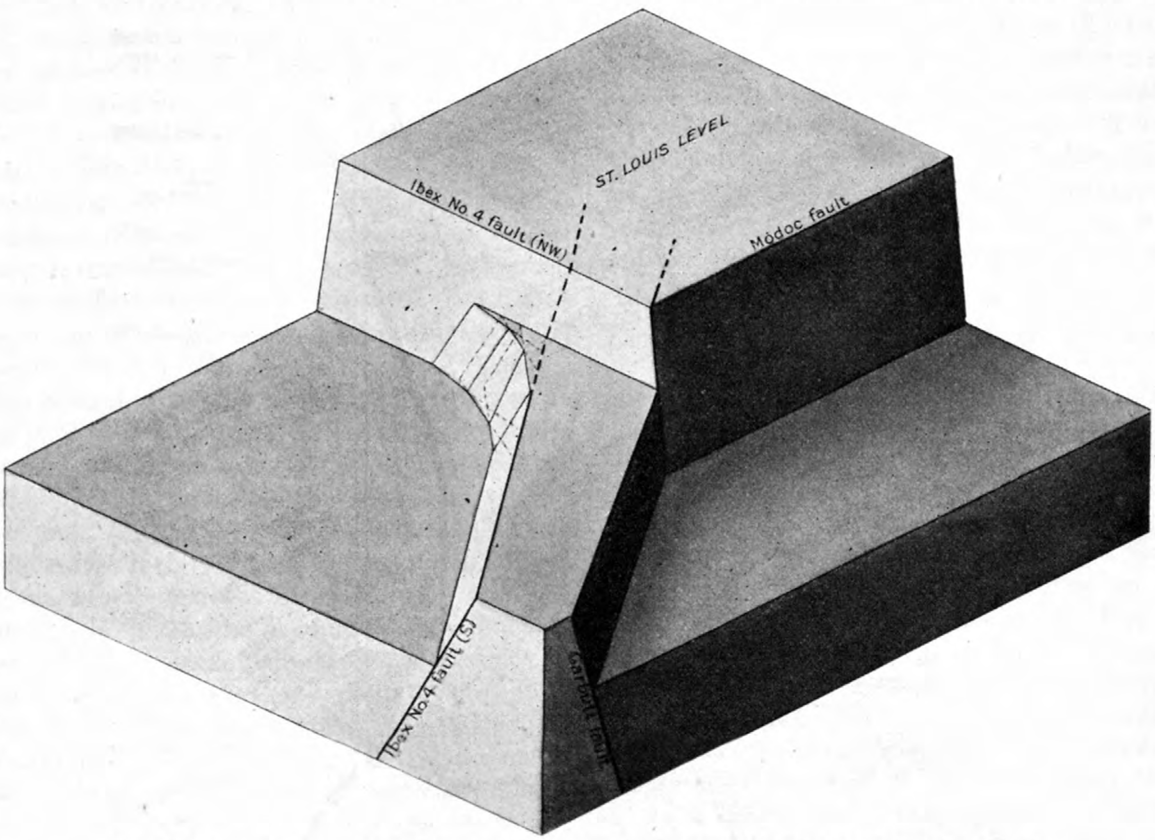


FIGURE 28.—Diagram representing depression of blocks bounded by the Modoc, Garbutt, and Ibex No. 4 faults

The Ibex No. 4 vein occupies another large fault, which apparently curves as suggested on Plates 27 and 57. The fault forms the north and east sides of a second local depressed block and is therefore equivalent to the combined Modoc and Garbutt faults. (See fig. 28.) The displacement is about 600 feet along its northwestern part, near the Weston fault; this is more than that along its southern part, and the difference may be due to a minor fault or group of faults that connect its northwestern part with the Modoc fault. Plate 57 shows many but probably not all of the veins in the Ibex ground. Minor faulting has occurred along several of these veins, and the average slip is probably less than 20 feet, but although considerable time was devoted by Irving to the study of the mine, the data obtained did not suffice to afford a satisfactory interpretation of the structure. Several of these minor faults are steep reverse faults. The principal movement evidently took place along the Modoc, Garbutt, and Ibex No. 4 faults and resulted in the relative depression of two lateral blocks with respect to a central wedge-shaped block; but all three blocks and the ground north of them are completely dissected by minor faults, many of which terminate upward at the

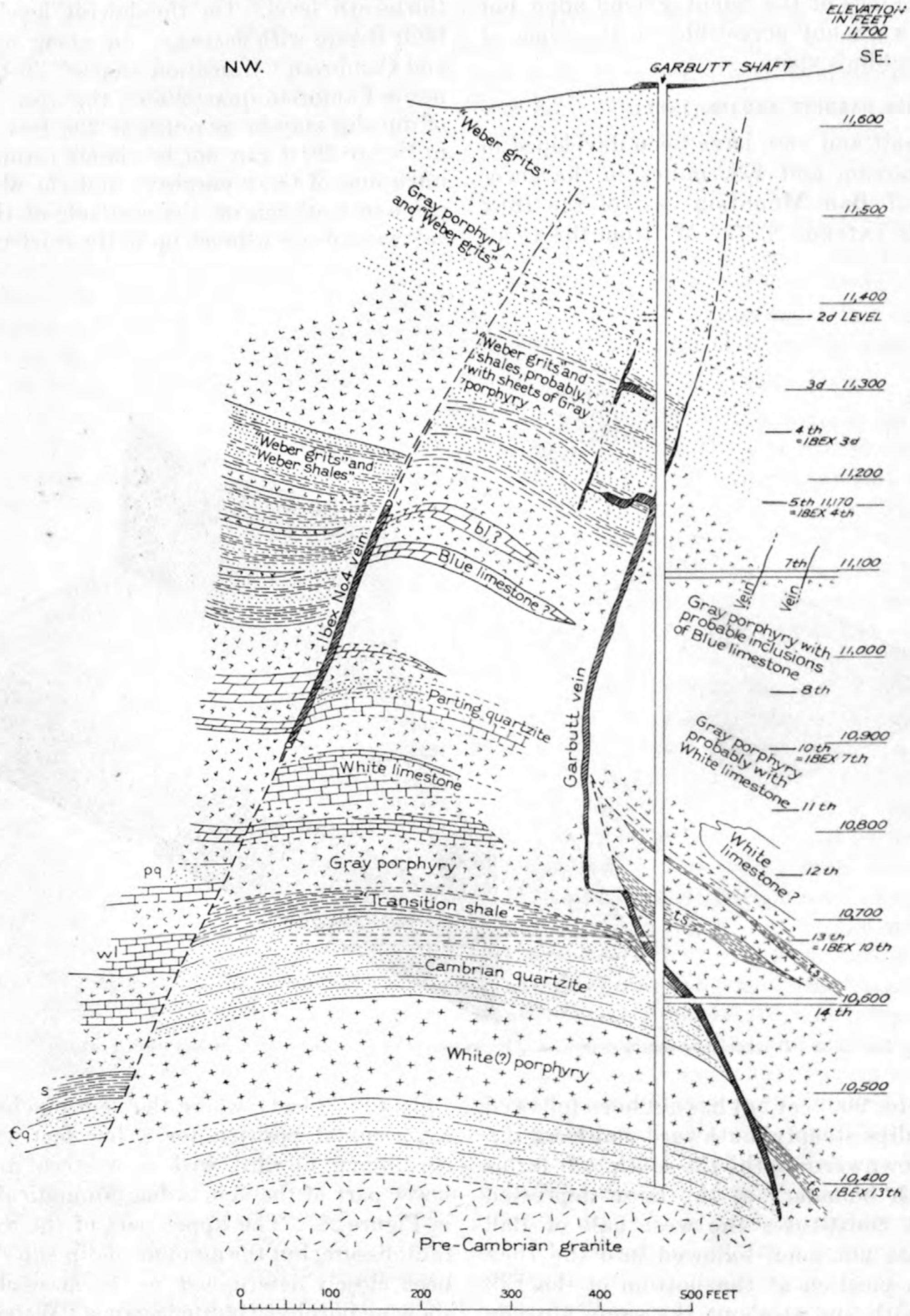


FIGURE 29.—Section N. 70° W. through Garbutt shaft, showing faulting along Garbutt and Ibex No. 4 veins. bl, Blue limestone; pq, Parting quartzite; wl, White limestone; s, "Transition shale"; Єq, Cambrian quartzite

base of the Weber (?) formation or at lower shaly beds. The two small depressed blocks form parts of the great depressed block that extends southward to the Iowa Gulch fault. Although there are many shallow shafts and prospect pits on the surface of this great block they are all in "Weber grits" and Gray porphyry and afford little opportunity to interpret the geologic structure. This is the least understood part of the Leadville district.

BALL MOUNTAIN FAULT

The Ball Mountain fault was originally mapped by Emmons to include the Silent Friend fault, which at that time was not known to be mineralized. In view of the premineral age of the Silent Friend fault and the relatively small and varying amount of displacement along it, it is separately described (pp. 82–83). What is here recognized as the Ball Mountain fault extends southward from the junction of the Modoc and Colorado Prince faults. Between the Modoc fault and the summit of Ball Mountain the Ball Mountain fault splits into two or more members, along each of which there has been considerable displacement, and it is difficult, from surface observations alone, to distinguish these members from the southern part of the Silent Friend fault and the southeastern part of the Colorado Prince fault. (See pl. 57.)

The Ball Mountain fault has not been cut by mine workings and is therefore one of the least-known faults of the district. It forms the east boundary of the great depressed block that underlies the west slope of Ball Mountain, and it must therefore be connected with the Modoc fault, which forms part of the north boundary. As the Modoc fault is of premineral age, the Ball Mountain fault may be also, but no evidence of mineralization along this fault has been reported, and the possibility of postmineral movement along it must be considered. Its classification, like that of the part of the Weston fault that forms the west boundary of the depressed block, must therefore be left in doubt.

The curving course of the fault over the summit of Ball Mountain indicates a strike of S. 25°–30° E. and a dip of 50° W. About 1,500 feet northwest of the summit a dragged block in the fault zone is marked by an outcrop of Blue limestone. The total dip slip in this vicinity is about 2,000 feet, whereas close to the Modoc fault it is nearer 1,000 feet.

Farther south, toward Iowa Gulch, the fault, as mapped by Emmons (pl. 11), curves to a southward course as far as the summit of Long & Derry Hill, where it ends against the Mosquito fault. South of its junction with the Iowa fault its displacement is downward on the east.

OTHER FAULTS

Although other faults and fissures belong to this group, none are well enough known or large enough to be described in any detail here. Plate 57 shows some west of the Weston fault, but the workings there are too small and few to give an accurate idea of their number. It is reported that the Sunday vein, in the southwestern part of Ball Mountain, occupies a fault fissure which trends about S. 20° W., approximately parallel to the Garbutt fault, and is in line with the Union fault, which lies south of Iowa Gulch. The Union fault, however, has been regarded as a postmineral fault, and it is not known whether the mineralized fissures between the Union and Weston faults are accessory to the Weston fault or were formed subsequently. The same question may be raised regarding the mineralized fissures in the London mine, although their positions favor their interpretation as accessory to the London fault. The trend of the long ore shoots in Iron Hill, parallel to the Cord fissure, suggests that other mineralized fissures may be present beneath them; but none of considerable extent have been proved. Other mineralized fractures in the vicinity of the "blanket" ore bodies in limestone in the western part of the district are numerous but can not be definitely correlated with either the group of fissures under consideration or with fissures of earlier origin.

FAULTS FORMED SUBSEQUENT TO ORE DEPOSITION

GENERAL FEATURES

With the exception of the Mike, Weston, and London faults and the northern part of the Mosquito fault, the largest and most conspicuous faults of the region are of postmineral age. As faulting has taken place at different times in the region, a few of these faults may represent renewed movement along old surfaces, but their prominence is due to postmineral movement. Faults of this class in the western part of the district have been more thoroughly explored than any others, and movement along them has been almost wholly along their dips, for the ore bodies have been only slightly offset by them along their strike. For the most part they strike east of north and dip west. With the exception of the northern part of the Mikado fault, those having markedly different strikes or dips are auxiliary faults, though a few of them are of considerable size and are due to differential uplift of interfault blocks. Every fault of considerable size is really a fault zone characterized by parallel slips and crushed material, and in the Downtown and Iron Hill areas major and minor faults are so intimately connected that they form groups, which are known as the Pendery and Iron-Mikado groups. These groups may be regarded as fault zones of unusual width.

Movement along the postmineral faults has taken place at intervals until the present time. The principal movement occurred during the main uplift of the Mosquito Range, in mid-Tertiary time. Minor subsequent movement is indicated by faulting of rhyolitic agglomerate, "lake beds," oxidized ore, "wash," and mine workings. The evidence in the agglomerate bodies is least convincing. These bodies are younger than the ore bodies and fill certain fault fissures in the eastern part of the area. Most of these faults, however, were formed prior to ore deposition and may have been reopened and filled with agglomerate before the main period of postmineral faulting. The faulting of the agglomerate, therefore, may have either preceded, coincided with, or followed the main postmineral movement. In the Miner Boy tunnel, on the north slope of Breece Hill, a dike of agglomerate filling the fissure of the Colorado Prince reverse fault has been offset by a minor auxiliary cross fault as a result of renewed movement along the main fault. The agglomerate itself is sheeted, and a selvage has been developed between it and walls of the main fault. This renewed movement may have taken place at any time since the formation of the reverse faults.

Faulting since the deposition of the "lake beds" is either proved or strongly suggested at a number of places in the Downtown area and also at Graham Park. In the Revenue shaft the "lake beds" are clearly faulted. In the Hibschle mine Emmons found the "lake beds" ending abruptly against a fault surface to which fault breccia was clinging. He described more convincing evidence in the Elk and Walcott mines as follows:[18]

A drift across the Pendery fault, run westward from the Elk shaft at about 220 feet below the surface, has furnished data with regard to that fault that have so important a general bearing that they will be given in some detail. Toward the fault the Gray porphyry has been scored off, and the limestone and ore lie immediately beneath the wash. The drift on crossing the fault passes through limestone into brown clayey lake-bed material, which shows some sheeting parallel to the fault plane. Against the limestone, which forms the east wall, standing at an angle of 62°, there still rests a thin clay seam, in places black; at others a White porphyry clay containing fragments of chert, of such a nature that it could not have stood against an original cliff. It is thus proved that there must have been movement on the plane of this fault since the lake-bed material to the west of it was deposited. Further evidence is offered by the record of a drill hole, sunk from the same drift 160 feet west of the fault, which went through 78 feet of lake-bed material before reaching White porphyry in its normal position above the Blue limestone. On the east side of the fault there is 30 to 50 feet of rock above this drift before the wash is reached, so that we have a sudden deepening of the rock surface to the west of the fault of over 100 feet, much, if not all, of which difference in level may be attributed to movement on the fault plane since the lake beds were deposited. * * *

As shown in section IV [pl. 18], the [Walcott] No. 2 shaft was sunk in wash and lake beds just west of the fault, and the pronounced difference of level between the rock surface on either side of the fault affords additional evidence of movement on the fault plane since the deposition of the lake beds, though as the depth of this surface west of the fault has not been determined, its actual amount remains uncertain.

At several places along the Pendery fault group and at one each along the Mikado and Dome faults the abrupt change in altitude of the bedrock surface on opposite sides of a fault strongly indicates faulting. Mine workings so rarely enter the "lake beds" that it can not be definitely determined whether this faulting took place prior or subsequent to the deposition of the "lake beds," but in the light of the evidence just cited at least part of the faulting is believed to have been subsequent, as shown in the sections on Plate 18. Similar conditions are suggested in section A-A′, Plate 20. If this isolated deposit of "lake beds" at Graham Park was once continuous with the main deposit to the west considerable faulting accompanied by tilting of the local fault block must have taken place since their deposition.

The rock surface on opposite sides of the Dome fault has been disclosed in the Reindeer mine and also in the westward workings from the Dome mine, as shown in Figure 33. A distinct escarpment, represented by an uplifting of the eastern wall of the Dome fault, was here definitely determined. No information was available, however, as to the relative thickness of the "lake beds" and the overlying and more recent glacial moraine, so that the amount of movement can not be definitely determined at this point. If evidence from the nearest adjoining shafts is considered, it seems that the faulting that has occurred subsequent to the deposition of the "lake beds" aggregates about 200 feet.

No striking illustrations of faulted oxidized ore can be cited by the writers, but it is reported that zinc carbonate ores have been brecciated in the vicinity of faults. The "wash," the latest of the superficial deposits, shows an abrupt upturn on the east side of the Niles fault, which is attributed to slight renewed faulting in recent time. More recent still is the slight displacement that has occurred in the California tunnel noted by Emmons[19] whereby the timbering along the first 585 feet of the tunnel on the west side of the Pendery fault has been tilted 5° westward from its original vertical position.

The better-known postmineral faults are described in order from west to east. Others, like the "hypothetical" fault which is indicated by drill data near the west edge of the Leadville district, and the Louise fault, which is exposed only in the Louise mine beneath South Evans Gulch, are indicated on the geologic maps but do not require separate descriptions. The maps also show connections so intimate among faults in the Downtown area and also in the Iron Hill area that these faults are best described in groups.

CLOUD CITY AND VALENTINE FAULTS

The Cloud City fault, the westernmost fault of which there is any definite knowledge in the Leadville district, is a minor displacement lying about 1,800 feet west of the main Pendery fault. It dips 65°–75° W.

[18] U. S. Geol. Survey Bull. 320, pp. 40, 41, 1907.

[19] U. S. Geol. Survey Mon. 12, p. 413, 1886.

The fault is developed in the Bohn, Cloud City, Sixth Street, and Coronado mines. It trends northeastward from the Cloud City as far as the Coronado shaft, where it splits into a number of branches, each of which dies out within a short distance. Southward from the Cloud City mine it heads nearly due south and dies out before passing completely across the Bohn workings.

Another fault has been discovered in the workings of the Valentine mine. This fault lies in line with the Cloud City fault, and although the two are not connected by any recognizable displacement, it is probable that they lie along the same general line of rupture. The dip slip where measurable on the Cloud City fault ranges from 70 to 165 feet.

PENDERY FAULT GROUP

The Pendery fault group lies along the east boundary of the city of Leadville and extends northward and southward beyond the limits of the Leadville district, being known for a distance of 4 miles. It has a general N. 20° E. trend and appears to consist of a single fault at the north and also at the south boundary of the area but splits into several faults in the Downtown district. The fracture of greatest length and throw is the Pendery fault itself. Its throw is 400 to 850 feet in the northern part of the area. In the central part the throw along the Pendery fault is only 200 feet but the aggregate throw of the whole group is 900 feet. In the southern part the throw on the Pendery fault alone increases to 1,200 and perhaps to 2,000 feet (pl. 15, section G–G′). This fault is normal throughout and dips 50°–75° W. Toward the middle of its course the Pendery fault and its associated minor faults have been extensively explored, and the aggregate displacement along them is shown in Plate 41. Movements along the faults have been mostly along the dip; the strike slip indicated by offset ore bodies, is very small. The blocks between faults, however, are considerably distorted, although the most conspicuous distortion is a monoclinal fold that lies about where a down-faulted continuation of the Tucson-Maid reverse fault would be expected. Other distortions are attributed to differential uplift along the Pendery fault group, and the more pronounced of them may prove on further exploration to be associated with transverse auxiliary faults. The curvature of the faults themselves suggests the further adjustment of the interfault blocks along bedding faults which can not be represented in Plate 41. As nothing strikingly different from the data obtained by Emmons up to 1907 has been found along these faults, his descriptions in the Downtown bulletin with minor changes are given below.[20]

[20] U. S. Geol. Survey Bull. 320, pp. 27–28, 1907.

PENDERY FAULT

The Pendery fault is one of the great faults of the region. Its throw at each end, where it is a single fault, is 1,000 to 1,200 feet, which is probably a maximum. Between the Can and Walcott No. 2 shafts the throw indicated on the Pendery fault is variable, because its movement is distributed on a number of minor fault planes. The number of these minor faults is greatest in the vicinity of the parallel 39° 16′, where, as may be observed, the outcrop of the Pendery fault has a marked reentering curve to the west.

In such a reentering curve on the Iron fault the throw is also found to be distributed on a number of minor fault planes or step faults. Both of these reentering curves are at or near the intersections of the Pendery and Iron faults with the Tucson-Maid reverse fault.

CARBONATE FAULT

The Carbonate fault may be considered as one of the minor faults of the Pendery group. Between the Carbonate and Aetna mines it has a throw of 250 to 300 feet, but the amount of throw decreases toward the north to such an extent that it can not be traced continuously. What is assumed to be its continuation was found at about 175 feet west of the Harker shaft, where its movement is reversed, its downthrow being eastward and displacement not over 50 feet. Beyond that it has not been proved, and it may not extend much farther as a continuous plane of movement, though other small faults are known to exist in the Stray Horse Gulch depression. To the south it is represented as connecting with the Pendery fault by a sharp bend westward. The existence of this bend has not been proved, but is assumed as the most probable solution of the facts observed in the adjoining mines. It is possible that the fault continues more directly south and gradually dies out. Faults of small throw are more likely to have a small longitudinal extent, and it is probable that there are other faults of small throw in the region to the south on which such movement has been distributed. One such fault with a throw of about 150 feet has been cut just east of the Toledo Avenue shaft, in California Gulch, which can not be surely connected with any other, though it is probably the same one struck by the Revenue shaft beneath the mesa south of California Gulch. Small faults of less than 100 feet throw were found also in the Modoc and Thespian ground, under the top of Carbonate Hill.

In the Star Consolidated mine, southwest of the Evening Star No. 5 shaft, a west crosscut on the 10,320-foot level in Gray porphyry has penetrated a broad zone of shattered rock where the junction of the Carbonate and Wildcat fault is calculated to be. This and other structural evidence in the vicinity verifies section V, Plate 18.

NILES FAULT

The Niles fault, so named because it was best shown in a drift from the Niles shaft, is intermediate between the Carbonate and Pendery faults. Toward the north it was cut in the Buckeye Belle and Jolly workings, but it has not been proved farther north, where it probably passes into a slight fold. Its supposed continuation southward passes into the St. Mary, Washburn, and upper Weldon ground. That it connects with the Pendery fault, as indicated on the map, is not proved.

WILDCAT FAULTS

Curving faults in the Wildcat ground indicated on the map as connecting the Carbonate, Niles, and Pendery faults, have not been determined by observation, as they are in ground which was inaccessible at the time of visit. They are given as the most probable explanation of the relative position of the different formations as deduced from oral information.

BISON FAULT

The Bison fault, indicated on the map, is shown only in the workings of the Bison mine. Its indicated connection at each end with the Pendery fault is assumed, not observed. It has a normal westerly dip and is cut by the shaft and also by the drifts of the mine to the west of the shaft. There is another fault shown by these workings that has a reverse or easterly dip, so that the wedge-shaped block of ground included between this and the Pendery fault has dropped instead of being uplifted. It is indicated as a cross fault between the Bison and Pendery faults. All the complications of structure disclosed by the workings of the Bison mine could not be indicated on the present scale of drawing (pl. 18, section V), nor were the workings themselves sufficiently extensive at the time of visit to admit of their being fully worked out and explained.

WELDON FAULT

The Weldon fault, so named because its movement apparently reaches a maximum in the Weldon mine, is of a rather common type and may be called a monoclinal fold fault, as it belongs to a class of faults that usually pass into a monoclinal fold at each end. They are generally of small throw—in the Weldon not over 100 feet—and stand at rather steeper angles than the other normal faults; hence if they extend far enough in depth they will probably join the main fault as is shown in section X (pl. 18). This is, however, a theoretical deduction not proved by observation, and it is possible that their vertical extent is as slight as the horizontal has proved to be; hence, in the sections, many of these faults have not been represented as continuing up to the rock surface. South of the Weldon mine the Weldon fault has been observed in the Midland and P. O. S. ground with very much diminished throw. Farther north it was seen in the Pendery, Gray Eagle, and Bison areas, but whether it extends to a connection with the Pendery fault in the Midas ground was not determined. Other fold faults of comparatively small extent have been observed which are not indicated on the surface map, and some of these do not cross the plane of the section. In these the throw is but slight and the fold is not traceable for any considerable longitudinal extent.

TOLEDO FAULT

The extent and magnitude of the Toledo fault are not definitely known. It lies on the southwest slope of Carbonate Hill within the fault block between the Pendery and Iron fault zones. It was discovered in the Toledo Avenue shaft and is also found in the Modest Girl shaft. By detailed study on the surface beds and in prospects this fault has been traced southward from the Toledo Avenue shaft across the bed of California Gulch and in a direction slightly west of the Revenue No. 1 shaft, until it becomes concealed beneath "wash" and "lake beds." It may also extend farther northeast than it has been mapped, but it can not be traced in the area of White porphyry on Carbonate Hill. Its strike is directly toward the Wolftone mine. Certain slight displacements that exist in that mine may indicate a continuation of this fault. It is distinctly a minor fault, but its parallelism to the neighboring part of the Pendery fault, which trends about N. 25° E., appears to indicate that it was formed at the same time as the major faults.

IRON-MIKADO GROUP

The Dome, Iron, and Mikado faults are separated from the Pendery group on the west and the Mike fault on the east by broad areas in which only minor faults are present. They lie so close together through most of their course that they may properly be considered members of a zone of great displacement, which as a whole has a nearly north-south direction. In detail, however, their trends alternate from north-northeast to north-northwest, the two dominant directions of faulting in the district.

At the south edge of the Leadville district the Dome and Iron faults are connected by the Emmet, an oblique cross fault; at the north end of the zone the Mikado and Iron faults diverge widely from each other. As these faults are of steep dip the irregularity of their course along the bedrock surface is due only in slight measure to the topographic relief and to the extremely warped surfaces along which the faulting has taken place. The names Iron fault and Dome fault were applied in the Leadville monograph and are therefore retained with their original meaning. The Mikado fault has been discovered since that time by extensive underground exploration. There is some question as to whether the Dome fault is in reality a separate fault. It might as justly have been considered the southward extension of the Iron fault as the portion so indicated. The principal transverse auxiliary faults are the Adelaide, Ulster, Newton. Moyer, and Goodell.

IRON FAULT

The Iron fault is about 3.2 miles long. It apparently dies out at both ends, although it serves as a terminus for several other faults. The geologic structure north of Evans Gulch, which is not thoroughly known (pl. 14, section A–A′ prime), suggests that the Iron fault may terminate northward against the Weston fault, but the displacement along both faults diminishes northward, and a dying out of both is equally probable. On the south also its termination is unknown, as it passes beneath a heavy capping of "wash" and "lake beds" that cover the west slope of Dome Hill. Along its course through the Leadville district it is more extensively explored than any other fault in the region, so that its important features can be described with correspondingly great accuracy. It can not be detected at the surface, as it is everywhere covered by a deep mantle of "wash" and "lake beds."

The southernmost indication of the fault is the discrepancy in the altitude of the formations cut in the Coon Valley and Bessie Wilgus shafts. Similar evidence is given by the Columbia No. 2 and Keno shafts, 1,000 feet to the north. From the south edge of the Leadville district the fault runs nearly due north to California Gulch and then swings to the northeast. It is probably complicated beneath California Gulch by many additional cross and parallel faults which are not sufficiently explored to be mapped. Continuing northward, it is cut by the Yak tunnel and by the maze of underground workings which lie beneath the west slope of Iron Hill (sections A–A′ to D–D′, pl. 23; E-E′, pl. 24). Beyond the north Iron incline it is not cut in any but the Codfish Balls shaft, but its position is clearly indicated by the few isolated deep shafts and by other shallower pits that disclose the discrepancies in position of the several formations. From the Cumberland shaft northward for 1,500 feet the fault has been penetrated by shafts, drifts, and diamond-drill holes and even followed by inclined shafts, so that its features are known with great exactness to depths of more than 900 feet. At 1,600 feet north of the Mikado mine it is cut in the Fairplay and Hard Cash shafts, but thence northward it is cut only by the Pawnolos shaft, though its approximate position is shown by discrepancies in the formations cut in the many shafts on the north slope of Yankee Hill. The Pawnolos shaft, on the north side of Evans Gulch, is believed to have cut the fault when it passed through 16 feet of crushed material. Beyond this point the bedrock is deeply buried beneath glacial deposits, and little is known of the structure.

The fault dips to the west, but owing to the irregular curvature of the fault fissure its altitude varies from point to point, as shown in Figure 30. At the south edge of the Leadville district the dip is approximately 60°, in the Yak tunnel 61° 45′, in the McKeon mine 50°, and in the R. A. M. 62°; it probably averages about 60°. In the middle portion of Iron Hill, where the fault makes a sharp embayment toward the east, the angle of dip becomes less toward the surface. Minor curvatures on the dip are shown in sections on Plates 14–18 and 23–26.

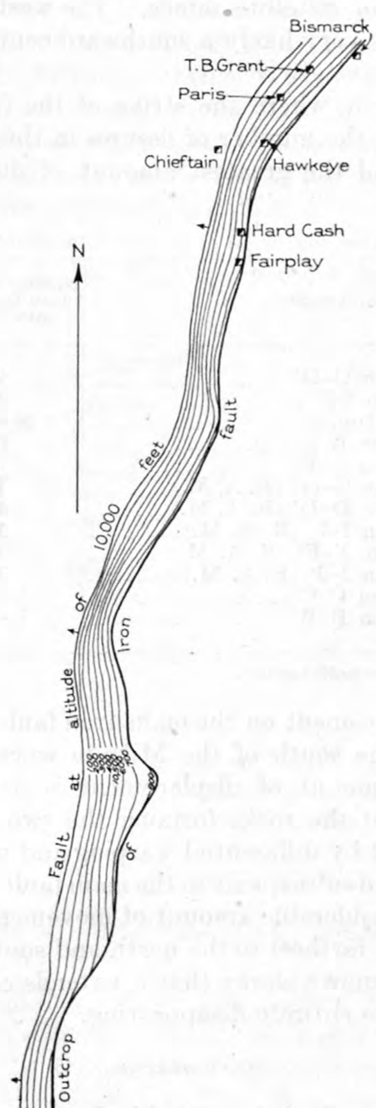


FIGURE 30.—Diagram showing outcrop of Iron fault and its intersection with a horizontal plane at an altitude of 10,000 feet

The displacement along the southwestern part of Iron Hill, where the fault is most irregular and is well explored, is distributed on several fissures. In the Yak tunnel there are eight or more, but any additional fissures east of those recognized are exposed only within the White porphyry, where the displacement can not be measured. These faults cut off the angular block of ground on the north side of the junction of the Iron and Dome faults. The sharp eastward reentrant curve of the main fault, close by its intersection with the Tucson-Maid reverse fault on the west slope of Iron Hill, has been exposed in detail by mine workings, and at least seven auxiliary faults have been found (pl. 24, section E–E′). These faults are parallel, with westward dip, and drop the strata westward in a series of steps, but the interfault blocks are much distorted. In plan the minor faults appear to end against the reentrant curve of the main fault, but their exact limits are not definitely known. They are well exposed in the workings of the McKeon, Star of the West, and Satellite mines. The westernmost of these faults is very likely a southward continuation of the Mikado fault.

To the north, where the strike of the Iron fault is more regular, the number of fissures in this fault zone decreases, and the greatest amount of displacement is found along the Mikado fault, which branches westward from the Iron fault.

The amount of strike slip can not be accurately measured, but it is not great, as shown by the offset parts of the North Iron ore shoot represented in Plates 22 and 45. The shoot is a little farther north on the west side of each fault than it is on the east side. As the strike of the shoot makes an angle of 48° with that of the fault zone, these successive horizontal offsets are almost wholly due to direct downward movement along the dip of the fault. A calculation as careful as the irregular form of the shoot permits indicates a slight northward strike slip on the west side of each fault. The amount of dip slip is recorded in the accompanying table.

Dip slip along Iron fault zone

Locality	Number of fault fissures	Dip slip (east to west) on separate faults (feet)	Aggregate dip slip (feet)
Plate 15, section G–G′	1		360
Plate 15, section F–F′	4	40, 40, 40, 160	280
Plate 26, Yak tunnel	8+	115, 17, 20, 15, 45, 12, 11, 82	1,055
Plate 23, section B–B′	5	8, 480, 32, 36, 28	584
Plate 24, section E–E′	7	20, 170, 100, 170, 40, 80, 325	905
Plate 21, section G–G′ (R. A. M.)	1	No minor faults	[a]1,460
Plate 20, section D–D′ (R. A. M.)	1	do	[a]1,530
Plate 21, section I–I′ (R. A. M.)	1	Mikado fault takes most of the displacement	600
Plate 21, section F–F′ (R. A. M.)	1	do	600
Plate 21, section J–J′ (R. A. M.)	1	do	600
Plate 14, section C–C′	1+	No minor faults known	660
Plate 14, section B–B′	1+	do	440

[a] Mikado and Iron faults together.

The displacement on the main Iron fault is greatest slightly to the south of the Mikado workings. The change in amount of displacement is irregular and indicates that the rocks forming the two walls have been affected by differential warping and minor faulting during and subsequent to the main fault movement. The very considerable amount of movement indicated at the points farthest to the north and south at which the fault is known shows that it extends considerably farther before entirely disappearing.

MIKADO FAULT

The Mikado fault is traceable for 1.8 miles within the Leadville district and extends beyond Canterbury Hill to the north. It is everywhere deeply buried beneath a heavy mantle of "lake beds," moraine, and "wash" and was therefore not discovered and correctly correlated until it was reached by the extensive exploration in North Iron, East Fryer, and Yankee hills. When discovered under East Fryer Hill it was at first supposed to be a continuation of the Iron fault, and it is still so indicated on some of the mine maps.

From its southern extremity, where it branches from the Iron fault on the slope of Iron Hill, its trend averages N. 16° E. for 2,300 feet. About midway in this portion of the fault is a sharp reentrant curve where the fault crosses Stray Horse Gulch. This curve is too marked to be wholly due to the westward dip of the fault; it is due mainly to variations in strike, which were found in the Allegheny, Shenango, and Highland Mary mines. Farther on the fault bends in a broad curve toward the north and northwest and has an average direction of N. 13° W. for a distance of 6,400 feet, to the north limit of the Leadville district.

The southernmost exposure of the fault is in the Cumberland shaft, which at a depth of 760 feet passes from the overlying White porphyry, which had been moved downward on the west, into the pre-Cambrian granite (section G–G′, pl. 21). It is next found in the west drift from the Devlin shaft, driven at the 300-foot level (section E–E′, pl. 20). This drift is reported to cut the Iron fault 58 feet west of the shaft and then to pass through a small quantity of ore-bearing "contact material" into the overlying porphyry and continue to the Mikado fault, along which a short winze is sunk.

Below the level of the west workings from the Devlin shaft the fault has been explored in the workings of the R. A. M. mine (pl. 20, section E–E′). From this point northward the fault has been extensively explored in the R. A. M., Mikado, Highland Mary, and Shenango mines, not only along the strike but for fully 1,700 feet downward along the dip, as shown in sections A–A′ and E–E′, Plate 20, and sections F–F′, I–I, and J–J′, Plate 21, from the workings of the Shenango northward for a distance of 850 feet the fault is indicated only by the depth of the contact between White porphyry and Blue limestone in the workings of the Raven, Right Angle, and McCormick mines. It is next found in the Allegheny Discovery shaft, which cuts one of the parallel slips just west of the main fault zone at a depth of 300 feet.

The fault has been cut in the workings of the Scooper No. 1 shaft, which passes through it at a depth of about 125 feet. It is next found between the workings of the El Paso and Chieftain tunnels (fig. 31.) The lower workings from the El Paso shaft cut the westernmost fissure of the Mikado fault zone somewhere between 50 and 100 feet east of the shaft. The rocks in this vicinity are dragged up abruptly toward

The extensive exploration along the Mikado fault in the mines above noted has disclosed very fully the remarkably irregular curvature of the fissure along which the movement took place. The dip varies as markedly as the strike, as shown in sections on Plates 20 and 21, especially section B–B′, which intersects the fault almost along its strike. The dip of the fault ranges from 43° to 67° W. and averages about 60°. The dip slip also varies irregularly. It is at a maximum in the workings of the R. A. M. mine (section E–E′, pl. 20), where it is 950 feet downward on the west. In the Mikado workings it is 830 feet. In the Scooper it has decreased to 480 feet. It increases in the Kennebec-Jamie Lee area to 850 feet and decreases in the Fitzhugh mine to 595 feet. Beyond this point it has not been closely determined.

The direction and amount of strike slip in the Mikado and R. A. M. workings can not be absolutely

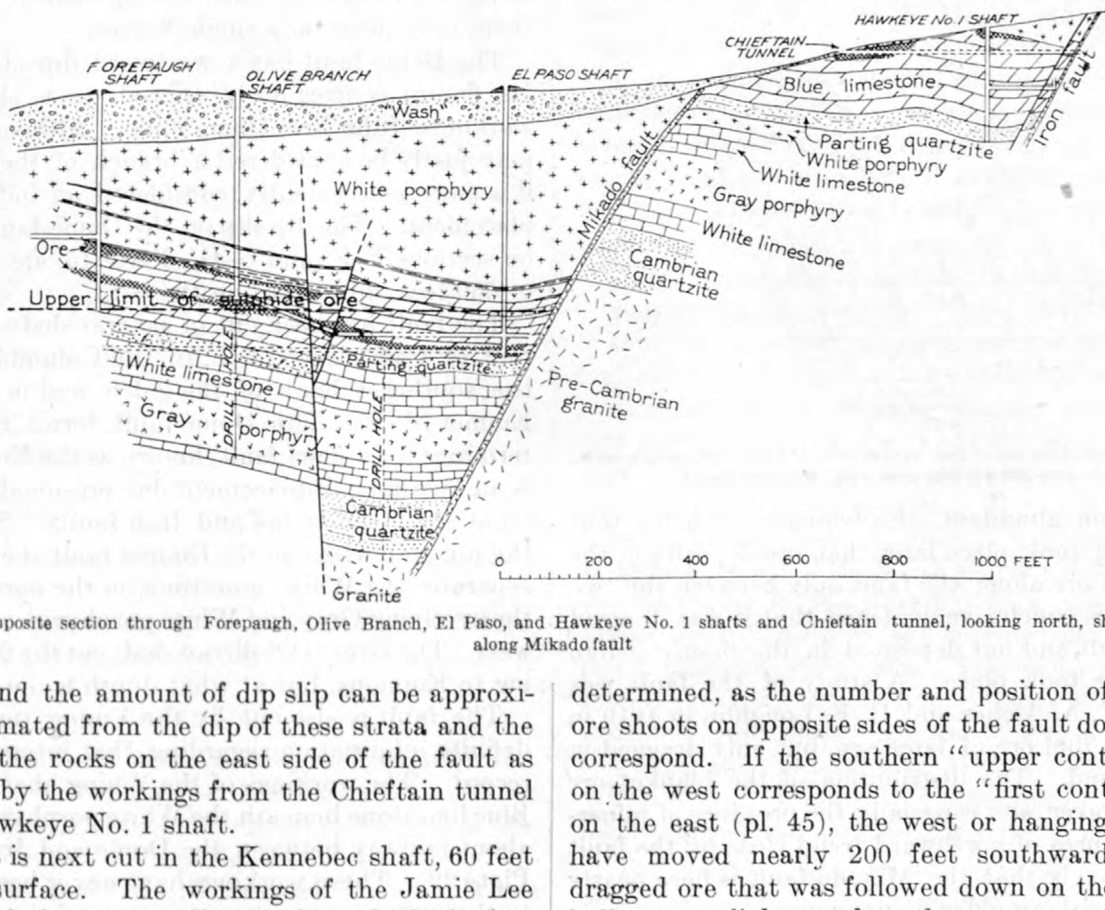


FIGURE 31.—Composite section through Forepaugh, Olive Branch, El Paso, and Hawkeye No. 1 shafts and Chieftain tunnel, looking north, showing structure along Mikado fault

the fault, and the amount of dip slip can be approximately estimated from the dip of these strata and the position of the rocks on the east side of the fault as determined by the workings from the Chieftain tunnel and the Hawkeye No. 1 shaft.

The fault is next cut in the Kennebec shaft, 60 feet below the surface. The workings of the Jamie Lee and Cullen shafts indicate the depth at which the formations are disclosed on the west side of the fault. Northward for a distance of 400 feet the fault had been explored in the workings of the Fitzhugh mine, which pass through the higher members of the sedimentary series, on the west, into the pre-Cambrian granite, on the east. It is cut here on the 300-foot level 45 feet east of the shaft and on the 500-foot level 60 feet west of the shaft. It crosses the Fitzhugh shaft at a depth of 400 feet.

determined, as the number and position of developed ore shoots on opposite sides of the fault do not closely correspond. If the southern "upper contact" shoot on the west corresponds to the "first contact" shoot on the east (pl. 45), the west or hanging wall must have moved nearly 200 feet southward; but the dragged ore that was followed down on the fault zone indicates a slight northward movement and a correlation with the northern shoot on the west side of the fault. This slight northward movement agrees with that along the Iron fault, of which the Mikado fault may be regarded as the northern continuation.

The fault throughout its course is accompanied by fewer parallel auxiliary faults than the other widely explored major faults. One such fracture is developed in the R. A. M. mine and is known as the R. A. M. fault. It has a southwestward trend and diverges from the main fault at a point somewhere near the New Mikado shaft. It has a displacement of about 70 feet downward on the west side. Other parallel surfaces are shown in the El Paso shaft, and probably there are others along those portions of the fault that have not afforded opportunity for detailed examination.

Along its passage through the Graham Park area the Mikado fault shows on both sides a pronounced drag. A large quantity of sulphide ore was mined in the fault zone in the New Mikado or Young America ground. This occurrence is illustrated in Figure 32 and section J–J′, Plate 21. From section J–J′ it will be seen that this ore forms a connection along the fault between the ore bodies found at several horizons in the workings of the Old Mikado shaft on the upthrown side of the fault and the ore bodies at similar horizons in the R. A. M. mine on the downthrown side. It does not, however, extend above or below these limits.

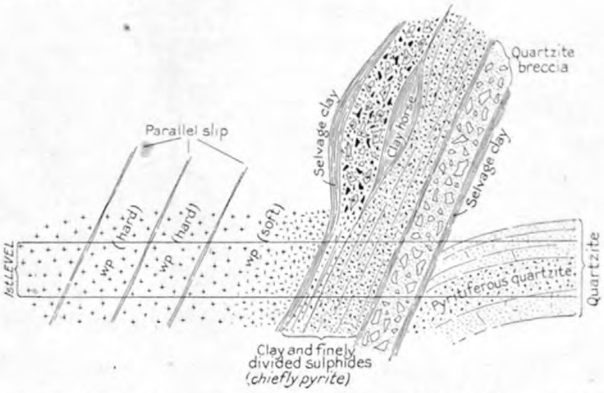


FIGURE 32.—Sketch of portion of first level of New Mikado shaft, looking north, showing Mikado fault zone. wp, White porphyry

Aside from abundant corroborative evidence that the faulting took place later than ore deposition, the existence of ore along the fault only between the two ore masses is conclusive evidence that it was dragged into the fault and not deposited in the fissure before the faulting took place. A study of the fault was made by F. A. Aicher and G. F. Loughlin in 1919 in an effort to find ore of later age, but only dragged-in ore was found. The distribution of the blanket ore bodies, however, and especially the presence of mineralized fractures of northward trend close by the fault suggest strongly that the Mikado fault is here nearly coincident with an older fissure zone.

The fault zone where exposed ranges from 10 to 50 feet and averages 20 feet in width. It consists of selvage clay, broken rock, and granulated ore in varying proportion. Tough blue clay or "bull hide," which owes its color largely to pulverized pyrite, is the most prominent. The broken rock, which grades from solid pieces to loose gritty and clayey material, consists largely of White altered granite and porphyry. The sulphide ore, principally pyrite, is in part disseminated through the other material and in part forms lenses with their longer axes in the direction of slip. These lenses consist of loose granular material inclosing angular fragments of solid sulphide ore.

DOME FAULT

The Dome fault extends from its junction with the Iron fault in the bed of California Gulch southeastward for a distance of 1,200 feet, then bends to a trend of S. 14° E. Its direction and extent south of the Leadville district are not positively known, but it is represented by Emmons (see pl. 11) as extending 4,000 feet farther to the south and there disappearing beneath glacial deposits. In the Leadville monograph what is now called the Dome fault was described as two faults, the Eagle and the Dome fault. There seems to be no good reason for regarding these as separate displacements; on the contrary, there appears to be every evidence that the movement ascribed to them took place on a single fissure.

The Dome fault has a westward dip of about 68°. Its fissure is irregularly curved, as is shown in the workings of the New Dome mine. Although the fault may justly be considered a branch of the Iron fault, it is more conveniently considered an individual displacement. The dip slip on the Dome fault, as shown on sections F–F′ and G–G′, Plate 15, amounts to 500 or 550 feet, downward on the west.

The fault has been cut in several shafts in the bottom of California Gulch, in the Columbia tunnel in the southeast bank of the gulch, and in the Robert Emmet shaft. The Dome fault forms the northern terminus for a short fault, known as the Emmet, which is an auxiliary displacement due presumably to movement along the Dome and Iron faults. Southeast of the junction with the the Emmet fault the Dome fault separates the White limestone on the northeast from the overlying Gray and White porphyries on the southwest. The Great O'Sullivan shaft cut the fault, according to Emmons, but at what depth is not known.

The fault is also cut by the Vining tunnel, but no definite information regarding that intersection is on record. The workings of the Vining shaft within the Blue limestone beneath the White porphyry are shown about midway between the Dome and Iron faults on Plate 22. These workings have never been accessible to the writers, nor are any records of them available. Mr. Warren F. Page, however, states that the Dome fault was cut in the bottom of the Vining shaft and that it showed at this point a displacement of 600 feet.

The next points that show the position and character of the Dome fault occur in three mines, the New Dome, Sequin, and Reindeer. In Figure 33 the passage of the fault through the workings of the Dome mine is shown. The fault is likewise cut by a drift on the second level 275 feet east of the shaft. It appears again at the eighth and ninth levels of the Reindeer shaft, where the brecciated material is 25 or 30 feet thick.

The west workings of the New Dome mine, notably the first and second levels, pass from White limestone into the fault breccia. There the White limestone forms a scarp 150 feet high, concealed by "lake beds" and "wash." The evidence here, though obscure, suggests that this scarp is due to movement along the fault subsequent to the deposition of the "lake beds." (See fig. 33.)

Although only a single surface of displacement has been shown in the Dome fault the different positions of the strata in the bottom of the Reindeer shaft on such sections as are available show that part of the

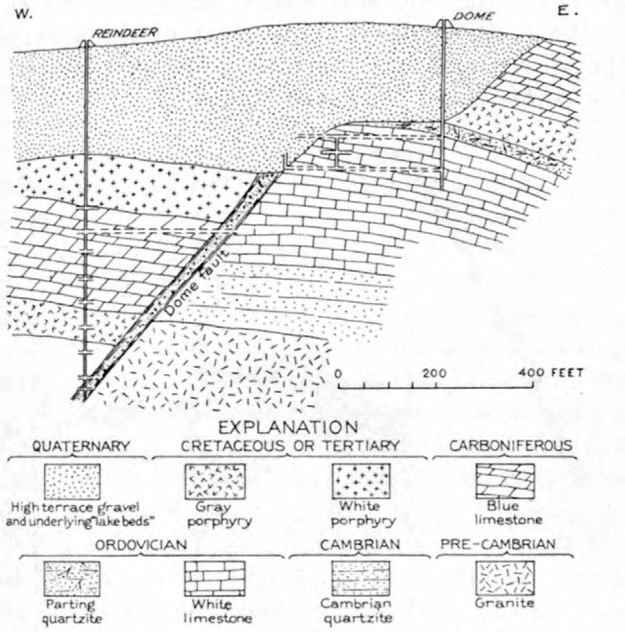


FIGURE 33.—Section through Reindeer and Dome shafts, showing exposure of the Dome fault

movement occurred on one or more auxiliary fissures which can not be delineated for lack of detailed information.

EMMET FAULT

The Emmet fault accounts for the presence of a large block of Blue limestone immediately adjacent to the porphyries between the Iron and Dome faults. No new evidence has been disclosed in regard to this fault since Emmons[21] wrote the description of it which follows:

> The Robert Emmet tunnel starts in near the contact of Gray porphyry and overlying White porphyry. A winze was sunk in the tunnel, from which a drift to the west has cut the Emmet fault, a short cross fault, by whose movement a little triangular block of ground is lifted up on the westward. Parallel with this fault is a slight anticlinal fold, along the axis of which the Columbia tunnel runs in on the contact and finds the formation dipping away to the right and left, but more steeply to the westward. The Blue limestone is found in actual rock outcrop on the bank of the gulch below this. The Crescentia shaft, a little west of the Columbia, has reached the Gray porphyry under the White porphyry at a depth of 335 feet. It is probable that this body of Gray porphyry thins out to the west of this.
>
> As to the exact line of the continuation of the Iron fault on the south side of the Gulch, if it extends so far, no data have yet been obtained, nor can it be definitely stated whether the Crescentia shaft is to the east or to the west of this line. The dip of the formation west of the Columbia tunnel is steep enough to account for the contact not yet having been reached in this shaft at a depth of 335 feet.

[21] U. S. Geol. Survey Mon. 12, p. 250, 1886.

ADELAIDE FAULT

The Adelaide fault extends along the east and north sides of Iron Hill for 1.1 miles. For the major portion of its course it has a strike of approximately N. 20° W., but it curves westward in its northern part and strikes about N. 75° W. where it joins the Iron fault. Its dip where exposed is 69°–81° W., and its slip is downward on the west. It has been extensively explored in the workings of the Moyer and North Moyer mines but it is not known by observation at its northwestern extremity. At its southern extremity, as mapped, there is a great thickness of White porphyry beneath which the sedimentary formations are deeply buried and have been little if at all explored. Its extent in that direction is therefore indefinite and may be much greater than is indicated. Its southernmost exposure is beneath California Gulch in the most southerly workings from the old Moyer shaft. The rocks in this portion of the mine are so broken by auxiliary faulting that the exact amount of displacement on this fault is difficult to determine with any accuracy. Farther north, at a point about 350 feet south of the Yak tunnel, it has been extensively explored in stopes and workings of the Moyer mine. It is cut in the Yak tunnel and has been extensively explored in all the easterly workings of the North Moyer mine. Throughout its course in the workings from the two Moyer shafts the fault has a dip slip ranging from 45 to 90 feet and a negligible strike slip. The width of its fissure zone ranges from 5 to 20 feet. Where it bends to the west, the displacement increases to a maximum of 730 feet along the line of section M–M′, Plate 17.

The zone of fracture along the Adelaide fault is complexly curved and consists in general of a breccia containing selvage. In most places nearly all the movement has been confined to a single fissure, but along part of the fault, represented by section A–A′, Plate 23, the movement is distributed among three fissures.

The displacement along the northern part of the fault is assumed to be that originally indicated by Emmons. There can be no question that the displacement in this direction is considerable, as the discrepancies of the formations are clearly indicated both by surface observation and by the position of the rocks along the line of section M–M′, Plate 17, as they approach the fault.

ULSTER-NEWTON FAULT

The name Ulster-Newton fault has been applied to one or more faults exposed in the Ulster-Newton, Horseshoe, Colorado No. 2, and Rubie mines. These exposures are represented on the cross sections of Plates 23–26 but have not been connected with sufficient certainty to indicate the strike. The indication of the faults on Plates 13 and 22 is therefore a rough approximation. The general trend of the fault or faults is southwestward, and the length, according to Irving, is 1,400 feet. The fault presumably joins the Adelaide fault on the northeast. It has been exposed in several places in the Colorado No. 2 and is best known where it faults the Colorado No. 2 ore shoot; but its exact position in the Rubie is not known, and it evidently dies out before reaching the Yak tunnel. At the Colorado No. 2 ore shoot the dip slip is 55 feet downward on the east, but it decreases southwestward. The dip also is eastward in this vicinity. The fault beneath the Horseshoe shaft, however, is reverse, with a westward dip and a dip slip of 25 feet downward on the east; but this may not be same as the fault in the Colorado No. 2. There is probably a considerable strike slip, but the complex local structure has not been satisfactorily worked out.

MOYER FAULT

The Moyer fault, along the southern part of Iron Hill, has a total length of 2,600 feet and an average trend of nearly N. 50° E. At the northeast it terminates against the Adelaide fault, and at the southwest it seems to die out near the limestone quarry at the south end of Iron Hill. The fault is normal throughout, and its downthrow is on the southeast side. The dip is slight in the southwestern part and increases to 150 feet in the Moyer shaft; the strike slip there, as indicated by the faulted ore shoot, is negligible, and northeast of the shaft the strike slip can not be definitely determined. The fault zone contains comparatively few longitudinal fractures, but several minor auxiliary faults meet the main fault at small angles.

The fault is very thoroughly explored by a large number of workings from the Forfeit, Norman Boardman, A. Y., Minnie, Sellers, and Moyers shafts. At the southwest extremity it is first encountered in the Daisy raise, just southeast of the Forfeit shaft. It has here a breccia zone 20 feet in width, a dip of 70° SE., and a dip slip of 46 feet downward on the southeast side. From this point it passes through the large stopes of the A. Y. mine. These stopes had been abandoned at the time of the visit, so that the displacement could not be actually observed, but it is stated by Freeland [22] to have been slight and is evidently not over 15 feet.

[22] Freeland, F. T., The sulphide deposit of South Iron Hill, Leadville, Colo.: Am. Inst. Min. Eng. Trans., vol. 14, pp. 181-189, 1886.

The large Moyer ore body, which extends northeastward from the La Plata workings to the A. Y. ground, beneath California Gulch, is intersected by this fault but has been only slightly displaced. Northeast of this intersection the fault has been explored extensively. From the Minnie shaft through the Sellers claim and up to its junction with the Adelaide fault, it brings the overlying Gray porphyry down against the southeastern border of the ore body, as may be seen at many places in the stopes.

Sections H-H′, Plate 24, and I-I′ and K-K′, Plate 25, show that the ground to the southeast of the large Moyer ore body has been but little explored. The sedimentary formations are here very deeply buried beneath two contiguous sills of Gray and White porphyry, the White porphyry lying above the Gray porphyry. From the Moyer shaft northeastward the dip of the fault carries it above most of the workings of the Moyer mine, and it is intersected at comparatively few points below the upper stopes.

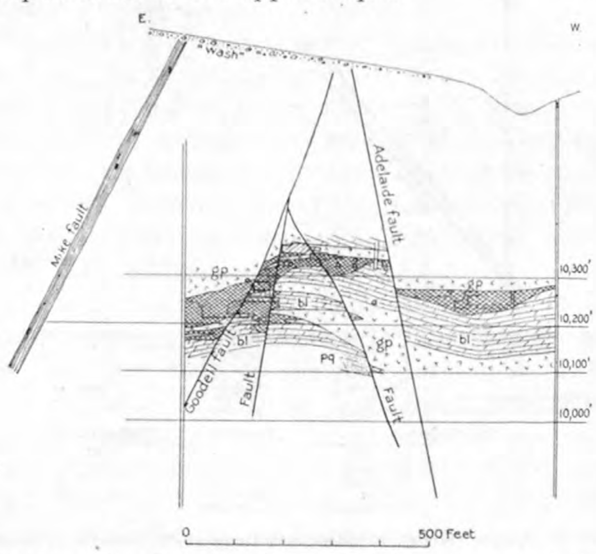


FIGURE 34.—Section of a portion of the Moyer mine, looking south, showing the manner in which the rock masses between the major faults have adjusted themselves by minor auxiliary faulting. gp, Gray porphyry; bl, Blue limestone; pq, Parting quartzite

The ground near the junction of the Moyer and Adelaide faults is excessively broken, and many minor displacements may be observed. (See fig. 34.) It has been difficult, therefore, to determine the displacement of this portion of the fault. The Moyer fault is irregularly curved throughout, and many of the curves are of comparatively small radius along both strike and dip. The fault breccia, exposed at several places, is characterized by thick marginal clay selvages between which lie masses of broken and pulverized rock and several thinner selvages.

GOODELL OR SOUTH NINE FAULT

The Goodell or South Nine fault is a minor normal fault prominent in the Moyer and Mike mines. It has been traced for 850 feet northward from its junction with the Adelaide fault. Its northern part bends slightly toward the west. It has been extensively developed in the Moyer workings, which immediately join those southwest of the Mike winze. It is cut again in the Yak tunnel, and from this point northward no definite information is available in regard to it. As it is not recognizable in the north Mike workings it has probably died out without reaching them. Its dip is 63°–74° E. and is nearly parallel to that of the Mike fault. The dip slip in the Yak tunnel is 30 feet; it is greater to the south and evidently decreases toward the north.

The fault is of some interest in that it displaces the large ore body in the South Nine stope of the Moyer mine. A portion of this ore body is left by this fault and the Adelaide fault at a higher altitude than the portions on each side. (See fig. 34.)

ORIGIN OF THE IRON-MIKADO FAULT GROUP

Although the principal movement of the Iron-Mikado fault group changes northward from the dome to the Iron and then to the Mikado fault, the uplift was uneven and the ground on both sides was strained until the auxiliary faults parallel and transverse to the main fault zone were developed. Uplift along the Iron fault itself reached a maximum just north of Stray Horse Gulch. South of this point the ground to the east of the fault was warped until it broke along the Adelaide fault. Iron Hill, therefore, represents a large block strained by the uplift along the Adelaide fault until it broke into three minor blocks separated or partly separated by the Ulster-Newton and Moyer faults. The movement may have produced other faults similar to these.

The Goodell fault, with down slip on the east, represents movement parallel to postmineral movement along the Mike fault, near by, and may therefore be more correctly correlated with the Mike fault, although it joins the Adelaide fault. It represents a local settling accompanying that between the Mike and Pilot faults, which took place during the general uplift, perhaps after the principal stage of uplift had been completed.

The Iron fault south of its junction with the Dome fault is similar to the Adelaide fault in origin. The principal movement there took place along the Dome fault, and the ground to the east was warped until it broke along the Iron fault.

The Mikado and Iron faults from Iron Hill to a point west of Yankee Hill are to be regarded as two principal members of a fault zone separated by a large narrow slab of ground. At the Mikado mine the greater amount of slip is along the Mikado fault (pl. 14, section D-D′), but west of Yankee Hill (section C–C′) it is along the Iron fault. This difference indicates a northward tilting of the slab between the faults. A little farther north (section B–B′) the greater slip is on the Mikado fault again, and it would not be surprising if this change were found to have taken place along a concealed transverse fault in the vicinity of the Chieftain mine. Thence northward the Mikado is the principal fault, and the Iron fault north of Yankee Hill represents another auxiliary break analogous to that along the Adelaide fault.

FAULTS IN THE EASTERN PART OF THE DISTRICT

Faults in the vicinity of Breece Hill and Ball Mountain belong in part to the postmineral class. Some movement has probably taken place along the northern part of the Mike fault, the Pilot fault, the Weston fault north of Iowa Gulch, and the Ball Mountain fault since the deposition of ore, but it has been more convenient to describe each of these faults completely under one of the preceding headings than to scatter the description of an apparently single fault under two or three headings. The same statement applies to the Mosquito fault, which is normal and of postmineral age in its southern part but reverse and evidently of premineral age in its northern part.

FAULTS SOUTHEAST OF THE LEADVILLE DISTRICT

Six other faults are shown on Plate 11 as originally mapped by Emmons. These are the Union, Iowa, Dyer, South Dyer, Sheridan, and Sherman faults.

The Union fault extends south-southwestward from its junction with the Weston fault in Iowa Gulch and crosses Long & Derry Hill and the west slope of Empire Hill, beyond which it disappears in an area of granite. Its dip slip is about 200 feet downward on the west near its south end and increases northward to a maximum of about 1,000 feet at its junction with the Weston fault. Although little known it is of interest because of its close association with the veins in the Clear Grit and adjoining properties, which are mentioned in connection with the Weston fault (p. 78); also because it is in line with the Sunday vein on the southwest slope of Ball Mountain. These relations suggest that it may be of premineral origin, but it is classed as postmineral for want of evidence.

The Iowa fault is exceptional in having an east-west course. It extends along the foot of a cliff on the south side of Iowa Gulch from the Weston to the Ball Mountain fault. The shafts and tunnels between it and the bed of the gulch are in either Gray porphyry or "Weber grits," whereas pre-Cambrian granite forms the cliff and slope to the south. The Iowa fault is also of interest as being the south boundary of the depressed block that forms the west part of Ball Mountain.

The Dyer fault is a minor fault trending S. 60° E. across the southwest spur of Dyer Mountain. It is indicated by a relatively small offset of the strata in Dyer and Iowa amphitheaters. It has not been traced beyond these two places, and it dies out before reaching East Ball Mountain.

The South Dyer fault extends S. 60° E. from the Mosquito fault to the Sheridan fault in the bed of Iowa Gulch and is indicated by a narrow strip of Cambrian quartzite with an included sheet of the White porphyry, which is faulted down against a north wall of granite. The apparent throw is about 800 feet. Along part of its southeastern portion its north wall is a dike of the White porphyry in pre-Cambrian granite, and thence to its junction with the Sheridan fault its south wall consists of Cambrian quartzite, White limestone, and overlying porphyry. These rocks occupy a triangular area between the two faults.

The Sheridan fault extends from this area south-southwestward between Sheridan and West Sheridan mountains and may continue as far as the Weston fault. Its west wall between the two mountains has dropped from 150 to 250 feet, according to Emmons's map, but at its junction with the South Dyer fault the drop is more than 500 feet.

The Sherman fault, as mapped by Emmons, is a minor, poorly defined displacement of southeastward trend.

ORIGIN OF FOLDS AND FAULTS

FOLDS AND PREMINERAL FAULTS

A detailed study of central Colorado if not of a larger region is no doubt necessary before the origin of the folds and faults in the vicinity of Leadville can be thoroughly understood, but the evidence at hand throws considerable light upon the problem. The common N. 30° E. trend of the folds, the steep dips of their western limbs, and the breaking of the western limbs by reverse faults all indicate regional compression by a force acting in a S. 60° W. direction. This force was so strong or acted so rapidly that the strata which had begun to yield by folding were broken along faults of northeastward dip, and the hanging wall of each fault was forced upward over the footwall. The shearing and compression along the faults ground much of the rock in the fault zones into an impervious pulp or gouge and left few openings along which circulation could take place freely. The rock on each side of the fault zone, however, particularly that on the footwall side, was subjected to tension while shearing was in progress, and auxiliary fissures normal and oblique to the reverse fault resulted. These tension fissures were favorable for circulation.

The folding and reverse faulting were distinctly later than the intrusions that produced the porphyry sills but were more closely related to later batholithic or stocklike intrusions. Crawford[23] has shown that in the Monarch-Tomichi district, 45 miles south of Leadville, batholithic intrusions of monzonitic rock followed or possibly accompanied reverse faulting. He has also shown that late batholithic or stocklike intrusions of monzonitic rock are present at several places in central Colorado.[24] The reverse faults in the Mosquito Range may be related to similar intrusive masses that have not been exposed.

Besides local tension along the walls of reverse faults there was regional tension or stretching of the rocks along the axes of the folds. This may have been sufficient during folding to produce some of the northeastward-trending fissures, but inasmuch as important fissures of this system, represented by the Cord and St. Louis fissures, cut reverse faults, they are better attributed to contraction or recoil along the axes of the folds after regional compression had ceased. According to either explanation they are tension fissures and favorable for circulation. Their continuity varied with the kind of rock traversed. They were most continuous in quartzite and pure dolomite (Blue limestone), less continuous in porphyry, shaly White limestone, and "Weber grits," and least continuous in the different shale beds.

The predominance of premineral faults in the eastern part of the district and the radial arrangement of some of them around Breece Hill stock strongly suggest a close relationship between the faults and the stock. Intrusive activity that could have caused these faults must be correlated with the intrusions that produced the late monzonitic stocks and not with those that produced the sills. Such a correlation implies the presence of an unexposed or at least unrecognized monzonitic intrusive body in the Breece Hill stock. The faults may be due in part to upward thrust during intrusion and in part to subsequent settling. Mineralization took place during or just after this period of settling.

POSTMINERAL FAULTS

The largest postmineral faults in the region shown in Plate 11 are the southern part of the Mosquito fault, the Iron fault, and the Pendery fault. All these faults are normal, and the east wall of each has risen relatively to the west wall. No noteworthy horizontal movement and no horizontal compression have taken place along any of them. The greatest displacement that occurred along any one fault zone was that along the Mosquito fault. This movement decreased toward the south, where it was apparently compensated to some extent by opposite movement along the Union fault; but the throw of the Union fault also decreases southward. The displacement in the Dome-Iron-Mikado fault group reaches its maximum just north of Iron Hill and diminishes both to the north and south. The Pendery fault, on the contrary, appears to increase southward and to die out or join the Mikado fault not far north of the Leadville district. This evidence, so far as it goes, indicates

[23] Crawford, R. D., Colorado Geol. Survey Bull. 4, p. 109, pls. 2, 3, 4, 1913.

[24] Crawford, R. D., A contribution to the igneous geology of central Colorado: Am. Jour. Sci., 5th ser., vol. 7, pp. 365–388, 1924.

a steplike relation of the principal postmineral faults, both vertically and horizontally.

It can not be proved whether the movement along these faults was one mainly of uplift or subsidence, but it seems more reasonable to infer an uplift along the Mosquito Range than a subsidence of the country to both sides of it. The local evidence cited in subsequent paragraphs also accords better with uplift than with subsidence, but it is realized that the problem in the vicinity of Leadville is only a small phase of a regional problem that involves all the mountainous part of Colorado and adjoining States.

The shifting of the main movement from the western to the eastern faults took place in the vicinity of Leadville, and the consequent adjustment within this area caused local faulting expressed by the White Prince and Pilot faults and renewed movement along the southern part of the Mike (reverse) fault. It also accounts for the local depressed block between the northern Mike and Pilot faults and in part for that bounded by the Weston, Ball Mountain, Modoc, and Ibex No. 4 faults. The history of the last-named block, however, is obscure. It was depressed to some extent prior to ore deposition, but the faulting which occurred at that time was on a comparatively small scale, and the greater part of the depression, especially of the southern part of the block, may be attributed to the postmineral faulting.

The local dropping of these blocks indicates some expansion of the earth's crust during the general uplift. Expansion, or bulging accompanied by breaking, is also indicated by the uplift itself and is best indicated by section D–D′, Plate 12. From the Mosquito fault eastward to and beyond the South Platte Valley the uplift is marked by an eastward tilting of the strata without pronounced postmineral faults, unless some postmineral movement took place along the London fault zone. The amount of uplift at the Mosquito fault with the reference to the strata at the South Platte Valley was about 7,000 feet; with reference to the strata west of the Cloud City fault it was about 8,000 feet and would doubtless be considerably more if these strata could be compared with bedrock at the east base of the Sawatch Range.

Although this uplift is best indicated in the Mosquito Range, it extended beyond the limits of that range. The Georgia Pass fault east of the Breckenridge district, is briefly described by Ransome [25] and is evidently analogous to the normal part of the Mosquito fault. The two faults form the east and west boundaries of a tilted block about 12 miles wide. No other faults equivalent to these have been mapped, and the limits of the faulted area are not known.

The relation of postmineral uplift, accompanied by extensive faulting, to earlier disturbances is similar to that in many other mining districts of the West, as pointed out by Spurr.[26] The general succession of events, according to Spurr is (1) igneous intrusion, (2) slight faulting, (3) ore deposition, (4) uplift or doming accompanied by prolonged and pronounced faulting and roughly coinciding in area with mineralization. The succession at Leadville was somewhat more complicated; folding and reverse faulting as well as subsequent local normal faulting and fissuring intervened between intrusion of the exposed igneous rocks and ore deposition. Furthermore, the postmineral faulting, though more thoroughly mapped in the Leadville district than elsewhere, extends over a much greater area; but this greater area contains several mining districts of more or less importance, so that uplift and mineralization may prove, in a large way, to coincide. Spurr [27] offers the plausible suggestion that the postmineral uplifts in general are due to the pressure of a plug of consolidated igneous rock forced upward by still fluid magma at its base. This explanation may be too simple to explain all the facts when the postmineral uplift of central Colorado is considered as a whole, but it is satisfactory in so far as it involves principally vertical movement and an expansion of the uplifted area. When the postmineral faults of central Colorado are more thoroughly mapped they may prove to be generally similar to the great postmineral faults of the Great Basin province and will await a similar explanation.

LOCAL DETAILS

In considering local structural details of the Leadville district, the blocks between the major faults or fault groups are the natural units. Eleven of these units are here discussed in successive order from west to east.

AREA WEST OF PENDERY FAULT GROUP

The area west of the Pendery fault zone may best be described as a unit, as no faults are known to extend completely across it in any direction. Its structure is shown in Plates 13–17.

There are no outcrops within the area, but the stratigraphy and structure beneath a considerable part of it are well known from mining operations. The Sequa, Hofer No. 1 and No. 2, and Villa shafts, in the northern part, have furnished valuable information, but between them relatively little drifting and extended exploration has been carried on. In the Whale, Neptune, Jason, and Fairview No. 4 mines a little more work has been done, and a long exploratory north-south drift with many drill holes was run by S. W. Mudd beneath Poverty Flat from the Delante No. 1 north toward the Hofer. South of the Delante No. 1

[25] Ransome, F. L., U. S. Geol. Survey Prof. Paper 75, pp 64-65, 1911

[26] Spurr, J. E., The relation of ore deposition to faulting: Econ. Geology, vol. 11, pp. 605-622, 1916.

[27] Idem, pp. 621-622.

and thence south to California Gulch the gravel east of the Cloud City fault has been extensively explored. The Newell, Capitol, Coronado, Sixth Street, Penrose, Alice, Cloud City, Lazy Bill, Starr, Bohn, Weldon No. 2, Midland, P. O. S., California Tunnel, and California Gulch shafts are the principal openings. On Capitol Hill the Spurr drill hole was put down to granite for exploratory purposes. West of the Cloud City fault are the Home Extension, Valentine, and Maple Street shafts, and on the far south the Owers drill hole and Thompson shaft. Southwest and west of these workings the geology as mapped is conjectural.

No shaft or drill hole within this entire area has entered granite except the Spurr drill hole, in which the granite lay directly beneath the "lake beds." Most of the other shafts mentioned passed through White or Gray porphyry in varying thickness above the Blue limestone, although the Alice entered the limestone immediately beneath the "lake beds."

The fault shown near the Leadville Driving Club is inferred from the relative positions of the granite in the Spurr drill hole and of an outcrop of White limestone 1¼ miles due west of the corner of Harrison Avenue and Ninth Street. Its position is not known within a considerable distance, neither is the amount of displacement along it nor the average dip of the strata west of it. The White limestone has been indicated as forming the entire bedrock surface west of the fault, but a dip somewhat steeper than that assumed in compiling the geologic map would bring the Parting quartzite and Blue limestone below the bedrock surface.

The irregularity of the bedrock surface in the more explored part of the area may be realized from the east-west and north-south sections on Plates 14–17. The dominant features are two broad depressions of westward trend—one at the latitude of 39° 15′, the other at the south edge of the area—which represent the preglacial valleys of Evans Creek and Iowa Creek. The broad rock ridge between these two depressions is a continuation of the ridge that includes Breece, Iron, and Carbonate hills. Its crest is penetrated by the Bon Air and Valentine shafts. The broad westward curve of the formation boundaries here is due to the intersection of eastward-dipping strata with the convex bedrock surface.

All the sedimentary formations and the White and Gray porphyries are exposed to some extent in the mines of this western area, but the Blue limestone has been far more extensively explored than the others. It averages about 200 feet in thickness and, as shown on page 34, contains several sandy beds well above the Parting quartzite, and a persistent layer of black jasperoid, or flinty quartz, 4 to 10 feet thick, which varies in stratigraphic position (fig. 10). As this jasperoid has been found only where oxidation has been thorough, Irving suggests that it has been deposited by descending waters; but he does not attempt to explain the process. In places it forms the floors beneath ore bodies, but it is also well developed where there is no ore.

The Parting quartzite ranges from 15 to 40 feet in thickness and commonly contains considerable sandy and argillaceous shale in its upper and lower parts. The White limestone is 160 feet thick and has no unusual or striking features in the few places where it has been explored.

The White porphyry is present in the eastern part of the area and exceeds 1,000 feet in maximum thickness. It forms the bedrock surface except where it is covered by the large sheet of Gray porphyry in the northern part. Beneath this Gray porphyry sheet the White porphyry is unusually thin. In most places it lies directly upon the Blue limestone, but locally as much as 40 or 50 feet of the micaceous beds of the Weber (?) formation may separate it from the limestone. Besides the Gray porphyry sheet just mentioned, which averages 150 feet in thickness, there is another Gray porphyry sheet in Blue limestone in the east-central part of the area. This sheet is a westward continuation of a thicker and more complicated intrusion under Carbonate and Iron hills. It reaches the bedrock surface in the small anticlinal area east of the Cloud City shaft. Its average thickness is about 50 feet, but it is very irregular. Its most common position, where it is a single sheet, is about the middle of the Blue limestone. Its most pronounced departure from this average position is in the vicinity of the Penrose and Midas shafts, where it rises in places to the top of the limestone and sends off branches to lower horizons (pl. 18, section XII). North of this area it descends abruptly in the Sixth Street-Coronado ground, and to the south it descends more gradually through the Weldon, Bon Air, and Bohn claims. Near the Bohn shaft it has a nearly vertical upward offshoot. East of the Penrose shaft the main sheet descends rather abruptly, and in the Bison ground it apparently splits into two sheets, although the structure here is complicated by faulting.

Although the strata as a whole are nearly horizontal, they undulate considerably (pl. 18, section XII) and locally have very steep dips. The steep dips are mostly due to drag along postmineral faults and in minor degree to distortion by the irregular sill of Gray porphyry. The undulations also may be due to adjustments within the fault block during the postmineral faulting; but the westward-trending monoclinal fold cut by the faults of the Pendery group (pl. 41) was formed earlier and, as suggested on page 75, may indicate the faulted continuation of the Tucson-Maid reverse fault.

The ore bodies thus far discovered west of the Pendery fault are coextensive with the Gray porphyry sheet, a relation suggesting that fissures developed by the intrusion afforded opportunity for the ore-forming solutions to permeate the limestone more thoroughly, whereas the Gray porphyry itself and the White porphyry acted as impervious barriers to the solutions. Auxiliary fissures along the suggested continuation of the Tucson-Maid reverse fault may also have afforded local access to the solutions. The principal channels through which the solutions reached the Downtown area, however, to judge from the longer dimensions of the ore bodies, trend southwestward.

Exploration and stoping thus far have been confined mainly to the Blue limestone. Drilling proved the White limestone in the Midas and Coronado ground to contain ore, which was being mined by the Downtown Mines Co. in 1918–1922. Drilling also found ore in White limestone south of the Penrose shaft (pl. 18, sections V and XII). Ore in White limestone was also stoped southward from the Hibschle shaft, and, as already suggested, may be associated with auxiliary fissures along the Tucson-Maid reverse fault. If this relation can be established the White limestone northwest and especially southeast of the Hibschle shaft is worthy of exploration.

West of the Cloud City fault there has been very little exploration, and the results obtained have not been encouraging. The Blue limestone is continuous for some distance, especially in the southwestern part of the area, but the Gray porphyry and premineral fissures associated with it are absent. From Capitol Hill northward both limestones are removed by erosion, and to the west beyond the hypothetical fault the details of structure and stratigraphy are not known. Furthermore, the glacial deposits on the whole thicken westward, and the relatively great expense in maintaining shafts and pumping in these deposits and the relatively poor chances of finding ore are discouraging to the prospector.

AREA BETWEEN PENDERY AND DOME-IRON-MIKADO FAULT GROUPS

The area between the Pendery and Iron-Mikado fault groups is a north-south strip of ground which narrows northward and probably pinches out beyond the limits of the Leadville district. It bulges slightly in the vicinity of Fryer Hill to a width of 5,000 feet, and narrows to 4,000 feet at Carbonate Hill. It is broadest at the south edge of the Leadville district, where it attains a width of 6,630 feet. At the northwest base of Carbonate Hill it is broken by the eastern members of the Pendery fault zone into a series of steps which form a transition into the area west of that zone. At the south end of Carbonate Hill it is broken by the Toledo fault. Other minor faults are undoubtedly present within this area but are not so numerous as in the Iron Hill area, to the east. The workings in the northern part of Iron Hill expose the Iron-Tucson fault as shown in the sections on Plates 20–21 and in Figure 26. This area is one of the most important in the district with reference to mining development, as it contains the mines of Fryer and Carbonate hills.

The bedrock reaches the surface along California Gulch and over the southern two-thirds of Carbonate Hill, although outcrops are few, owing to the prevalent thin veneer of porphyry talus. From latitude 39° 14′ southward the bedrock surface slopes beneath the deep sub-Pleistocene valley that is now filled with high terrace gravel and "lake beds."

Over the north and lower west slopes of Carbonate Hill the mine dumps are so numerous that scarcely any outcrops remain and the original topography of the hill is considerably modified. Some conception of the surface accumulation of dumps may be gained from the photograph reproduced in Plate 42. From Stray Horse Gulch northward the rock surface is covered with glacial deposits, and for the most part it has only minor undulations; but there is a marked exception beneath Graham Park, where "lake beds" occupy a bowl-shaped depression that measures roughly 1,600 feet from east to west and 2,500 feet from north to south. The bedrock surface on the north side of this depression slopes 28°, on the south 33°, on the west 20°, and on the east between 50° and 60° where the "lake beds" come directly against the Mikado fault surface. The depth of this bowl is roughly 1,000 feet, and marly "lake beds" resembling the main deposit in every respect fill it within 200 or 300 feet of the surface. Their eroded surface is covered by glacial gravel and morainal débris. This rock basin may be due in part to glacial overdeepening prior to deposition of the "lake beds," but it is attributed mainly to distortion which accompanied movement along the Mikado fault.

Underground exploration in this area, though extensive, is very unevenly distributed. The most fully explored portion of the area extends southward from Evans Gulch to the William Wallace, Mab, and Belle of Colorado shafts. The ground down to the Parting quartzite has been extensively explored throughout this part of the area. Recent exploration has extended in Fryer Hill to strata beneath the Parting quartzite, but the result has not proved sufficiently encouraging to justify extensive work. In East Fryer Hill a like situation is found, and only drill holes have extended below the Parting quartzite. Beneath Stray Horse Ridge and the north slope of Carbonate Hill from the Pendery fault eastward to the Mikado fault all the formations have been extensively explored down to and even including the Lower or Cambrian quartzite.

South of Graham Park the little exploration that has been carried on has consisted largely of shaft sinking with comparatively little drifting. In certain portions of this area, notably in and about Little Stray

Horse Gulch from the Turbot shaft westward to the Pendery fault, relatively few observations were made. A number of mines within this portion of the district were inaccessible at all times when visits were made, and representation of the rather complicated local structure is accordingly based on oral information furnished by men who had carried on the work, interpreted in the light of geologic data obtained near by. In the vicinity of the reentrant angle made by the Iron fault at the west base of Iron Hill a great deal of exploration has been carried on through the McKeon, Star of the West, and other shafts. Some of these were visited by Emmons in his earlier visit to the district, but the writers never had the opportunity to examine any of them. The geologic mapping here is therefore much generalized.

Little need be said regarding the Blue limestone and lower formations in this block, as they are all present in their normal development. The entire area except its western edge is covered by porphyry. In the northern part an extensive sheet of Gray porphyry, which has a thickness of 250 to 300 feet near the Mikado fault, is underlain by a sheet of White porphyry usually not over 60 feet thick. Farther south the White porphyry sheet attains a thickness of 500 to 600 feet at the summit of Carbonate Hill and of 700 to 900 feet adjacent to the Iron fault zone; but still farther south it is thinned by erosion. The Gray porphyry, on the other hand, diminishes southward until it thins out just south of Stray Horse Gulch.

Between the White and Gray porphyry and likewise between the White porphyry and the Blue limestone black Weber shales are found. In some places, as in the Price and Harvard No. 2 shafts, these attain a thickness of nearly 100 feet. Their stratigraphic and structural relations are shown in Figure 75. Farther north the White porphyry lies immediately beneath the Gray porphyry.

In the Graham Park area the White porphyry splits into two parts and a little farther north into three parts. The main or lower part lies beneath a large portion of the Blue limestone and at Fairview Hill cuts through the Parting quartzite also before it pinches out. The middle part, which is the thinnest and shortest of the three connects northward with the lower and southward with the upper part. The upper part is continuous from Stray Horse Gulch to the north limits of the area but is comparatively thin north of Fryer Hill. The rapid thinning of the lowest sheet apparently accounts for the local anticline at Fryer Hill, although distortion during faulting may account for it in part.

It is within the upper portion of the Blue limestone, between the middle and upper sheets of White porphyry, that the famous ore bodies of Fryer Hill and the very rich ores of the Small Hopes mine were found. The limestone was almost entirely replaced by ore and accompanying "vein material." This upper portion of the Blue limestone reaches the bedrock surface from the north edge of Graham Park to Fryer and Fairview hills. The presence of the upper layer of Blue limestone above the main or thicker White porphyry sheet delayed exploration of the Blue limestone below until the stratigraphy of the district was understood. The upper limestone decreases in importance as an ore carrier from Fryer Hill southward, but explorations in the vicinity of Graham Park have found large ore bodies in the limestone below the main White porphyry sheet.

Throughout the area, except in the extreme northern part, a persistent sheet of Gray porphyry is present in the Blue limestone. This sheet increases irregularly in thickness southward and reaches a maximum of more than 100 feet beneath Graham Park. It splits into two sheets in places and jumps abruptly from one bed to another. It also sends out forks and tongues, many of which are indicated in the section on Plates 20 and 21. In the northeast portion of the Graham Park area sills of Gray porphyry cut down through the Parting quartzite into the White limestone. An additional sill of Gray porphyry at or near the top of the Blue limestone is found in the southern part of the area (sections F–F′, pl. 15, and O–O′, pl. 17). This sill crops out in the bed of California Gulch immediately beneath the White porphyry. This upper Gray porphyry still is of minor extent, and as it lies for the most part immediately beneath the White porphyry it has escaped detection in some places.

Some of the many offshoots from the very irregular main sheet of Gray porphyry were regarded, when discovered, as dikes but they can not properly be so classified. One of these offshoots extending upward vertically was found in the Moyer mine beneath Nugget Gulch and for a long time was believed to be a dike; but exploration in the deeper levels proved it to connect downward with the main Gray porphyry sill and not to extend below it. Porphyry masses cut in Fryer Hill are of the same character, and one of them is indicated on section O–O′, Plate 17, as extending upward through White porphyry into the Blue limestone.

The White limestone is free from Gray porphyry intrusions except along the eastern border of the area, where the main porphyry sill has cut down from the Blue limestone through the Parting quartzite. A few isolated tongues supposed to be Gray porphyry have been found also in the White limestone beneath Graham Park, but these proved to consist of the porcelain-like shale which is so frequently mistaken for porphyry elsewhere.

This area shows perhaps better than any other the synclinal form developed by tilting and drag during faulting. The strata dip from the western edge at angles of 10° to 22°, with perhaps an average of 17°. The downward drag on the western edge has affected

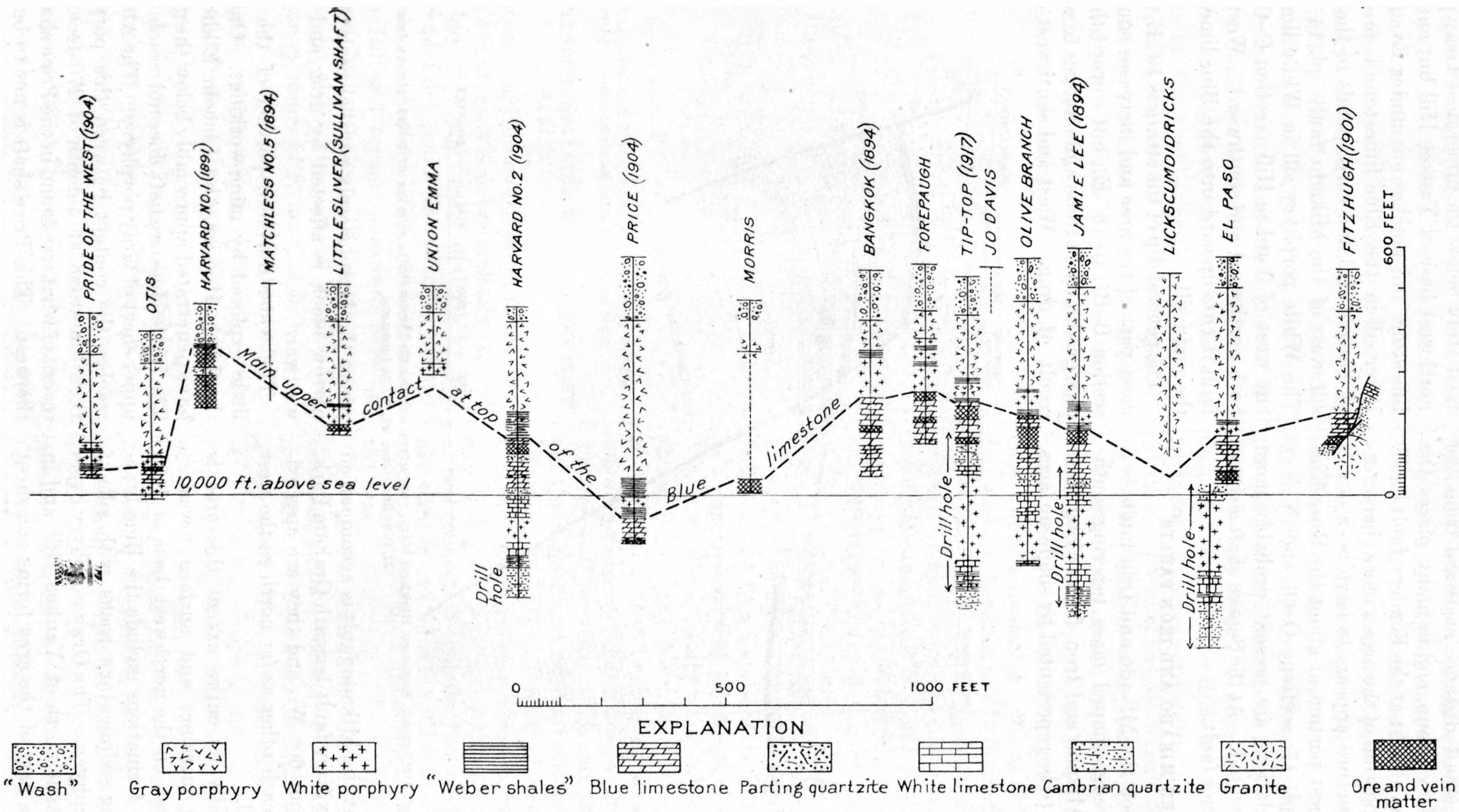


FIGURE 35.—Sections of shafts between Small Hopes mine, Fryer Hill, and Mikado fault, projected on a vertical plane trending N. 25° W. through Harvard No. 2 and Olive Branch shafts. Show developed ore bodies and relative amount of exploration of lower "contacts" in the years indicated

them only a very small distance eastward from the faults of the Pendery group, and in many places the eastward dip begins almost at the Pendery fault itself.

In the northern portion of the area a more characteristic basin-like structure appears to have been developed, with its deepest portion at about the Rose-Emmet shaft. (See pl. 17, sections O–O′ and N–N′.) Many minor undulations are present, probably more than have been indicated. At the Seneca shaft a sharp fold is cut by a minor fault.

AREA BETWEEN MIKADO AND IRON FAULTS

The block between the Mikado and Iron faults is a sharply pointed wedge-shaped mass tapering southward. Both the Mikado and Iron faults along most of this area appear to be represented by single surfaces of displacement, but the Mikado fault is accompanied by the R. A. M. auxiliary fault beneath Graham Park. Both faults dip about 60° W., and they are approximately parallel to each other as far north as the west base of Yankee Hill.

Through practically its entire extent this area is covered by glacial moraines and surface "wash." This cover is thinnest on the northwest base of Iron Hill. The bedrock formations include the Blue limestone and underlying sedimentary rocks, with sills of Gray and White porphyry. The Gray porphyry overlies the Blue limestone north of Yankee Hill and in the narrow southern part of the area forms one sheet within the Blue limestone and two others in the White limestone (pl. 14, section D–D′). The White porphyry forms two sills in the Blue limestone and another in the White limestone. The uppermost sill lies immediately below the uppermost Gray porphyry at the northwest base of Yankee Hill but cuts down into the limestone and pinches out under Evans Gulch. The lower sill in the Blue limestone is present southwest of Yankee Hill and corresponds to the lowest or main sill west of the Mikado fault (pl. 14, section D–D′). The White porphyry sill in White limestone is present west of Yankee Hill (section C–C′) but pinches both northward and southward. West of the Mikado fault it cuts upward into the Blue limestone and joins the main sill.

The general dip of the strata is 10° E. in the northernmost part of the area and increases southward (pl. 14, section B–B′) to 18° E.; but toward the Iron fault the dips gradually flattens and changes to westward, as the result of drag. West and southwest of Yankee Hill, where the faults closely parallel each other, the entire narrow block is affected by drag, and the strata dip westward.

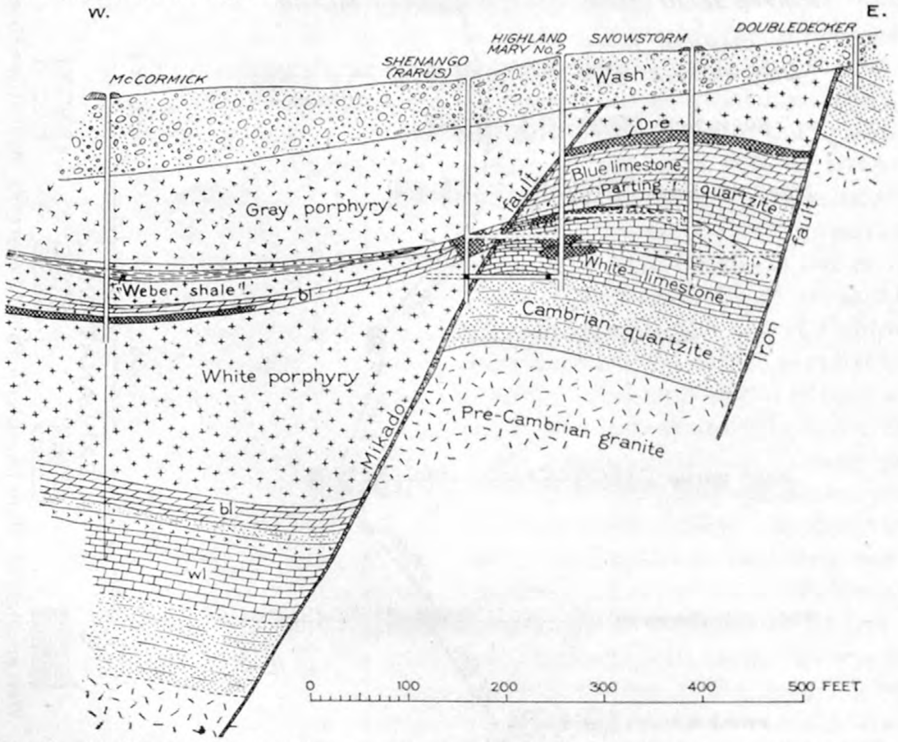


FIGURE 36.—Section through McCormick, Shenango, Highland Mary, Snowstorm, and Double Decker shafts, showing ore bodies between Iron and Mikado faults. bl, Blue limestone; wl, White limestone

The wider northern portion of the area has been little explored by mine workings. Only four shafts, the Little Hoosier, Abe Lincoln, Elkhorn, and Price, have penetrated appreciably below the glacial moraine. The Little Hoosier shaft does not reach the base of the upper sheet of Gray porphyry. The Abe Lincoln shaft reaches the contact between this porphyry and the Blue limestone at a depth of 270 feet. There is no record of what was found in the Price shaft 1,200 feet to the west. This Price shaft is not to be confused with the better-known Price shaft 1,600 feet farther west, across the Mikado fault.

The Elkhorn shaft serves as a basis for a large portion of the information in this part of the area. It is

864 feet deep, passes through 118 feet of "wash," 84 feet of Gray porphyry, and 20 feet of shale, reaching the underlying Blue limestone at a depth of 222 feet; and ends 50 feet below the top of the Cambrian quartzite.

The next workings of any importance to the south include several shafts south of the wagon road on the northwest and west slopes of Yankee Hill. Between the Fairplay shaft on the north and the Indian shaft on the south the ground has been relatively little explored. Farther south extensive exploration has been carried on as far as the Cumberland shaft, and the geologic structure is illustrated by Figures 36 and 37. Some of the shafts were started west of the Mikado fault but cut it in depth. Further details as to the occurrence of ore and the structure will be found in the section on the blanket ore bodies (pp. 187–208).

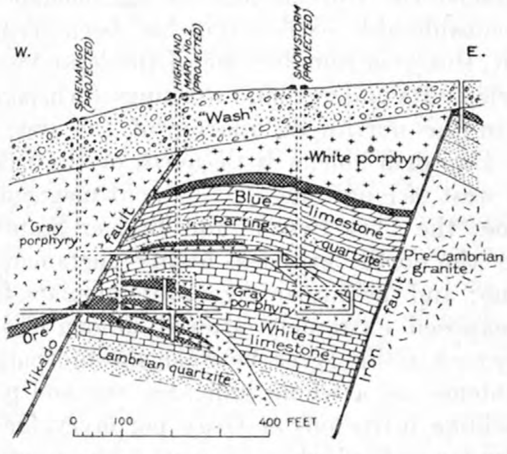


FIGURE 37.—Section through Highland Mary, Shenango (south drift), and Snowstorm shafts, showing ore bodies between Mikado and Iron faults

AREA BOUNDED BY IRON, ADELAIDE, GOODELL, AND MIKE FAULTS

The area between the Iron and Weston faults may be considered as a unit, as it is not completely crossed by any faults; but it is practically divided by the Adelaide, Mike, and Pilot faults into four parts, each of which is described separately. That first described includes Yankee Hill and tapers southward between the Adelaide and Mike faults. The northernmost part of this area and the south slope of Yankee Hill are covered by the moraines of Evans Gulch, but bedrock is close to the surface east of Johnson Gulch. A veneer of "wash" covers much of the remaining area, but the saddle between Iron and Breece hills is comparatively bare.

The entire series of strata exclusive of the Weber (?) formation is represented on the bedrock surface (pl. 13). The basal granite borders the Iron fault southwest of Yankee Hill, and the eastward-dipping sedimentary rocks, somewhat complicated by porphyry intrusions, lie in succession to the east of it as far as the east slope of the hill, where the Blue limestone is overlain by the main sheet of Gray porphyry. The Gray porphyry also forms a broad dikelike mass (pl. 14, section D–D′) which extends northward from the Adelaide fault nearly to the summit of Yankee Hill. Although its south end appears to be beveled by the Adelaide fault, its continuation beyond the fault has not been found. Farther south (pl. 15, section E–E′) the Gray porphyry forms three or more complex sills in the Blue and White limestones. The White porphyry forms a thick sill that overlies the Blue limestone from the south limit of the area to the south slope of Yankee Hill, where it forks, the upper part continuing along or near the top of the Blue limestone and the lower part cutting downward into the White limestone. At the north end of the Mike fault the area is bounded by the Eureka pipe of agglomerate.

The structure at and near Yankee Hill approaches a basin shape. Close to the Iron fault the dip is westward owing to the down drag, but on the whole it is eastward at a moderate angle as far as longitude 106° 15′, where it becomes nearly horizontal and continues so to the White Prince fault, which has not been exposed by mine workings and can only be approximately located. East of Iron Hill the strata are about horizontal as a whole but are locally distorted by the intrusions of Gray porphyry.

The area has been little explored north of Johnson Gulch. The Moose shaft, on the southwest slope of Prospect Mountain, and the Estey drill hole, near by, both reached Blue limestone beneath Gray porphyry at a depth of 562 feet and found sulphides. The two Valunder shafts in the same vicinity did not pass through the Gray porphyry. The Mammoth shaft, to the south, near the bed of Evans Gulch, is also reported to have reached ore in the Blue limestone. The reported presence of ore and the possibility that the Colorado Prince reverse fault may continue northwestward entitle this part of the area to further consideration for prospecting, provided the cost of handling water is not prohibitive. It may be noted in this connection that the tunnel being driven southeastward from Canterbury Hill by the Leadville Mine Development Co. is intended to drain this part of the area.

In the area extending southward from the north slopes of Yankee Hill across Adelaide Park and into the narrow strip between the Mike and Adelaide faults a very much larger amount of exploration has been carried on; but except in the vicinity of Iron Hill and Nugget Gulch little other than shaft and drill-hole records have been available for study. None of the openings in these places have been examined by either Emmons or the writers, and relatively little is known concerning the detailed structure of this fault block. Delineation of the rock formations has been made possible, however, by the interpretation of records of the several shafts and other openings.

AREA BETWEEN IRON AND ADELAIDE FAULTS

In most of the area between the Iron and Adelaide faults bedrock reaches the surface or is covered only by a thin veneer of "wash," but on the north slope of Rock Hill it is partly covered by high terrace gravel, and on the south slope by the north moraine of the Iowa Gulch glacier. All the sedimentary formations are present, from the lowermost shale of the Weber (?) formation down, and they are cut by a greater number of complex Gray porphyry sills than in any other area except northern Breece Hill (pls. 22–26). White porphyry occurs in one thick sheet overlying the Blue limestone and basal "Weber shales" and forms the bedrock surface except at the extreme north end of the area and along the bed and slopes of California Gulch on the west side. It was in the Blue limestone outcrops on these slopes that the first blanket ore bodies were discovered. A smaller sill of White porphyry is present in the White limestone at the north end of the area.

The general structure approaches that of a spoon-shaped syncline broken by several minor transverse faults, of which the Moyer and Ulster-Newton are the most prominent. Only the Moyer fault can be shown with approximate accuracy on the geologic map, as the others either fail to reach the bedrock surface or are concealed in the monotonous area of disintegrated White porphyry. The synclinal structure is the result of tilting during postmineral faulting and drag along the faults. The drag is most pronounced at the north end of the area, against the Adelaide fault; along the southern part of the same fault it is comparatively inconspicuous. In the south half of Iron Hill the average dip is 14° E. near the Iron fault and decreases eastward with one marked undulation, until near the Adelaide fault the beds lie flat or dip slightly westward. The undulation lies along the Tucson reverse fault, which extends from the Iron fault southeastward through the Tucson mine to the Yak tunnel, where it appears to branch and die out.

This area is one of the most thoroughly explored in the Leadville district. The north end was developed in the early days through the Argentine and Camp Bird tunnels and the Mammoth workings, but during neither the earlier nor the later surveys were these workings accessible. The complexity of the workings in the south half of Iron Hill and the north slope of Rock Hill can not be adequately described in words, but may be partly appreciated from the sections on Plates 23–26.

The ore bodies include the long shoots that extend east-northeast along the "first contact" between Blue limestone and White porphyry or Weber shales and the "second contact" beneath the Gray porphyry sill in Blue limestone. Smaller shoots are found at other contacts, but horizons below the Blue limestone have been comparatively little explored except in the Tucson mine and the Cord and South Cord workings below the Yak tunnel. These shoots, which are of considerable size but not nearly so large as the old "first contact" bodies, have been worked along the Tucson fault, particularly on its footwall side. The most instructive occurrence is in the Cord mine, where the ore was introduced along an east-northeast fissure and replaced White limestone as well as formed stockworks ("brecciated ore") in Cambrian quartzite and Gray porphyry where the ground was shattered at the intersection of the east-northeast fissure with the older reverse fault.

AREA BETWEEN MIKE AND PILOT FAULTS

The southward-pointing wedge-shaped block between the Mike and Pilot faults consists entirely of porphyry covered by the usual veneer of "wash." Its northern and western parts are White porphyry and the remainder Gray porphyry. It terminates northward against the Eureka pipe of agglomerate. Although considerable exploration has been carried on within it, this area remains one of the least known in the district. Its underground workings are in porphyry except in the northwest quarter of the area, where the My Day drill hole, a little north of the Yak tunnel and west of longitude 106° 15′, cut magnetite and limestone; the Park Benton and Badger State workings, to the north, exposed highly metamorphosed limestone; and the Ishpeming and Penn mines, farther north, exposed extremely altered unidentified sedimentary rock in thin layers between sheets of porphyry. The evidence as a whole indicates one and perhaps two stocklike intrusions of Gray porphyry, the western boundary of which is obscured by inclusions of metamorphosed rocks and numerous sill-like branches. The northern and larger stock under the west slope of Breece Hill extends considerably to the east of the Pilot fault; the small southern stock beneath the west end of Printer Boy Hill extends southward across the Mike fault and may join the larger stock to the north. The delineation of the deeper boundaries of these stocks in the sections on Plates 14–17 is largely conjectural and doubtless much too simple.

AREA BETWEEN PILOT-WHITE PRINCE AND WESTON FAULTS

The area between the Pilot and White Prince faults on the west and the Weston fault on the east tapers northward and attains a maximum width of 1 mile at Printer Boy Hill. It continues southward across Iowa Gulch but has not been studied there since Emmons's original survey. Bedrock with a veneer of wash lies close to the surface except where it is covered by moraine on the north slope of Breece Hill and by moraine and landslides on Printer Boy Hill, as shown in Plate 7.

Gray porphyry forms the surface from the north end of this block as far as the north slope of California Gulch and is represented as a mushroom-shaped or laccolithic mass that rose through the conduit beneath the west slope of Breece Hill and raised a part of the sedimentary rocks above the present surface of erosion (pl. 16, section L–L′). It spread in all directions as thick sills, but north of Breece Hill none of the strata above the upper sill remain. The structure around the underlying stock and its junction with the overlying sills is complex and inadequately exposed, but the Gray porphyry incloses large masses of sedimentary rocks showing various degrees of metamorphism and deformation. They have been most extensively explored in the Penn and Breece iron mines. At no other place in the district are the sedimentary rocks so disguised by contact metamorphism and subsequent sericitization. In many places they can be distinguished from the adjacent porphyry only by their banded structure. To the south White porphyry and White limestone below the upper sill of Gray porphyry crop out near the Comstock tunnel and overlie a lower sill of Gray porphyry, which cuts upward to the east through the White limestone. The White porphyry thickens and also cuts upward to the south, and on the west slope of Printer Boy Hill it overlies nearly the entire thickness of Blue limestone. The vertical dikes of Gray porphyry with northward trend which cut the White porphyry and underlying rocks of Printer Boy Hill were mapped by Emmons during the original survey. A dikelike mass of agglomerate with northeastward trend is cut by the Jay Bird tunnel at the head of California Gulch.

Faulting, which has raised this block with respect to those on each side of it, has apparently dragged the strata into an anticlinal position in the northern part, but the folding is so pronounced that it may be due partly to distortion by porphyry intrusions and may also represent a minor anticline formed at the same time as the Colorado Prince anticline, to the east. The anticlinal structure at Printer Boy Hill is associated with the earlier Mike reverse fault rather than with later postmineral faulting.

The ore deposits in this area comprise magnetite and specularite in metamorphic limestone, veins and stockworks in porphyry and metamorphic sedimentary rocks, and, beyond the limits of metamorphism, some comparatively small "blanket" deposits in limestone. Although magnetite-specularite ore was formerly produced in the Breece iron mine for fluxing, ore of this class is of little or no commercial value at present. The main mass of Gray porphyry has been explored in several shafts and tunnels, but no deposit of great width or continuity has been discovered in it, except the stockwork in the Antioch mine, which was worked intermittently in the early days. To the south gold ore has been taken from veins in Printer Boy Hill, and some blanket ores in Blue limestone at this place have been worked in the Lillian mine; but these and other workings in the vicinity have not been studied since Emmons's original survey. To the north much work has been done in the strata beneath the Gray porphyry, and valuable bodies of siliceous gold ore have been mined in the Penn, Nettie Morgan, Little Prince, and Great Hope mines.

AREA BOUNDED BY WESTON, COLORADO PRINCE, SILENT FRIEND, AND WINNIE-LUEMA FAULTS

The area north of the Colorado Prince fault between the Weston fault on the west and the Winnie-Luema and Silent Friend faults on the east is largely covered by the moraines (pl. 7), but with the exception of the north moraine of Evans Gulch the covering is thin. The bedrock structure consists mainly of the deeply eroded Colorado Prince anticline of northwestward trend. The central part of the anticline is granite, separated by a White porphyry sill from the surrounding and overlying Cambrian quartzite. The quartzite is overlain on the north by younger strata in normal succession, except for a thin sill of White porphyry and a thick sill of Gray porphyry just above it, which separate the Blue limestone from the Weber (?) formation. The southeast corner of the area contains the Ollie Reed pipe and a smaller pipe of agglomerate both of which are concealed at the surface and only imperfectly outlined by mine workings. A minor sill of Gray porphyry is exposed in prospects just south of the Ollie Reed pipe, and a small part of the main White porphyry sill reaches the surface just beyond it.

The complicated structure along the southern edge of the block, the result of folding, reverse faulting, later faulting and vein deposition, intrusion of the agglomerate, and still later minor faulting has been exposed in the numerous workings and is illustrated in the sections on Plates 14–17 and 28. The principal ore bodies worked within this area are the Colorado Prince and Big Four veins, which trend southwestward across the Colorado Prince reverse fault. The Silent Friend and Winnie-Luema veins have been worked along the east boundary of the area, but no blanket ore bodies have been found in the limestones west of these veins. Some low-grade oxidized siliceous gold-silver and lead ores have replaced Blue limestone below the north end of the Silver Spoon tunnel, where the Winnie-Luema vein branches and probably dies out.

NORTHEAST CORNER OF LEADVILLE DISTRICT

The northeast corner of the Leadville district is part of a large wedge-shaped block bounded by the Winnie-Luema and Ball Mountain faults on the west and the Mosquito fault on the east. It is crossed by moraines, but only the north moraine along Evans Gulch is very thick. The dominant structure of the tract is homoclinal, the strata dipping northeast at an average of 10° to 15° and a maximum of 30°; but a southeastward continuation of the Colorado Prince anticline and reverse fault is present on the north slope of Ball Mountain, where pre-Cambrian granite and Cambrian quartzite separated by a White porphyry sill are exposed. The structure there is very obscure. White limestone, bounded above and below by sills of White porphyry, is also present on Ball Mountain and in South Evans Gulch. Blue limestone, the most important rock to the miners, extends southward from the Luema mine, where its dip is locally eastward to South Evans Gulch and then turns southeastward. It is separated from the Weber (?) formation most of the way by a White porphyry sill from 30 to 160 feet thick. The dip carries the Blue limestone to lower and lower depths northeastward beneath a thickening cover of Weber (?) shales and grits.

The only other formations of considerable extent that reach the surface are the Josie pipe of agglomerate, in Evans Gulch, and just north of it the triangular mass of Evans Gulch porphyry (quartz monzonite), only the southern part of which is exposed along the edge of the thick moraine. Besides these the workings of the Resurrection mine expose an inclined dike of Gray porphyry that crosscuts the Cambrian quartzite and connects with a sill near the middle of the White limestone. The dike fills a fissure which at one place appears to be a reverse fault offsetting only the strata below the sill (pl. 14, section B–B′); at another place (section C–C′) there is no conspicuous faulting, and along the Yak tunnel it is represented as a normal fault. The structure here is evidently complex and has not been satisfactorily determined. Another dike of Gray porphyry lies along the southern part of the Winnie-Luema fault (section C–C′) but is older than the fault.

The ore bodies of this area include "blankets" or replacement deposits in Blue limestone under Ellen Hill and in the mines along the line of the Yak tunnel. Those in the Resurrection mine connect with vertical veins that fill minor faults of northeastward trend.

AREA BOUNDED BY WESTON, COLORADO PRINCE, MODOC, GARBUTT, AND IBEX NO. 4 FAULTS

The small area bounded by the Colorado Prince, Modoc, and Ibex No. 4 faults may, owing to the obscurity and irregularity of its southern boundary, be at first regarded as part of the large area to the south; but this large area covers a block depressed on all sides whereas the ground under consideration has been comparatively elevated on all but its northeast side, where it is bounded by the Colorado Prince reverse fault. It is roughly triangular, except for the curved southward projection between the Garbutt fault and the southern part of the Ibex No. 4 fault. The bedrock surface is concealed by moraine and mine dumps over all but the southern part of the area, where it is mostly covered by a thin veneer of "wash."

The general structure is irregularly synclinal, as shown in the sections on Plates 14–17 and 28. The surface of the main part of the block consists of Blue limestone and lower formations, whereas that of the southern projection is mainly Weber grit. Sills of White and Gray porphyry are found within the Cambrian quartzite and both limestones. Gray porphyry also overlies the Blue limestone and is intercalated with the lower beds of the Weber (?) formation. It is probable that the apparently continuous area of Gray porphyry that forms much of the bedrock surface contains a considerable proportion of Weber (?) beds which were not recorded during shaft sinking and have not been explored underground. Structural data in the southward projection of the area, so far as they have been recorded, are very obscure. The Garbutt workings apparently extend downward through Weber (?) beds and Gray porphyry to Cambrian quartzite without exposing any of the limestone (fig. 29), which may be locally thrust aside by crosscutting porphyry intrusions or may be so obscured by metamorphism that it has been mistaken for altered porphyry.

Extensive mining has been conducted in this block through the St. Louis and Yak tunnels and the Fannie Rawlings, Big Four, Little Johnny, Black Prince, Little Vinnie, Little Alice, and Ibex No. 1 and No. 2 shafts, but the complications introduced by faults, contact metamorphism, mineralization, and other features, together with the inaccessibility of many of the workings, have prevented a satisfactory interpretation of the geology. The broad general features, however, have been worked out and are presented in the description of the Ibex ore bodies (pp. 295–306).

Prospecting in this block began near its northern and northeastern border, along the outcrop of the steeply dipping Blue limestone, and led to the development of the Fannie Rawlings, St. Louis, Miner Boy, Chemung, Highland Chief (Hunter), and other workings, including the Little Johnny, where mining down the southward-dipping limestone led to the large rich ore bodies of the Ibex mine. Many of the Ibex and neighboring deposits are veins from which "blanket" bodies extend along certain limestone beds. In the Golden Eagle workings many of the veins are only a few inches thick in the porphyry sills but connect with small "blanket" bodies in White limestone (fig. 55).

AREA BETWEEN BALL MOUNTAIN AND WESTON FAULTS

The only rocks that crop out in the area between the Ball Mountain and Weston faults within the Leadville district are "Weber grits" and thick sills of Gray porphyry. As shown in the sections on Plates 14–17 these formations as a whole lie nearly horizontal.

The northwestern corner of the block is cut by the Yak tunnel and the westernmost Ibex workings. Elsewhere the only extensive workings are the Garibaldi tunnel and the Sunday mine, neither of which is deep enough to reach the Blue limestone. The Sunday vein is one of the larger veins of the district.

CHAPTER 6. GEOLOGIC HISTORY

The geologic history of the region may be divided into three parts—deposition of Paleozoic and Mesozoic sediments; igneous intrusion and accompanying deformation and ore deposition; later deformation and upheaval followed by glaciation and postglacial events.

The legible geologic record begins with the close of pre-Cambrian time, when a vast complex of schist, gneiss, and intruded granite had been reduced by prolonged erosion approximately to base-level. Subsidence of this old land caused invasion of the sea from the Pacific region and gave rise to the deposition of quartz sand, which was later consolidated into the Sawatch or Cambrian quartzite. So far as field evidence gathered in the region around Leadville shows, subsidence apparently continued until increased distance from shore caused a gradual change in the character of the sediment from sand to mud and later to calcareous ooze that soon became dolomitized; but study of stratigraphy and fossils from a much more extensive region indicates that in Upper Cambrian time the sea retreated westward from Colorado, which remained land until after the beginning of Ordovician time.

During this interval the Sawatch quartzite was subjected to erosion and in places entirely removed, as in the Monarch district, to the south of Leadville, where the relations between Cambrian and Ordovician rocks indicate that at least the southern part of the present Sawatch Range was elevated above the areas to the east and west. In Ordovician time subsidence of the entire region took place, and the Yule limestone was deposited, either upon the Sawatch quartzite as at Leadville, or upon the pre-Cambrian rocks, as at Monarch. Although no interruptions in sedimentation are clearly indicated in the Yule limestone, the alternation of limestone and shale and the ultimate predominance of shale point to oscillations of land, with elevation finally predominating.

According to evidence based on the study of fossils found outside of the Leadville district, the region became land again for a considerable period, only to subside once more during the last epoch of Ordovician time, when the sand now represented by the Parting quartzite was deposited. This sand was presumably derived from impurities in the White limestone and from Cambrian quartzite and pre-Cambrian granite. The name Yule limestone as now interpreted (to include the White limestone and the Parting quartzite), therefore, does not signify strata deposited continuously but strata separated by at least one unconformity.

Elevation again took place, and the region remained land throughout Silurian and most if not all of Devonian time. Erosion during this long interval evidently accounts for the variations in thickness of the parting quartzite; but the general continuity of the quartzite in spite of the long erosion shows that the land can have attained but little relief. Invasion by the sea during late Devonian time may have caused deposition of the lower beds of the Leadville limestone, though the evidence in the Leadville district regarding the age of these beds is very obscure. Land again existed for a brief interval at the beginning of Mississippian time, but the sea advanced early in Mississippian time, when the greater part of the Leadville limestone was deposited. These repeated changes of level were accompanied by so little disturbance of strata that unconformities which are known from fossil evidence to represent long intervals of erosion are very obscure. An angular unconformity between the Leadville limestone and Parting quartzite has thus been detected at only one place in the region around Leadville. It may be that at some places beds of Devonian age and at others beds of Mississippian age rest upon the Parting quartzite.

The Leadville limestone and older formations are so generally uniform in composition and texture as to afford almost no local evidence regarding the location of shore lines during Mississippian and earlier time. Regional evidence, however, indicates that the shore lines lay in eastern and at times in southern and southwestern Colorado, and that the sea which periodically invaded central Colorado connected northwestward and at times southwestward with the Pacific Ocean.[1] The only noteworthy local evidence is the sandstone within the Leadville limestone, which is most conspicuous in the western part of the district and suggests a shore line in the vicinity of the present Sawatch Range, where an island may have existed while part or all of this limestone was being deposited. With this exception, there is no evidence that islands of pre-Cambrian rock existed, as at first supposed by Emmons, throughout Paleozoic time.

Central Colorado was land during the last half of the Mississippian epoch but subsided again early in Pennsylvanian time, when the shales ("Weber shales") at the base of the Weber (?) formation were deposited. The fossils in the shales prove them to be of Pacific

[1] Schuchert, Charles, Paleogeographic maps of North America: Geol. Soc. America Bull., vol. 20, pp. 427-606, pls. 46-101, 1910.

marine origin, but the associated beds of impure coal indicate intermittent marshy conditions and perhaps deposition in fresh water on a low-lying coast. Elevation of the land immediately to the east and northeast of the Leadville, Alma, and Tenmile regions increased the relief and the rate of erosion and caused rapid deposition of the "Weber grits" above the shales. Intermittent changes during this epoch were marked by the deposition of shale and limestone. The limestone, which was dolomitic in composition, was doubtless of marine origin, but remains of land plants (Equisetaceae) in the upper beds of grit indicate deposition in fresh water or shallow ocean water close to shore.

That the position of the shore line during Weber (?) time was in the vicinity of Breckenridge is suggested by the absence there of any "Weber grits" between the "Wyoming" formation and the pre-Cambrian granite. The similarity in mineral composition between the "Weber grits" and the Maroon and "Wyoming" formations implies similar conditions of erosion, and the distribution of the three formations indicates gradual subsidence of the land whereby newly deposited strata overlapped progressively eastward.[2] Oscillations resulting in brief intervals of erosion may have occurred, but proof of them has not been detected. With this vast accumulation of detritus from the pre-Cambrian rocks that constituted the old land, the Paleozoic era came to a close.

During the greater part of Mesozoic time[3] (all of the Triassic and Jurassic) the region around Leadville remained above sea level, although it was probably covered at two or three different times by continental deposits. No trace of these deposits remains to-day, however, and Mesozoic time, including the Lower Cretaceous epoch, was in the main an interval of erosion, during which the entire Rocky Mountain region of Colorado was reduced practically to base-level.[4] How much of the Mesozoic and late Carboniferous rocks was eroded from the Leadville region at this time is not known. Gradual subsidence of this base-leveled land during Upper Cretaceous time was accompanied by an advance of the sea from the Gulf region and deposition of the Dakota sandstone and overlying shales.

The Cretaceous closed with the Laramide revolution, which raised the Rocky Mountain region permanently above sea level. Considerable folding of the strata took place at this time and was accompanied by reverse faulting. Folding was preceded at Leadville and elsewhere by the intrusion of sills of monzonitic and granodioritic porphyry. It was followed at some places by batholithic and stocklike intrusions of monzonitic rock. Closely following these stocklike intrusions, normal faults and fissures were developed, and along these openings mineralized waters rose and spread along the strata at favorable places, particularly along limestone beds beneath impervious covers of porphyry or shale.

This great uplift, accompanied by rapid erosion, continued during Tertiary time, formed the large post-mineral faults at Leadville, and gave rise to the Rocky Mountains in essentially their present form. Late in Tertiary (Pliocene) time or early in Quaternary time climatic change caused the first stage of glaciation and deposition of the "lake beds." Two later stages of glaciation accompanied by the deposition of moraines and high terrace gravel followed, and from then until the present time the region has been subjected to erosion and occasional renewal of faulting.

As erosion during Tertiary time gradually brought the ore bodies above the level of ground water, which was comparatively deep, oxidation and local enrichment of the ores began, and these processes were far advanced before their interruption by the glacial stages, when circulation above the level of ground water was negligible. Oxidation was renewed during interglacial stages, but the ore bodies, already deeply oxidized and buried beneath thick glacial deposits, were but little affected. Erosion during interglacial stages deepened gulches and reopened them where they had been obstructed by moraines or high terrace gravel. Erosion and oxidation since glacial time have been comparatively insignificant. The oxidation of ores is considered fully in chapter 12 (pp. 248–273).

[2] Ransome, F. L., Geology and ore deposits of the Breckenridge district, Colo.: U. S. Geol. Survey Prof. Paper 75, p. 33, 1911.

[3] This statement assumes that the "Wyoming" (Lykins?) formation is of Permian age.

[4] Lee, W.T. op. cit., pp. 27–40.

PART III. ORE DEPOSITS

Chapter 7. PRODUCTION, HISTORY, AND MINE DEVELOPMENT [1]

By Charles W. Henderson

LEADVILLE'S RANK AMONG MINING DISTRICTS

The Leadville district ranks sixth among the mining districts of the United States in total value of nonferrous metals produced. From 1860, when the first placer gold was shipped, to the end of 1923 this value amounted to $425,784,550, of which 12 per cent represented gold, 45 per cent silver, 20 per cent lead, 20 per cent zinc, and 3 per cent copper (fig. 38).

This value does not include that of manganiferous iron ores sold for the manufacture of ferromanganese; that part of the pyrite sold for its sulphur content only, exclusive of precious metal bearing pyrite first roasted for the manufacture of sulphuric acid, and bismuth. These minor products aggregate less than $4,000,000. The grand total is still incomplete, however, for in the early years of the district mixed hematite and magnetite, low in silica, containing as much as 68.3 per cent of iron, was shipped from the Breece iron mine to steel mills, but no record of totals is available.

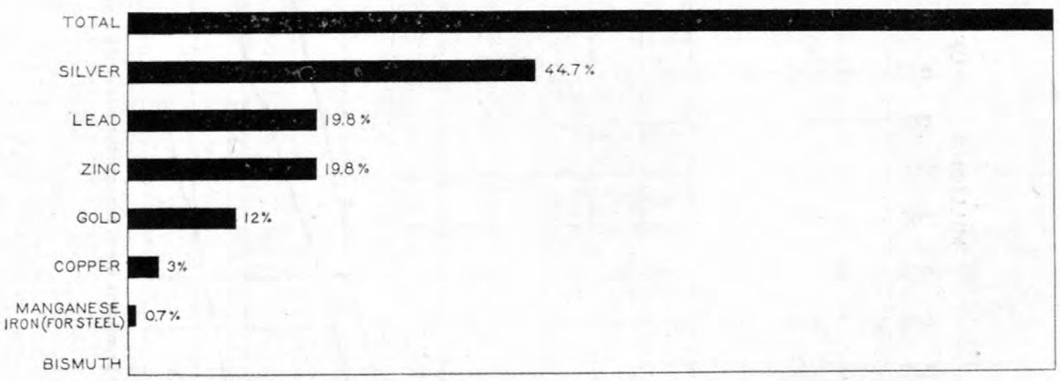


Figure 38.—Value of metals produced in Leadville district, 1860-1923

The rank of Leadville and other prominent mining districts in the country is represented in Figure 39. In this figure the curve of Leadville production is interesting in that it is steepest for the earlier years but gradually assumes a lower and lower slope, owing largely to decrease in richness of the ores and in recent years to decrease in tonnage. The districts that surpass Leadville, except the Comstock, show curves whose still-increasing steepness expresses a persistent increase in tonnage and maintenance of richness and indicates that these districts have not yet attained the zenith of their productive capacity.

The Butte district of Montana is easily the most productive district in the United States, and the Lake Superior copper region is second. The vast sums which these two districts have added to the world's wealth are exceeded by only two mining districts—the Rand gold fields of South Africa, with a production of 163,623,725 fine ounces, valued at $3,382,102,536, from 1887 to 1922, and perhaps the Veta Madre of Mexico, with a production estimated at $800,000,000 to $1,000,000,000 up to 1883. The Bingham, Coeur d'Alene, and Joplin districts also exceed Leadville in the magnitude of their product.

The figure is especially interesting in showing the subordinate position still occupied by many districts like Goldfield, Tonopah, and Cripple Creek, whose phenomenal rise within the last 30 years has been the subject of so much public discussion that it may have given an exaggerated impression of their total output.

Until 1891 the Leadville district was exceeded in value of output only by the Lake Superior copper district and the Comstock lode, but in that year it was passed by the Butte district, falling into fourth place, and in 1912 it was outranked by the Joplin region.

[1] Many details in this chapter are taken from Mineral Resources, 1908-1923. For more complete details the reader should consult these reports.

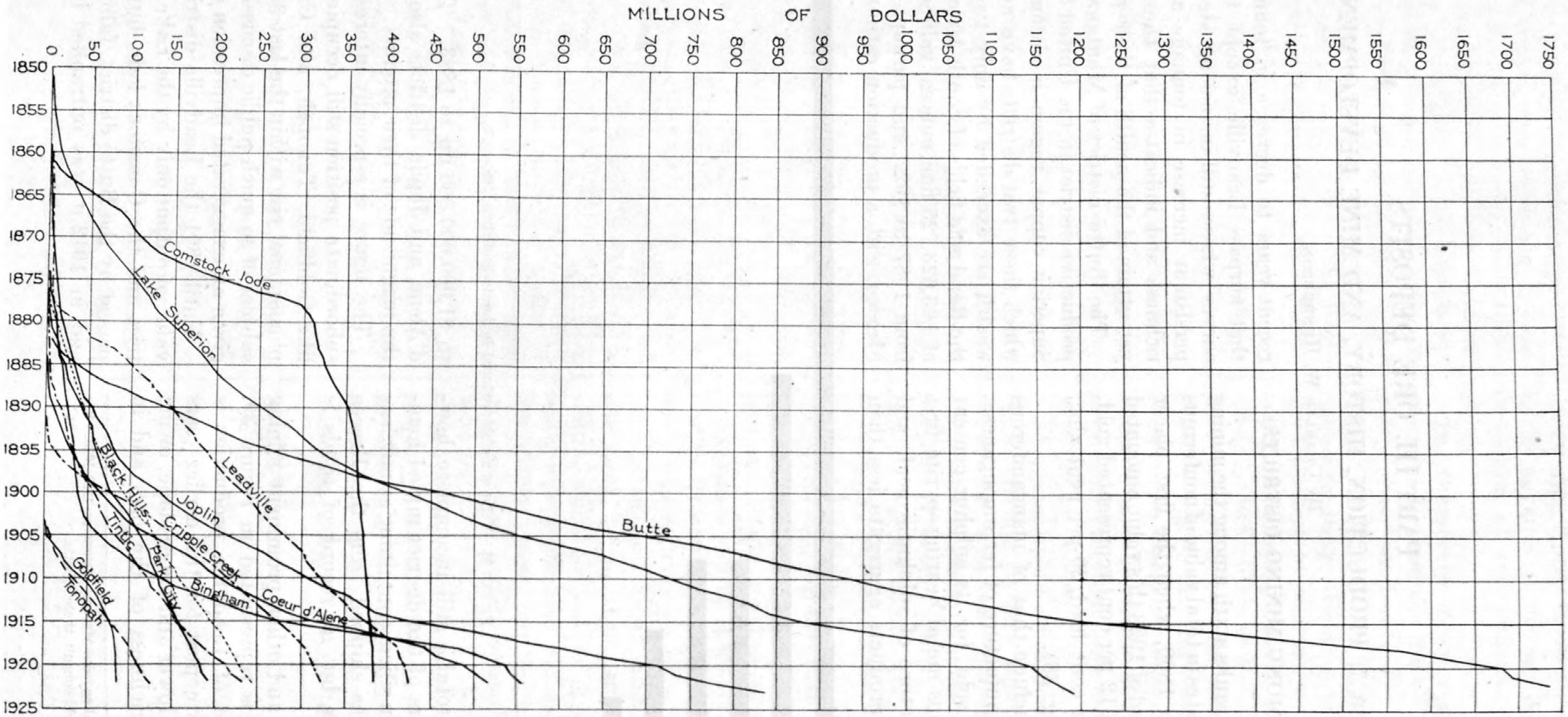


FIGURE 39.—Total value of metals produced by prominent metal-mining districts of the United States, 1860–1923. Curves show for each year the total up to that time

LEADVILLE'S PRODUCTION OF METALS, 1860–1923

SUMMARY

The accompanying statistics have been compiled from the most reliable sources available, principally the United States Mint reports, the annual volumes of Mineral Resources of the United States, and the Leadville newspapers. For the years prior to 1911 only figures for Lake County as a whole are available, but as the output of the other districts (St. Kevin, Twin Lakes, Sugar Loaf, Lackawanna Gulch, Tennessee Pass, Homestake Mountain, Weston Pass, Alicante, and Big English Gulch) aggregates less than 1 per cent of the annual totals the county figures represent the Leadville district satisfactorily. The Sugar Loaf district has made a regular but comparatively small production since 1881 or possibly earlier.

The values given on page 112 have been computed from the average annual market price of each metal. For many years it was the custom of the United States Mint to figure the annual value for silver by multiplying the coinage value of the silver by the number of ounces produced, a procedure which results in a figure above the actual sale price of the refined silver. The table gives the output of the area now included in Lake County. In the earlier years Lake County included what is now Chaffee County, but the output of that portion has been deducted.

Further details as to the source of the figures are given in the history of mining in Colorado recently published.[2]

The quantity and value of the annual output from 1860 to 1922 are shown in Figure 40. The production of each metal for the same period is shown in Figures 42 and 43, and the corresponding percentages of total annual value are shown in Figure 41. According to these charts the history of the district may be divided into three periods in which the predominating metals were successively gold, silver and lead, and zinc.

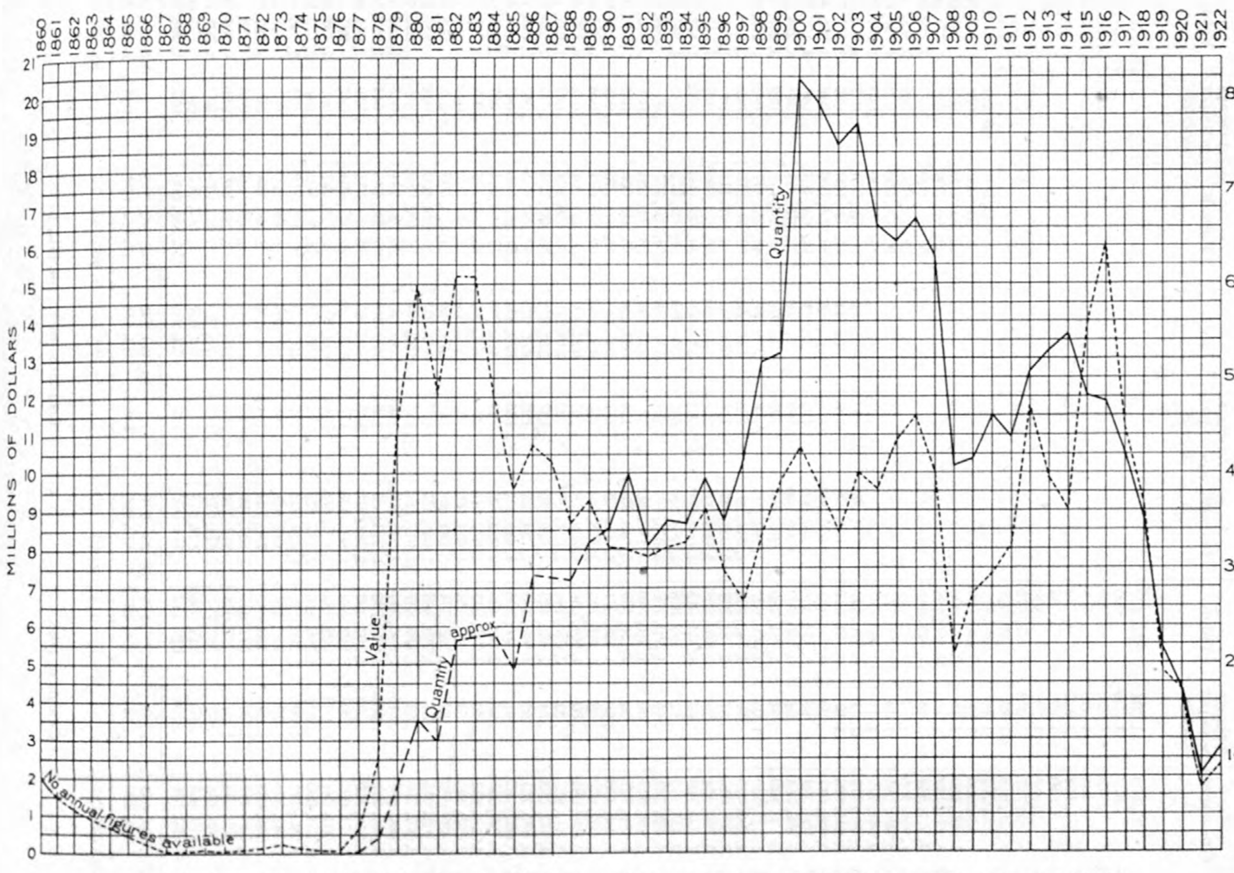


FIGURE 40.—Total quantity and value of gold, silver, lead, zinc, and copper ore shipped from Lake County, 1860–1922

GOLD PERIOD, 1860–1875

DISCOVERY OF PLACER GOLD[3]

The history of the discovery of the Leadville deposits presents a striking picture of the life of the pioneer miner in the West and of the large element of chance connected with it. This history is therefore given here with all the fullness of detail which the somewhat imperfect data obtainable will allow.

[2] Henderson, C. W., Mining in Colorado: U. S. Geol. Survey Prof. Paper 138, pp. 130–175, 1926.

[3] The following paragraphs to page 118 are adapted from U. S. Geol. Survey Mon. 12, 1886, with very little change.

Gold, silver, copper, lead, and zinc recovered in Lake County, 1859–1926

Year	Ore (short tons, dry weight)	Gold (value)			Silver			Copper			Lead			Zinc			Total value
		Placer	Lode	Total	Fine ounces	Average price per ounce	Value	Pounds	Average price per pound	Value	Pounds	Average price per pound	Value	Pounds	Average price per pound	Value	
1859–1867		$5,272,000		$5,272,000	37,600	$1.341	$50,422										$5,322,422
1868		60,000		60,000	452	1.326	600										60,600
1869		80,000	$10,000	90,000	679	1.325	900										90,900
1870		65,000		65,000	465	1.328	618										65,618
1871		50,000	50,000	100,000	1,158	1.325	1,534										101,534
1872		66,500	66,500	133,000	1,540	1.322	2,036										135,036
1873		75,000	150,000	225,000	2,937	1.297	3,809										228,809
1874		70,000	143,503	213,503	2,797	1.278	3,575										217,078
1875		17,237	25,862	43,099	16,668	1.24	20,668										63,767
1876		30,000	30,000	60,000	23,203	1.16	26,915				15,000	$0.061	$915				87,830
1877		[a]30,000	25,000	55,000	458,000	1.20	549,600				1,200,000	.055	66,000				670,600
1878		[a]30,000	30,000	60,000	1,800,000	1.15	2,070,000				10,000,000	.036	360,000				2,490,000
1879		30,000	60,000	90,000	8,411,132	1.12	9,420,468				43,288,000	.041	1,774,808				11,285,276
1880	[b]140,623	70,000	34,014	104,014	9,977,344	1.15	11,473,946				66,658,000	.05	3,332,900				14,910,860
1881		69,000	231,000	300,000	7,966,406	1.13	9,002,039				58,464,000	.048	2,806,272				12,108,311
1882		63,500	256,500	320,000	8,894,531	1.14	10,139,765				97,890,000	.049	4,796,610				15,256,375
1883		25,000	375,000	400,000	9,049,219	1.11	10,044,633				111,575,000	.043	4,797,725				15,242,358
1884	[c]232,002	30,000	470,000	500,000	7,270,313	1.11	8,070,047	[a]100,000	$0.13	$13,000	93,628,000	.037	3,464,236				12,047,283
1885		[a]15,000	555,000	570,000	6,441,693	1.07	6,892,612	[a]100,000	.108	10,800	55,522,000	.039	2,165,358	50,000	$0.043	$2,150	9,640,920
1886		[a]5,000	428,691	433,691	6,486,047	.98	6,421,187	[a]100,000	.111	11,100	84,400,000	.046	3,882,400	50,000	.044	2,200	10,750,578
1887			243,694	243,694	5,994,324	.98	5,874,438	[a]200,000	.138	27,600	92,359,103	.045	4,156,160	50,000	.046	2,300	10,304,192
1888			310,891	310,891	5,486,064	.94	5,156,900	[a]200,000	.168	33,600	73,378,149	.044	3,228,639	150,000	.049	7,350	8,737,380
1889			189,397	189,397	6,150,839	.94	5,781,789	266,489	.135	35,976	83,785,918	.039	3,267,651	150,000	.05	7,500	9,282,313
1890	342,163		295,063	295,063	5,313,930	1.05	5,579,627	1,766,035	.156	275,501	43,623,477	.045	1,963,056	150,000	.055	8,250	8,121,497
1891	403,135	2,894	345,525	348,419	4,793,015	.99	4,745,085	4,544,202	.128	581,658	53,444,973	.043	2,298,134	150,000	.05	7,500	7,980,796
1892	323,187	9,000	242,296	251,296	5,898,020	.87	5,131,277	5,928,863	.116	687,748	44,009,114	.04	1,760,365	562,500	.046	25,875	7,856,561
1893	351,794		902,244	902,244	6,795,454	.78	5,300,455	5,000,000	.108	540,000	36,274,889	.037	1,342,171	[c]735,000	.04	29,400	8,114,270
1894	347,143		1,499,314	1,499,314	7,695,108	.63	4,847,918	4,000,000	.095	380,000	44,733,000	.033	1,476,189	[a]1,000,000	.035	35,000	8,238,421
1895	394,710		1,386,359	1,386,359	9,435,413	.65	6,133,018	2,803,550	.107	299,980	38,922,572	.032	1,245,522	1,265,000	.036	45,540	9,110,419
1896	349,333		1,453,458	1,453,458	6,623,764	.68	4,504,160	4,071,761	.108	439,750	31,993,777	.03	959,813	642,000	.039	25,038	7,382,219
1897	413,552		2,063,858	2,063,858	5,451,317	.60	3,270,790	3,146,802	.12	377,616	23,700,908	.036	853,233	2,201,500	.041	90,262	6,655,759
1898	517,992		2,073,036	2,073,036	7,068,727	.59	4,170,550	5,543,954	.124	687,450	35,945,006	.038	1,365,910	2,673,500	.046	122,981	8,419,927
1899	525,728		2,196,498	2,196,498	7,230,118	.60	4,338,071	3,202,828	.171	547,684	48,598,720	.045	2,186,942	10,575,240	.058	613,364	9,882,559
1900	618,071		2,529,512	2,529,512	6,967,279	.62	4,319,713	2,728,553	.166	452,940	62,599,654	.044	2,754,385	14,441,000	.044	635,404	10,691,954
1901	793,014		1,776,132	1,776,132	6,830,084	.60	4,098,050	1,930,556	.167	322,403	56,359,708	.043	2,423,467	23,167,140	.041	949,853	9,569,905
1902	748,946		1,203,924	1,203,924	5,641,857	.53	2,990,184	2,611,167	.122	318,562	39,450,178	.041	1,617,457	47,637,490	.048	2,286,600	8,416,727
1903	770,000		1,339,974	1,339,974	4,973,033	.54	2,685,438	2,556,583	.137	350,252	36,353,239	.042	1,526,836	76,566,000	.054	4,134,564	10,037,064
1904	663,487		1,186,851	1,186,851	5,085,151	.58	2,949,388	3,734,593	.128	478,028	47,180,865	.043	2,028,777	58,254,353	.051	2,970,972	9,614,016
1905	648,464		1,180,401	1,180,401	4,033,762	.61	2,460,595	4,486,115	.156	699,834	51,162,040	.047	2,404,616	70,238,634	.059	4,144,079	10,889,525
1906	672,055	264	1,508,146	1,508,410	3,890,338	.68	2,645,430	2,092,735	.193	403,898	47,456,964	.057	2,705,047	70,198,462	.061	4,282,106	11,544,891
1907	631,273	510	1,064,180	1,064,690	4,154,913	.66	2,742,243	2,679,510	.20	535,902	32,519,796	.053	1,723,549	67,247,381	.059	3,967,595	10,033,979
1908	408,711		1,228,449	1,228,449	2,893,496	.53	1,533,553	4,674,502	.132	617,034	19,646,007	.042	825,132	23,188,080	.047	1,089,840	5,294,008
1909	417,297		1,435,431	1,435,431	3,423,642	.52	1,780,294	5,182,608	.13	673,739	21,073,992	.043	906,182	38,637,315	.054	2,086,415	6,882,061
1910	462,033		1,213,134	1,213,134	3,322,015	.54	1,793,888	3,645,157	.127	462,935	19,249,503	.044	846,978	56,367,445	.054	3,043,842	7,360,777
1911	438,419		1,133,442	1,133,442	3,007,296	.53	1,593,867	4,017,504	.125	502,188	18,499,089	.045	832,459	71,610,456	.057	4,081,796	8,143,752
1912	507,591		1,103,230	1,103,230	3,000,397	.615	1,845,244	2,065,800	.165	340,857	26,234,244	.045	1,180,541	105,945,783	.069	7,310,259	11,780,131
1913	528,311		1,023,631	1,023,631	3,400,318	.604	2,053,792	1,923,987	.155	298,218	29,286,183	.044	1,288,592	93,842,857	.057	5,255,200	9,919,433
1914	547,463		1,571,451	1,571,451	3,810,830	.553	2,107,389	2,382,910	.133	316,927	26,784,615	.039	1,044,600	78,763,334	.051	4,016,930	9,057,297
1915	481,620	69,009	2,177,143	2,246,152	2,571,002	.507	1,303,498	1,803,423	.175	315,599	20,957,404	.047	984,998	72,493,178	.124	8,989,154	13,839,401
1916	477,240	119,169	1,601,271	1,720,440	2,931,281	.658	1,928,783	2,621,675	.246	644,932	21,719,392	.069	1,498,638	76,785,567	.134	10,289,266	16,082,059
1917	422,428	110,325	1,064,894	1,175,219	2,184,000	.824	1,799,616	2,182,623	.273	595,856	18,301,802	.086	1,573,955	60,254,333	.102	6,145,942	11,290,588
1918	355,840	92,066	751,173	843,239	2,290,121	1.00	2,290,121	1,626,534	.247	401,754	22,469,915	.071	1,595,364	46,715,736	.091	4,251,132	9,381,610
1919	217,667	81,688	544,268	625,956	1,542,324	1.12	1,727,403	888,628	.186	165,285	11,299,076	.053	598,851	23,165,219	.073	1,691,061	4,808,556
1920	172,988	138,864	629,501	768,365	1,099,688	1.09	1,198,660	799,744	.184	147,153	8,590,188	.08	687,215	18,754,531	.081	1,519,117	4,320,510
1921	80,501	6,184	302,960	309,144	1,043,497	1.00	1,043,497	1,107,295	.129	142,841	3,537,889	.045	159,205	1,821,000	.05	91,050	1,745,737
1922	112,547	315	412,743	413,058	952,048	1.00	952,048	871,370	.135	117,635	5,521,818	.055	303,700	9,003,000	.057	513,171	2,299,612
1923	115,975	15,224	256,280	271,504	655,838	.82	537,787	511,776	.147	75,231	5,624,958	.07	393,747	9,415,000	.068	640,220	1,918,489
1924	165,593	23,453	956,701	980,154	519,460	.67	348,038	122.878	.131	16,097	9,687,587	.08	775,007	9,191,000	.065	597,415	2,716,711
1925[d]	217,765	36,260	407,725	443,985	892,135	.694	619,142	171,000	.142	24,282	13,888,000	.087	1,208,256	7,460,000	.076	566,960	2,862,625
Total 1859–1925		6,858,462	45,745,250	52,603,712	231,894,082		190,377,113	100,393,710		14,369,845	1,948,863,712		87,438,563	1,251,569,034		86,574,653	431,363,886
1926[d]				375,539	635,300	.624	396,427	112,000	.138	15,456	17,882,000	.083	1,484,206	22,100,000	.073	1,613,300	3,884,928
				52,979,251	232,529,382		190,773,540	100,505,710		14,385,301	1,966,745,712		88,922,769	1,273,669,034		88,187,953	435,248,814

[a] Estimated by C. W. Henderson. [b] Census of 1880. [c] Emmons, S. F., op. cit., p. 18. [d] Estimates subject to revision.

The earliest published record of exploration of the valley of the upper Arkansas was that made by the third expedition of Frémont in 1845. In his second expedition, in 1842, Frémont had aimed at tracing Arkansas River to its source, but, unwittingly leaving the main stream, he had followed up the Fontaine qui bouille, now called Fountain Creek, probably passing near the present site of Denver, and struck into the mountains at some point nearly opposite that place. In 1845, however, as indicated by General Warren, he probably entered the mountains near the place where Canon City now stands and crossed the south end of South Park, reaching the upper Arkansas Valley through the valley of Trout Creek. Thence, following the Arkansas to its head, he crossed what was then called Utah Pass and descended Eagle or Piney River to its confluence with the Grand, now the Colorado. It seems probable, therefore, that the name Frémont Pass, which is given to that of Tenmile Creek, would have been more appropriately applied to Tennessee Pass, which divides Eagle River from the head of the Arkansas. There is little doubt that this striking valley was afterward visited by trappers and individual explorers,[1] but of such visits no record is known to have been left. This region, like that of the parks, formed part of the debatable ground between the tribes of the Arapahoes and Utes, who were constantly at war with each other and who made excursions to these mountain valleys simply for the purpose of hunting and without any permanent occupancy.

During the spring, summer, and fall of 1859, at the time of the great "Pikes Peak excitement," a continuous stream of emigrant wagons stretched across the plains, headed chiefly for Gregory diggings, by three routes, all destined for what was broadly called the Pikes Peak region. As is generally the case in such mining rushes, the golden dreams of many of those attracted by the marvelous stories of the wealth that existed in the streams issuing from the mountains were never realized. Many of the wagons that had crossed the plains in the early summer, carrying the triumphant device "Pikes Peak or bust," returned later over the same route with this device significantly altered to "Busted." The more adventurous and hardy of these pioneers pushed resolutely up through the rocky gorges toward the sources of the streams. Some of these found gold in North and South Clear creeks, in Russell Gulch, and on North, South, and Middle Boulder creeks, where the first mining developments were made within the State and where now stand the mining towns of Idaho Springs, Central City, Blackhawk, Rollinsville, and Gold Hill and

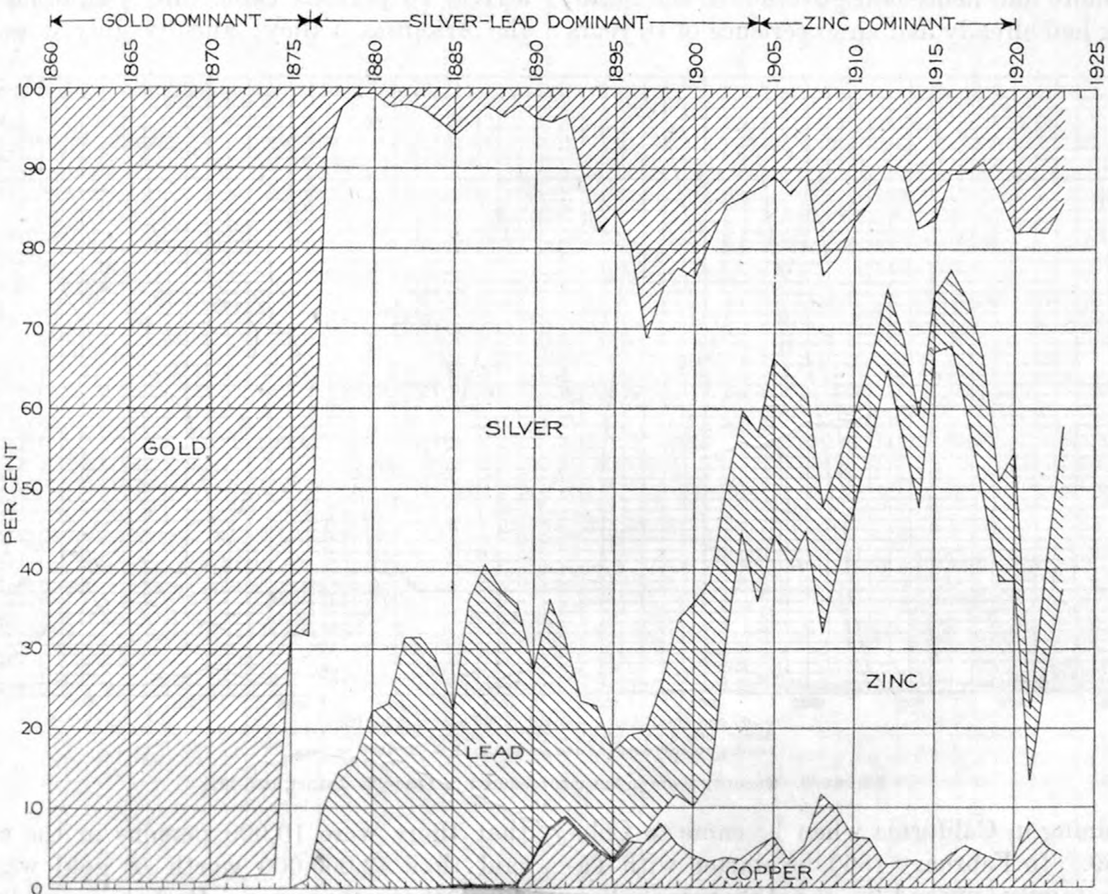


FIGURE 41.—Production of metals in Leadville district, 1860-1923, in percentages of total annual value

[1] Recent studies indicate that trappers and individual explorers visited this region even before Frémont.—C. W. H.

the university city of Boulder. Others wandered across the Colorado Range into South Park and found gold-bearing deposits on its northern border, in Tarryall Creek, and on the Platte in the neighborhood of Fairplay. Others went up Michigan Creek and crossed over to Georgia Gulch and found gold near the present town of Breckenridge. Still others crossed over Trout Creek Pass into the Arkansas River valley and found gold on Cache Creek, Lake Creek, and Clear Creek and in the bed of the Arkansas.

Early in the spring of 1860 parties of prospectors were mining or prospecting the headwaters of the Arkansas. Among them were Samuel B. Kellogg, later justice of the peace at Granite, and H. A. W. Tabor, later millionaire and lieutenant governor of the State. Mr. Kellogg had already had an experience of 10 years in placer mining in California when he came to Colorado in 1859. In February 1860, he started with Tabor and his family, pushed up the Arkansas Valley, and about April 1 settled down at the site of the present town of Granite, 18 miles below Leadville. Here, having discovered gold in Cache Creek, where placer deposits were worked until 1911, they whipsawed lumber to make sluices for washing its gravels. A few days after their arrival news was brought to them of the discovery of gold in California Gulch.

Prospectors had, it seems, already preceded them. Foremost among the names of California Gulch pioneers are those of Slater, Currier, Ike Rafferty, George Stevens, Tom Williams, and Dick Wilson, from the last of whom many of the following facts were obtained. The first hole dug in California Gulch was about 200 feet above the site of the present Jordan tunnel; the second just below the now abandoned town of Oro. Owing to the richness of the ground and the number of the persons present, gold was discovered at an unusual number of points, and 14 discovery claims of 100 feet each were located. Kellogg and Tabor met the prospectors at the mouth of Iowa Gulch, as they returned from locating the discovery claims, and agreed to prospect that gulch. They returned to Cache Creek for provisions and went finally to California Gulch on April 26, 1860, as Iowa Gulch had yielded little fruit to their labors.

In spite of the difficulties of communication in this wild region, the news of the rich discovery of gold spread with amazing rapidity. The day after their arrival 70 persons came into California Gulch from the Arkansas Valley; and by July it was estimated that there were 10,000 persons in the camp. It is said that $2,000,000 worth of gold was taken out during the first summer. Probably considerable deductions may be made from this estimate to allow for the exaggeration that fills men's minds in moments of such excitement. The record of claims located, however, shows enormous activity in mining during this summer. In California Gulch alone 339 claims, each 100 feet in width, were located. Some of the miners are said to have carried away from $80,000 to $100,000 each as the result of their first summer's labor. Tabor and Kellogg worked their own claims and made about $75,000 in six days. The total production of the placer claims is generally stated at $5,000,000 to $10,000,000, but a more conservative estimate places it at $2,500,000 to $3,000,000. The climax was soon reached, and after the first year the population of this

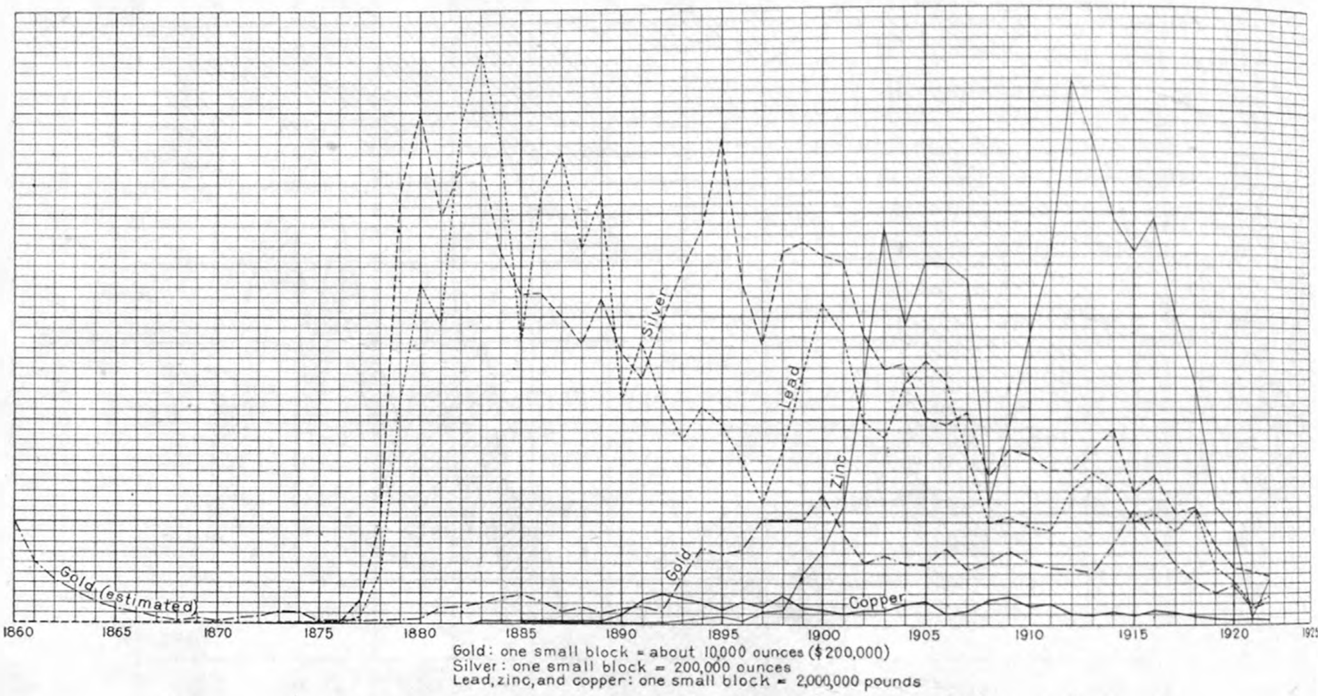


FIGURE 42.—Quantity of ore and metals produced in Leadville district, 1860-1922

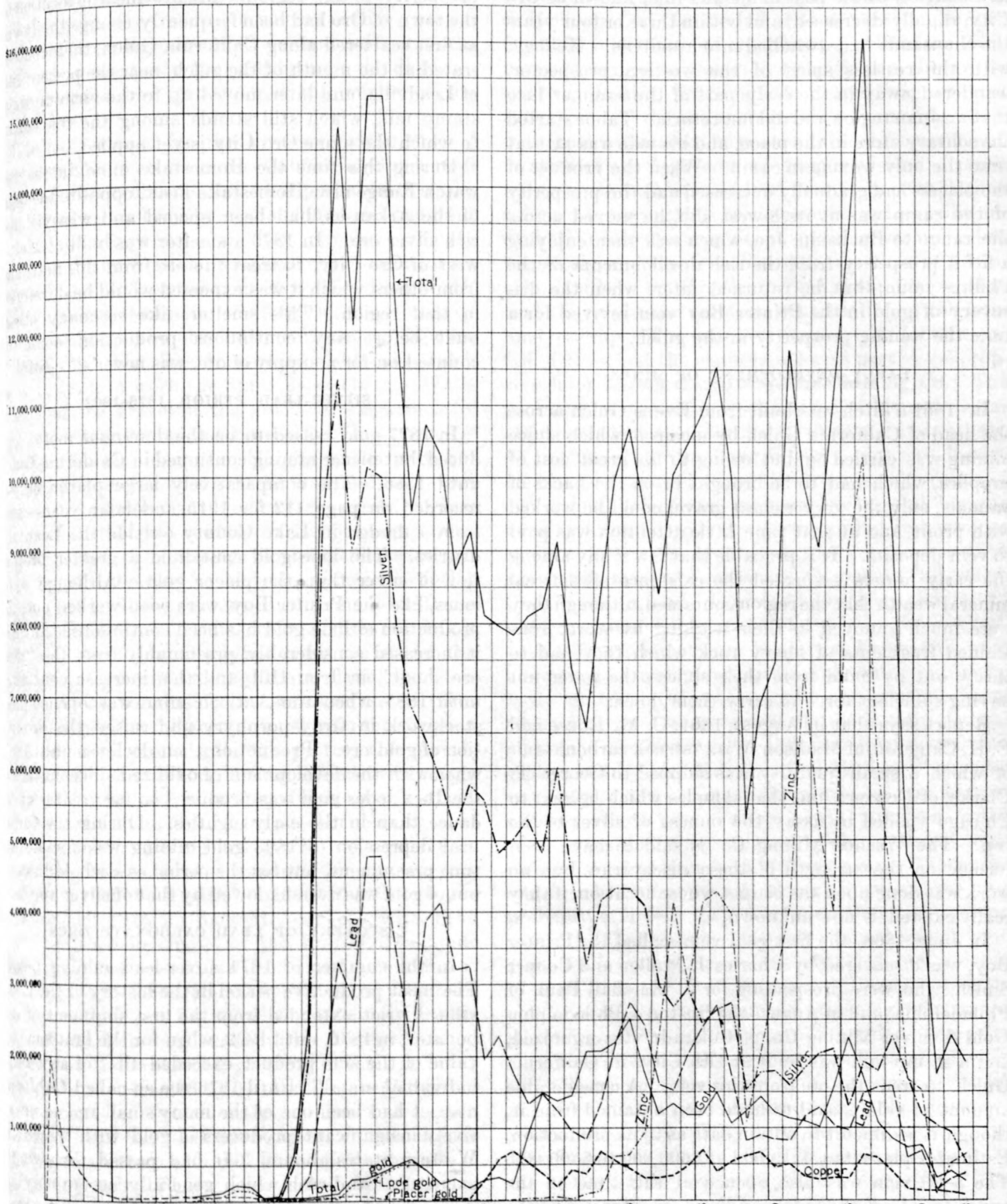


FIGURE 43.—Value of ore and metals produced in Leadville district, 1860–1923

new district, whose post office was then known as Oro City, rapidly decreased, and within three or four years the thousands had dwindled into hundreds. Kellogg, with the restless spirit of the western prospector, wandered away in the early part of the summer into the San Juan region and did not return. Tabor started the solitary store in the place, and his wife was at that time the only woman in camp. When the product of the placers had gradually decreased and the prosperity of the camp was at its lowest ebb, he moved across the range to Buckskin Joe, which was then enjoying a fitful prosperity from the rich developments of the Phillips mine; but he returned later, when the discovery of gold in the Printer Boy vein revived for a time the waning prosperity in the gulch.

EARLY DEVELOPMENT OF MINES

In 1861 a ditch was built from Evans Gulch across the head of California Gulch by means of which sluice mining was carried on, but owing to the great cost of supplies, which had to be brought in on the backs of animals, only the very richest gravel could be worked with profit, and at that time little attention was paid to vein deposits. It is probable that few if any among the early miners suspected the existence of the real mineral wealth that the region contained, although they were much annoyed in their working by worn, iron-stained fragments of heavy rock which they had to throw out by hand from their sluices, the water not having sufficient force to carry them down.

Report says that in August, 1861, C. M. Rouse and C. H. Cameron, of Madison, Wis., "struck carbonates," of which a small quantity was shipped to George T. Clarke, of Denver; and that samples which he sent to Chicago yielded by assay 164 ounces of silver to the ton. The Washoe Mining Co. is said to have been formed on the strength of these discoveries, but no work was done upon the claims, whose location, if they really existed, is now unknown.

In June, 1868, the first gold vein, called the Printer Boy, was discovered by Charles J. Mullen and Cooper Smith, who were prospecting for J. Marshall Paul, of Philadelphia, and in August the Boston & Philadelphia Gold & Silver Mining Co. of Colorado was organized, and a stamp mill was built at Oro City, in California Gulch, to treat the ore from this vein. A considerable amount of gold is said to have been obtained from it, though it is difficult to obtain data as to its production. Estimates place its total yield at $600,000 to $800,000. The 5–20 vein was also opened at this time on the opposite side of the gulch, and also an extension of the Printer Boy, called the Lower Printer Boy. A 5-stamp mill was erected on the 5–20 property in 1871. The working of these mines, in which the gold was found in nests of lead carbonate, was carried on more or less continuously until 1877 and imparted at times a fitful prosperity to the region. Meanwhile the location of the town of Oro had been frequently changed. It was at first scattered along California Gulch, then concentrated at the mouth of the gulch, near the present city of Leadville, and later moved up to the vicinity of the stamp mill, which still stands among the few cabins to which the name Oro City is yet applied.

During this time the Homestake mine, in the Sawatch Range near Homestake Peak, opposite the head of the Arkansas, had been opened and was yielding rich silver ore. In 1875 a smelter was built at Malta, west of Oro City, to treat the ore from this mine and from others which it was expected would be developed in that region. This smelter, like so many others built before any continuous production could be counted on for a supply of ore, was never successful.

SILVER-LEAD PERIOD, 1876–1902

In 1877 gold ceased to be the dominant metal produced, but placer mining continued in California Gulch until 1886. The comparatively large placer output recorded on page 112 for 1915 and later years came from a dredge in Lake County outside the Leadville district. The lode gold contained a greater proportion of silver than the placer gold. Although some lodes, like the Printer Boy, were soon worked out, the production of lode gold has been continuous. In 1881 it increased considerably, presumably from the "gold ore shoot" in Iron Hill, and this increase continued until 1885, when the Antioch mine was opened in a stockwork in Gray porphyry and raised the production of gold ore. Production then declined until 1891, when with the development of oxidized siliceous ores in the Ibex lodes gold was produced in far greater abundance than in the early eighties. During the industrial depression of 1893 gold mining was for a short time preeminent, but for the period as a whole the output of gold was overshadowed by that of silver and lead.

DISCOVERY OF LEAD CARBONATE ORES

In the summer of 1874 silver-lead mining began. The most productive period in the history of the Leadville district extended from the first shipment of carbonates, in 1876, until 1902, when for the first time the value of the zinc product exceeded that of any other individual metal. Until 1876 the so-called California district had been one of the many small and comparatively insignificant producers of gold with which the Western States abound. It had passed through the excitement and rush which generally accompany the discovery of rich placer gold, rapidly attained a maximum production in the year following the discovery, and then as rapidly declined. Owing to the waning production after 1869 Oro City was in 1874 almost deserted, only a few of the 10,000 miners remaining to earn a scant return from a few still profitable claims.

The site of the present city of Leadville was an unbroken wilderness, and no suspicion of the existence of the immense deposits of silver-lead and zinc ores that were to constitute the chief basis of the district's mineral wealth had yet entered the minds of the prospectors.

If it had not been for the extensive experience of two men who had come to California Gulch well equipped with technical skill it is probable that the region would soon have been abandoned and the great bodies of silver-lead ores would have remained securely concealed to await the chance discovery of some future generation. To these two men, A. B. Wood and W. H. Stevens, is due the credit of being the first to recognize the value of the now famous carbonate deposits of Leadville. Mr. Wood came to California Gulch in April, 1874, to work the Starr placer claim. While examining the gravel in the gulch he was struck by the appearance of what the miners call "heavy rock," some of which he assayed. His specimens were not rich, yielding only 27 per cent of lead and 15 ounces of silver to the ton; but the matter seemed to him worthy of further investigation. He put prospectors to work to find the croppings of the ore deposits, and in June, 1874, the first carbonate in place was found at the mouth of the present Rock tunnel on Dome Hill. About the same time ore was discovered in a shaft sunk by a Mr. Bradshaw near the bed of the gulch on the present Oro La Plata claim, but it is maintained by some that this ore was not in place but was simply "wash" accumulated from the abrasion of the adjoining croppings. Prospecting was quietly continued by Mr. Wood, but no claims were taken up, as the older placer claims, which though abandoned would still be in force for another year, covered all the ground adjoining the gulch. Meanwhile he studied the occurrence of the mineral and the outcrops of limestone on both sides of California Gulch. In the spring of 1875 he took Mr. Stevens, with Prof. H. Beeger, then in charge of the Boston & Colorado Smelting Works at Alma, to Iron and Dome hills and showed them in the forest that covered the slopes the outcrops on the Lime, Rock, and Dome claims. During this and the following summer the principal claims that constitute the valuable property of the Iron Silver Mining Co. were located by Messrs. Wood and Stevens in the interest of Detroit persons. The first ore was extracted from the Rock mine, where a large mass of hard carbonate formed a cliff outcrop on the side of California Gulch. This ore was rich in lead but very low in silver. During the summer of 1876 ore was first taken from the outcrops on the Iron and Bulls Eye claims, and some rich assays, as high as 600 to 800 ounces to the ton, were obtained from it.

The first working tests of Leadville ore were made by A. R. Meyer, a graduate of European mining schools, who first came to California Gulch in 1867 from Alma, acting as agent for the St. Louis Smelting & Refining Co. In the fall of that year he shipped from 200 to 300 tons of ore, principally from the Rock mine, by wagon to Colorado Springs and thence by rail to St. Louis. The freight to Colorado Springs cost $25 a ton, and the ore averaged only 7 ounces in silver to the ton; it contained 60 per cent of lead, however, and in spite of the high cost of freight yielded a profit owing to the high price of lead (7 cents a pound) then ruling. It having thus been proved that Leadville ore could be worked at a profit, prospecting was carried on vigorously, and the next discovery was that of Gallagher Brothers on the Camp Bird claim, supposed at that time to be the northern continuation of the iron-lime outcrop. This discovery was made late in the fall of 1876, and the claim now forms part of the property later known as the Argentine Mining Co. The A. Y. mine, on the southeast slope of Iron Hill, was also located in 1876 by A. Y. Corman and others. During the winter the Long & Derry mine was discovered by two prospectors of these names, who retained ownership of the mine for many years and became wealthy from its product. In the spring and summer of 1876 discoveries were made along what was then known as the second contact on Carbonate Hill, where the Carbonate and Shamrock mines were the first to yield considerable quantities of ore.

In 1877 the famous ore bodies on Fryer Hill were discovered by a singular chance. At this point there is no outcrop, the whole surface of the hill being covered to an average depth of 100 feet by detrital material. Tradition has it that two prospectors were grubstaked by Mr. Tabor, half of all they discovered to belong to him. Among the provisions was a jug of whiskey, which proved so strong a temptation to the prospectors that they stopped to discuss its contents before they had gone a mile from town. When the whiskey had disappeared, though its influence was probably still felt, they concluded that the spot on which they had thus prematurely camped was as good a site for a prospecting hole as any other. At a depth of 25 or 30 feet their shaft struck the famous ore body of the Little Pittsburgh mine, at the only point on the whole area of the hill where rock in place comes so near the surface. Discoveries rapidly multiplied in this region; immense amounts of ore were taken out, and the claims changed hands at prices that advanced with marvelous rapidity into the millions. A half interest on one claim, which was sold one morning for $50,000 after being transferred through several hands, is said to have been repurchased by one of the original holders for $225,000 on the following morning.

The foundation of Mr. Tabor's wealth was laid in the first discovery on Fryer Hill, but its amount was materially increased in a singular way. When the fame of the rich discovery of Fryer Hill became known at Denver, wholesale dealers from whom he was in the habit of buying his provisions commissioned him to buy for them a promising claim. On his return to Leadville, in accordance with the agreement, he purchased on their account, for the sum of $40,000, the claim of a somewhat notorious prospector, known as Chicken Bill, on what is now Chrysolite ground. Chicken Bill, in his haste to realize, had not waited until his shaft reached rock in place but had "salted" it with ore taken from a neighboring mine. After the bargain had been concluded he could not resist the temptation of relating to a few of his friends the part he had played in the transaction. The report of what he had done thus reached the ears of Mr. Tabor's Denver correspondents before he himself arrived to deliver the property; not unnaturally they declined to receive it, and Mr. Tabor was obliged to keep it for himself. With his associates, under the title of Tabor, Borden & Co., he afterward bought and developed some adjoining claims, from which they are said to have taken out about $1,500,000 and later to have sold their property to the Chrysolite Co. for a like sum, probably in 1879.

In 1877 Mr. Meyer persuaded the St. Louis Smelting & Refining Co., of St. Louis, Mo., that a smelter should be erected at Leadville. This company started building in 1878 the plant later known as the Harrison Reduction Works, which commenced smelting in October, 1878. This was the sixth smelter built in the district, although three earlier ones—the Malta and the Lizzie, at Malta, and the Leadville, in California Gulch—were not successful. The Grant smelter and the La Plata smelter, both in California Gulch, commenced smelting in June and September, 1878, respectively.

Although the production of the Leadville district has since been exceeded by that of other districts, in only a few of them has the maximum value of production been attained so soon after discovery. The first shipment of lead carbonate was made in the fall of 1875, and in 1880, only five years later, the annual production amounted to nearly 10,000,000 ounces of silver and 66,600,000 pounds of lead, and its total value to nearly $15,000,000.

It is natural that this exceedingly rapid rise to commercial prosperity should have produced a typical western boom, during which overspeculation was rife and lawless characters were attracted in great numbers to the town. In 1879, when the boom was at its height, the city abounded in footpads, and assaults and holdups were so common on the streets at night that the citizens dared not venture out alone, and even real estate was sometimes boldly appropriated by armed ruffians against whom the owners had no redress. Finally the overtried citizens organized a force of vigilantes and hanged two of the most noted characters, so that with the passing of the boom year the town assumed a more law-abiding character. The boom of 1879 was followed by a reaction, as is indicated by the decline in production in 1881, and the district then settled down to a long period of prosperity.

On May 26, 1880, a strike started at the instigation of a miner named Mooney which tied up the mines for 22 days. For a time it assumed a character so threatening that on June 13 martial law was declared by Governor Pitkin, and by June 18 order was restored and the mines resumed operations. This strike was so brief that it had no effect on the district's production.

ADVENT OF THE RAILROADS

In the earlier years of Leadville's history—that is, until the development of the lead carbonate ores had brought real prosperity to the district—the only means of transportation for ores and supplies was the pack train. Early in the silver period, however, with the characteristic energy that generally follows so closely on the heels of important mining discoveries, railroads were extended to the district and afforded ample means for the importation of supplies and the exportation of ores.

The first railroad that made a near approach to the district was the Denver, South Park & Pacific. This line was started in 1877, before the commercial importance of Leadville had been appreciated, and when in 1878 the Leadville boom began, work was vigorously pushed with a view to the acquisition of the traffic which so prominent a mining center would be certain to furnish. The road followed the Platte Canyon and then climbed up out of the canyon into South Park over Kenosha Hill. Early in the spring of 1880 it reached Buena Vista, and then the endeavor to reach Leadville was abandoned, as the Denver & Rio Grande and the Atchison, Topeka & Santa Fe had both secured the right of way up the valley of the Arkansas. After the construction of the Denver & Rio Grande line, however, the South Park road by agreement was enabled to use its tracks from Buena Vista into Leadville. In 1884 Leadville was connected with Como, on the South Park line, by way of the East Fork of Arkansas River, Fremont Pass, Tenmile Creek, Blue River, Boreas Pass, and Tarryall Creek. This line is now a part of the Colorado & Southern system.

The first railroad to reach Leadville was the Denver & Rio Grande. This road (now the Denver & Rio Grande Western) runs through the impressive canyon of Arkansas River—the Royal Gorge—to Salida and thence up the beautiful open valley of the river to Leadville. The first train was operated August 2, 1880. Seven years later the Colorado Midland Railway, running eastward from Colorado Springs up the south fork of North Platte River into the Arkansas Valley at Buena Vista and thence up the valley, was extended into Leadville. Its track was completed and its first regular train run into Leadville on September 3, 1887.

RISE AND FALL IN PRODUCTION OF EACH METAL

The economic history of the Leadville district during the silver-lead period may best be appreciated by reference to Figures 40, 42, and 43.

From 1876 to 1880 the total value of metals produced rose to nearly $15,000,000, from 140,000 tons of ore. Silver then reached its maximum output, as the ore mined was rich in chloride and bromide of silver. After the reaction of 1881 production increased; in 1883 lead attained its maximum output, but the output of silver did not equal that of 1880, as the silver content of the ore had already begun to decline. Owing to changing prices the maximum value for this part of the period was attained in 1882 and was not exceeded until 1912.

The production of silver and lead continued steadily, but owing to decreasing richness of the ores and generally declining prices of silver the quantity and value of each metal decreased on the whole, although there was an increase in the tonnage of ore mined. In 1887 the ratio of silver to lead was 1 ounce to 3 pounds; in 1878 and 1879 it was 1 ounce to 5 pounds, and thereafter it declined annually until in 1884 it was 1 ounce to 13 pounds. In 1885 it increased to 1 ounce to 9 pounds, owing to the production of considerable silver from lode gold ore; but from 1886 to 1890 it was about 1 ounce to 14 pounds. The price of silver decreased from $1.278 a fine ounce in 1874 to 92 cents in 1889. In this year work was begun in the Downtown district, and by 1891 10 shafts had been sunk and ore discovered in four mines. The Downtown district became the center of mining activity in 1892 and continued to be the center for the next three years.

An added impetus was temporarily given to silver mining by the rapid rise in the price of silver from 89 cents a fine ounce in July, 1889, to $1.17 in August, 1890, but this advance was immediately followed by a pronounced fall in silver prices. From $1.17 a fine ounce in August, 1890, the price fell to 61 cents in March, 1894. The most precipitate drop occurred in the summer of 1893 and, coupled with the serious financial depression of that year, resulted in an almost complete shutdown of the silver-lead mines of the district in June. Only the mines that produced gold or had the richer bonanza ores were able to continue operations. In some mines the pulling of pumps preparatory to the final abandonment of the properties was contemplated, and it was for a time feared that the mining of the silver ores of the district might not be able to recover.

These extreme measures, however, proved unnecessary. A partial readjustment to the conditions of extreme depression was effected by an agreement between mine owners and laborers, reached on September 23, 1893, for the adoption of a lower wage scale. This measure enabled most of the mines to resume operation and materially assisted in tiding over a difficult stage in silver mining.

The results of the decline in the price of silver were somewhat offset by the added stimulus given to the prospecting and mining of gold. The gold-producing area of Breece Hill and vicinity had been attracting attention since the exploration of the Ibex mine in 1891, and under the stimulus of declining prices of silver the search for gold ores so increased that the production of gold rose sharply from $251,269 in 1892 to $1,499,314 in 1893. Since then the annual production has fluctuated only slightly from this figure. The maintenance of the total production of silver with so slight variation during the period of rapid decline in prices of silver that culminated in the shutdown of so many of the silver-lead mines was due in part to the large amount of silver recovered from the newly exploited gold ores. The increase in production of silver in 1895 is due to the same cause.

The mining of ores of all classes at Leadville gradually recovered from the effects of this decline in prices of silver and continued successfully over a long period in which the prices were much lower than at the time of the shutdown in 1893. This interesting fact appears to show that it was not so much the price of silver that prevented profitable mining as the rapidity with which the price fell. If the decline from 89 cents in 1889 to 61 cents in 1894 has been gradual the mining companies might have adjusted themselves to the changing conditions and the industry need have suffered no serious setback. In this aspect the sudden rise in the price of silver in 1890 is to be regarded as a serious misfortune, for it undoubtedly encouraged the undertaking of much mining work which could not have continued profitably unless the prevailing high prices were kept up. Production of silver was retarded by the strike in 1896–97 (see pp. 120–121) and then continued steadily, but since 1900 the output of silver and lead on the whole has decreased.

In the winter of 1898 the mines were largely shut down by the most prolonged snowstorm in the history of the district. Snow fell steadily for 57 days and blocked all routes of transportation. In the summer of 1899 a smelter strike interfered with the activity of the district and for a time threatened to be serious.

By 1890 the average calculated gross value of metals recovered from the ore mined, which was $105 a ton in 1880 and $52 in 1884, had declined to less than $25. It decreased further in 1891 but returned to nearly $25 from 1892 to 1895. It then decreased almost continuously until the beginning of the zinc period in 1902, when it was only $11.37. This decline was due in part to the gradual depletion of oxidized ores and the opening of sulphide ores, but more particularly to the application of milling to the sulphide ores. When Emmons's first survey was completed, in 1881, almost the only sulphides reached were isolated masses of galena with the oxidized ores. In that year, however, a body of galena and pyrite 7 feet thick was found in the Wolftone mine 663 feet below the surface. In the Ruby mine, on Iron Hill, streaks of galena and pyrite had also been found. The Miner Boy, on Breece Hill, was producing sulphides, and the Tiger mine, on Ball Mountain, was producing galena from a vein in Gray porphyry.

In 1882 several of the smelting companies installed plants for the treatment of sulphides, and in 1883 the mines on Iron Hill, notably the A. Y. and Collateral, opened large bodies of sulphides. The production of sulphide ores offered a serious metallurgical problem to the smelters. The oxidized ores had consisted mainly of lead carbonate and silver chloride, with oxides of iron and manganese and varying quantities of silica. The first sulphides reached were partly leached and consisted mainly of galena and pyrite, with varying quantities of carbonate and silica gangue; but below the zone of leaching the sulphides contained large quantities of zinc and small quantities of copper.

Zinc in ores sold to the lead blast furnaces or copper furnaces has always been and still is penalized by the smelters if over 10 per cent and until a market was established for zinc ores was regarded by the miners as a thing to be avoided. Only sulphide ores from which zinc had been leached or could be readily separated were mined. These ores contained more silver than the unleached sulphides but less than the oxidized ore or the residual masses of enriched galena within the oxidized ore, and the total value of ore produced therefore decreased while the quantity increased. The percentage of lead in the ore probably decreased also, but records of the quantity of ore produced are too few to afford comparison. The declines in production of lead were due largely to the business depression of 1893 and the miners' strike in 1896–97 (pp. 120–121) rather than to exhaustion of known ore reserves.

The ratio of silver to lead shown in Figure 42 does not represent the oxidized and sulphide lead ores only, as considerable silver came from gold ores, particularly from the Antioch mine in 1885 and from the Ibex and other mines in the gold belt during 1893 and later years. By 1895, when work on the Yak tunnel began, the gold belt, which includes Printer Boy Hill, Breece Hill, and the area to the north and northeast, became prominent. The oxidized ores first discovered changed downward into sulphide ores, but considerable contents of gold and silver, though not in constant ratio to each other, continued to the lowest levels reached. The marked rise in gold production to its maximum in 1900 was due to the opening of gold ores in the Penn and Ballard mines, on the northwest slope of Breece Hill. These mines were large producers for a short time, but the bulk of the gold continued to come from the Ibex lodes. The maximum tonnage of ore was also shipped in 1900.

Copper has always been a very minor product of the Leadville ores. None was found in the oxidized silver-lead ores and, except in a few places, only very small percentages in the corresponding sulphide ores of the western part of the district; although because of their great quantity these ores contributed materially to the district's production of copper. The sulphide ores of the gold belt contributed somewhat more copper per ton. Some copper was doubtless obtained from the corresponding oxidized ores, as indicated on page 129, where the composition of similar ore (oxidized siliceous copper ore) mined in recent years is stated. The copper ores in both the oxidized and sulphide zones form local shoots in the gold and gold-silver ores.

The production of copper began in 1884 but did not assume any importance until 1890, when one of the exceptional deposits was found in the Henriett-Maid of Erin mine. It reached a maximum in 1892, when a considerable quantity of copper sulphate was found in the Ibex mine just above and grading into the sulphide zone. For a time shipments of this unusual ore amounted to 70 tons a day. Since 1892 the output of copper has fluctuated and shown no definite relation to the output of any of the other metals.

Zinc was also a very minor product during this period, as set forth in the section covering the zinc period (p. 121).

THE STRIKE OF 1896–97

The strike that occurred in 1896 closed nearly all the mines for four months and may be regarded as one of the serious strikes in the early history of the western metal industry. Unlike the strike of 1880 it was started by the activities of delegates of the Western Federation of Miners. The trouble arose over the question of wages. The agreement made between the mine owners and miners on September 23, 1893, after the decline in the price of silver, had reduced wages from $3 to $2.50 a day during all months when silver did not reach 83½ cents a fine ounce. In all months when it reached or exceeded that figure $3 a day was to be paid. During the next three years silver never reached the 83½-cent limit, and although the increased production of gold had enabled the camp to recover, wages had, in accordance with the agreement, remained stationary. The dissatisfaction arising from this condition continued to increase until it culminated in a strike on June 21, 1896, when 1,600 men walked out and 90 per cent of the mines in the district shut down. The strike continued until March, 1897.

At first the strikers were orderly, and little trouble was experienced, but the importation of nonunion men led to the usual difficulties, and conditions soon became so threatening that in several of the mines arsenals were installed and armed guards employed, and at the Ibex mine a stockade was built completely around the property. Until September 20, 1896, practically no mining was done, and even the pumps were idle. On that date the militia was called out and work was resumed on a smaller scale. These conditions continued over a period of nearly nine months, but the importation of new men and the gradual resumption of operations resulted eventually in the defeat of the union, and on March 9 the strike was declared off.

The effect of this strike was serious. The production of all classes of ore except high-grade gold ore fell off enormously. The production for 1896 represents almost wholly the first six months of the year, as may be seen from the sudden drop in all the production curves for that year. (See fig. 41.) The drop was still greater in 1897, although the strike terminated in March, because many of the mines were flooded and had to be pumped out before operations could be resumed. The process of unwatering offered more than the usual difficulties in the Downtown mines, because the surface waters that had filled the mines had carried down with them great quantities of extremely fine silt composed of disintegrated grains of dolomite, locally known as "dolomite sand," which was deposited in all drifts and stopes, filling many of them nearly solid from floor to roof. This material had to be mined out, a task that vastly increased the expense and the length of time required to reopen the workings. In fact, in 1901, five years later, when Irving first visited the district he found many drifts still filled nearly solid with dolomite sand. In some places the expense of reopening could not be borne by the owners, and many mines, notably the group on Fryer Hill, were abandoned. No attempts to reopen them were made for more than ten years. A few in which the silt has not been removed stand idle yet. So widespread was the flooding of the mines that it is even now customary to refer to the strike days as the time of the "flood."

In the mines of the Downtown district, beneath the city of Leadville, where the drainage problems were the most difficult owing to the lower altitude of the surface, attempts to unwater the mines did not begin until October, 1898, when a pumping association composed of practically all the leasing companies and owners of land in the area was formed. Unwatering was completed in April, 1899, when 15,000,000 gallons a day was being removed.

ZINC PERIOD, 1903 TO THE PRESENT TIME

GROWTH OF ZINC PRODUCTION

The first recorded output of zinc was made in 1885, but the production of zinc, like that of copper, was insignificant for several years. Much zinc blende from which galena had been separated was discarded and either lost or reclaimed later, when the demand for zinc became appreciable. The zinc produced up to 1898 evidently came mostly from concentrates from mixed sulphide ores and to some extent from shoots of zinc blende accompanied by only small amounts of other minerals. In 1899, however, the shipments of zinc ore and concentrates began to grow rapidly, owing to the enterprise of a broker, who bought cheaply the unvalued zinc products and shipped them to Belgium. Soon afterward American plants began to buy the zinc products, hitherto avoided because of their iron content. In 1902 the output of zinc exceeded that of lead, and in 1903 the value of its output exceeded that of silver. Since then it has led all the other metals in quantity and value of output except in 1908, when the sudden fall in the price of zinc, due to the financial depression, reduced the value below that of silver and gold, and in 1921, when, during the worst depression in the history of the district, there was almost no market for zinc. The maximum output of zinc from sulphide ore was made in 1903, and the slight decline in 1904 was evidently due to the failure of new developments to keep pace with production. The maximum value of zinc from sulphide ore was recorded in 1906.

In 1907–8 occurred a financial panic which seriously affected Leadville mining. Silver, lead, and zinc declined abruptly in 1908 to less than 50 per cent of their values in 1907, and with them fell the total production. During the panic, when the prices of all the metals except gold fell so precipitately, the output of copper and gold remained unaffected. The maintenance of gold is readily understandable because its price is standard, and the increased production of copper in spite of a decrease in price signifies that the bulk of the copper produced was a by-product of the gold ores.

DISCOVERY AND DEVELOPMENT OF OXIDIZED ZINC ORES

Recovery from the depression of 1907–8 was slow. The Downtown area had again become flooded, and plans for unwatering it were not carried out until 1914. The parts of Iron and Breece hills drained by the Yak tunnel, then about 3 miles long, were more favored, but Leadville's future did not look very bright until the discovery of large quantities of oxidized zinc ore in 1909 and 1910. That these ores had been overlooked for 30 years or more caused both chagrin and amusement, and considerable discussion arose as to where the blame should be placed. Old shafts had been sunk and drifts opened through thick bodies of the ore, and it had been exposed along the sides or floors of lead carbonate stopes; nevertheless all who had had the oppportunity to recognize it—practical miners, engineers, and geologists—failed to note its presence in commercial quantity. The recognition of these ores finally came just when the district needed stimulation.

EARLY RECOGNITION OF ZINC CARBONATE AND SILICATE

The presence of both silicate and carbonate of zinc had been recognized as early as 1882, as shown by the following quotation:[5]

> Mr. Garrison (of St. Louis) makes the prediction that at an early date Colorado will be made tributary to the western spelter industry. Probably the first call will be made for carbonates, calcined before shipping. This class of zinc ores often so closely resembles limestone that the ordinary prospector would not detect its value. If we remember correctly, Prof. König, of Philadelphia, has found calamine, or carbonate ore, in the vicinity of Leadville. Should a closer search, which we trust will be made at an early date, reveal the presence of larger bodies of this ore, zinc mining might soon be added to the list of Colorado industries.

Zinc was then evidently of insufficient interest to stimulate prospecting for bodies of high-grade zinc ore.

In 1881 or later Emmons[6] noted the occurrence of calamine at Leadville and mentioned zinc blende and calamine as accessory minerals. He evidently had considered the problem of the disposition of the zinc in the oxidized zone, as he shows in his description of the old Iron mine:

> In the body of the limestone, on the eighth level, not far from the north incline, a natural jointing plane forming one wall of the drift was observed to be coated with fine, silky white crystals which chemical examination proved to be calamine or silicate of zinc. If the sulphureted ores, which will undoubtedly be found when the mine workings shall have reached the limits of the zone of oxidation, are as rich in blende as those which have been found in the A. Y. mine, it seems singular that little or no zinc has hitherto been found associated with the oxidized ore. This occurrence would seem to show that, owing probably to greater solubility, the alteration products of blende have been removed during secondary deposition to a greater distance from their original location than those of the other sulphurets.

Again, he writes:

> Zinc occurs in the lead carbonate ores in very small proportion and probably in the form of silicate (calamine), since this is the only mineral of zinc that has been observed in the Leadville deposits. It is rarely visible and generally forms fine, needle-like silky-white crystals, lining drusy cavities and cracks or joints in vein material and limestone. There is little doubt that it originally occurred as zinc blende, and, from analogy with the Tenmile deposits, it may be presumed that it formed a much larger proportion of the deposit than it does now. The much greater solubility of its sulphate than that of the other metals would account for its more thorough removal by surface waters.

He noted the absence of zinc in analyses of samples of basic ferric sulphate, a feature in accordance with the observation, quoted above, that the zinc had been further removed from the original ore bodies than the other metals, owing to the more ready solubility of its sulphate, and he states that in spite of the comparative absence of zinc this metal was "quite uniformly detected in the products of smelting."

The analyses of different vein materials show little or no zinc. A siliceous hematite from the Chrysolite mine, carrying 2.56 per cent of zinc oxide, was said to contain "a rather unusual percentage of zinc." As these vein materials were in large part similar in color and other visible features to the reddish-brown zinc ores now mined, the absence in all of them of any considerable amount of zinc may well have diverted Emmons's attention, both then and in later years, from such iron-stained bodies as possible oxidized zinc ores. Very little drifting or other work beneath the old lead stopes had then been done, and no ground with abundant pockets of calamine, such as characterize much of the oxidized zinc ore mined since 1909, had been exposed. Even after some of the extensive zinc ore bodies had been exposed along drifts and other workings the strong resemblance of the reddish-brown ore to iron ore at one extreme and iron-stained limestone at the other and the close resemblance of the gray ore to partly leached but unstained limestone were hardly likely to lead one to suspect the presence of high-grade zinc ore. These ores are in general so different in color and texture from the more crystalline and brilliant specimens from other districts, so common in museums and other collections, that failure to recognize them without chemical examination is not surprising.

Emmons, however, did recognize the rather exceptional occurrences of small quantities of the dense white zinc ore that is identical in appearance with "Chinese talc," as shown by his discussion of the analyses. He regarded this material as a mixture of hydrated silicates of alumina and silicate of zinc and remarked that "the occurrence of the zinc was somewhat unexpected." In the extensive mining of oxidized zinc ores during the last few years ore of this type has been found only in small quantities and of a grade too low for shipment except during a short time when the price of zinc was abnormally high. It is indeed striking that none of the many specimens of ores and vein matter taken during the extensive study of the ores in the earlier days proved to contain any considerable quantity of zinc carbonate.

In 1889, after a period of extensive development, during which many of the oxidized lead bodies had been followed down to the sulphide zone, Blow[7] called attention to the abundance of zinc blende just below the zone of oxidation and offered the conclusion that it was the result of downward sulphide enrichment. In his own words,

> The zinc sulphides are the most widely disseminated and show plainly the result of their more ready solubility than the other sulphides and the redeposition of a large portion of the zinc, which has thus been removed from the carbonate ores. This fact is clearly shown in many ways but most satisfactorily just at the line of transition. The sulphides first encountered are invariably heavy sulphides of zinc, carrying a little iron and very little lead. They have a close crystalline structure and lie in a laminated form, the lines of fracture being nearly vertical. Upon these cleavage planes crystals of cerusite are found and often a small incrustation of native silver. Such deposits,

[5] Eng. and Min. Jour., vol. 34, p. 16, 1882.

[6] Emmons, S. F., Geology and mining industry of Leadville, Colo.: U. S. Geol. Survey Mon. 12, pp. 376, 389, 398, 547, 550, 556, 557, 560, 1886.

[7] Blow, A. A., The geology and ore deposits of Iron Hill, Leadville, Colo.: Am. Inst. Min. Eng. Trans., vol. 18, pp. 168–172, 1890.

where first encountered in passing from oxidized to unoxidized ores, are always lowest in silver. In their further extension the zinc gradually grows less and the laminated structure disappears. Beyond this, again, the zinc sulphides appear to predominate along cleavage and contact planes with the gray porphyry, or along the lines of minor faults and cracks in the limestone. Such characteristics are also universally observed in other instances besides those of Iron Hill. * * *

In advancing further within the ore shoots the zinc appears to lose its preponderance over the other sulphides. * * * It seems probable that a large proportion of the zinc, which was totally removed from the carbonate ores, has been redeposited as a sulphide, and principally just below the line of complete oxidation, by surface waters, and such redeposition has advanced and increased pari passu with the limit and extent of such oxidizing action.

As a corollary of the above, it is believed that at the present stage of development in Leadville, the sulphide of zinc forms a larger part of the unoxidized ores than will be found in future and deeper exploration.

This conclusion, in view of the fact that no zinc carbonate ore bodies had then been discovered or recognized seemed very plausible from the evidence in hand. It was evidently adopted by Emmons and Irving,[8] who wrote in 1907:

The hydrous zinc sulphate is presumably more soluble and less stable than the corresponding iron sulphate. In Leadville, like gypsum, which should have been formed by the reaction between iron sulphate and limestone, it is practically absent from the oxidized zone and must have been carried away in solution or redeposited as a sulphide below the zone of oxidation. It has, in fact, been observed that the sulphide ores are much richer in zinc blende immediately below the limit of oxidation than elsewhere.

This hypothesis of downward enrichment of zinc blende tended to delay the search for and discovery of the zinc carbonate ores, as the possible existence of such ores must have been dismissed from the minds of the geologists and consequently from the minds of the operators. The field evidence on which this hypothesis was based, however, may be interpreted in another way, as shown on page 246; furthermore, later developments have shown that rich bodies of zinc blende are not limited to the top of the sulphide zone; finally, recent experimental evidence and field observations in other parts of the world have shown that such deposition of secondary zinc blende is very unlikely.

After the large shipments of oxidized zinc ore in 1910 had attracted wide attention Emmons addressed a letter from Dinard, France, to the Leadville Herald-Democrat,[9] in which he said:

At the time of my first study of the Leadville district, in 1880, I was much puzzled to know what had become of the zinc. * * * I assumed then that owing to the superior solubility of the zinc sulphate, the oxidation products of that metal had been carried much further than those of lead before being transformed into the now stable carbonate and had possibly been entirely removed in the run-off.

Blow's observation that on Iron Hill secondary zinc blende had accumulated in the upper part of the sulphide zone seemed to account for some of the missing zinc, and from accounts published by you it is evident that much of it has accumulated as calamine in the zone of change from sulphide to oxide.

Though I have particularly desired to study the zinc of Leadville, I have never been able to, because in 1880 mine workings had not yet reached it, and when I next visited the district (1890) they had gone beyond it, and owing to the soft nature of the ground in that zone the drifts leading to it were for the most part caved and inaccessible.

It certainly seems rather strange that those in charge of mines when this zone was exploited did not notice such bodies of calamine as you describe, but it must be borne in mind that calamine is generally a white-brown earthy-looking material, which would not attract attention unless especially sought for, and that it was pay ore rather than material of only mineralogical interest that they were seeking, and at that time zinciferous ores were a particularly undesirable product.

Another reason, mentioned by several writers,[10] for the failure to recognize oxidized zinc ores is the fact that in the earlier days the presence of zinc in the lead-silver ores and also in the iron ores was a decided detriment, and miners in consequence avoided points where assays showed a considerable percentage of zinc. According to G. O. Argall and E. W. Keith, the presence of zinc was especially noticeable in shipments from the Carbonate Hill and Fryer Hill mines. The object of search in those days was lead-silver ore, and as there was then no market for zinc there was no incentive to look for it, even though some of the early operators may have recognized its character. Argall further states that it was after the gradual depletion of the sulphide ores and in consequence of the increasing expense of deep operations that exploitation turned again to the upper levels in search of ore that might not have been profitably mined when first opened and thus led to the discovery of the character and value of the oxidized zinc deposits.

RECENT DISCOVERY OF ORE BODIES

Accounts of the recent discovery of oxidized zinc ores in extensive bodies at Leadville are not in accord.[11] Some state that the discovery was made through the curiosity of a Leadville assayer, who took the time and trouble to determine the contents of a sample of high specific gravity, which had been shown by assays to contain little or no lead, silver, or gold; others state that the character of the material was recognized by those who had discovered and worked oxidized zinc ores elsewhere in the State. According to J. B. McDonald,[11a]

[8] Emmons, S. F., and Irving, J. D., The Downtown district of Leadville, Colo. U. S. Geol. Survey Bull. 320, pp. 32-33, 1907.

[9] This letter, dated Oct. 11, 1910, has been quoted by the Engineering and Mining Journal (Nov. 12, 1910, p. 954) and by H. E. Burton in Mines and Minerals (February, 1911, p. 436).

[10] Mining World, Dec. 17, 1910, p. 1147. Keith, E. W., Leadville Herald-Democrat, Sept. 20, 1910, p. 1. Argall, G. O., Oxidized zinc ores at Leadville: Eng. and Min. Jour., Aug. 26, 1911, p. 399.

[11] Leadville Herald-Democrat, Sept. 11, 1910, and Jan. 1, 1911; Eng. and Min. Jour, Nov. 12, 1910, p. 954, and Aug. 26, 1911, p. 399; Min. World, Dec. 17, 1910, p. 1147; Mines and Minerals, Feb. 11, 1911, p. 436; Min. Sci., July 27, 1911, p. 85.

[11a] Personal interview. A similar account is given in Min. Sci., July 27, 1911, p. 85.

the first silicate of zinc shipped from the State was from the Madonna mine, at Monarch, Chaffee County, in 1902. * * * Several hundred tons of the ore were shipped. * * * The first carbonate of zinc ever shipped from the State came from the Monarch Pool mine, at Monarch, and the two highest grade cars of carbonate of zinc ever shipped out of the State to this day came from this mine. One car ran 46.7 per cent and the other 47 per cent zinc.

The following year (1903) Mr. McDonald and Mr. Harry Paul procured a lease on the Eclipse mine, at Monarch, and shipped a mixed carbonate and silicate ore almost identical in character with that discovered in Leadville seven years later. Mr. McDonald states that in the spring of 1906 he found the first carbonate and silicate of zinc ever found in commercial quantities in the Leadville region. This was at the Hilltop mine, in the Horseshoe district, which adjoins the Leadville district on the divide between Lake and Park counties.

The first discovery of ore of this kind within the Leadville district in recent years was made in 1909 by W. E. Jones, a lessee in the Robert E. Lee mine, who found a large body of zinc carbonate. Shipments were made from this body and also from the Penrose dump but were of too low grade for treatment and failed to arouse much interest in oxidized zinc ores. In 1910 the first high-grade zinc ore, reported as calamine, was discovered by H. E. Burton, H. K. White, and Alfred Thielen in a lease at the Hayden shaft of the May Queen mine. This property was the first to ship high-grade calamine ore. After this discovery S. D. Nicholson, manager of the Western Mining Co.'s properties, began a search for oxidized zinc ores in the old workings of the Wolftone and adjoining claims and discovered in them the largest bodies yet found in the district. So much were the owners impressed with the discovery that a banquet was held in one of the larger stopes (the "banquet hall stope") to celebrate a new era of zinc mining. A general search for the ore throughout the district followed, with the result that smithsonite and calamine in varying amounts were found in a number of properties from Fryer Hill on the north to Weston Pass on the south.

PRODUCTION

These discoveries were made at a time when there was an increasing demand for zinc, and although shipments of oxidized zinc ores began only at the end of 1910, they became very large in 1911, offsetting a marked decline in the production of zinc sulphide ore and increasing the output of metallic zinc in Lake County by 15,243,011 pounds. This increase, in spite of a decrease of 7,996 tons in total shipments of zinc ores from the Leadville district, was due to the higher grade of the oxidized ores. At first only oxidized ores that averaged 30 per cent or more in zinc were shipped, but the increasing price, which culminated at 7 cents a pound late in 1912 and early in 1913, allowed profitable mining of ore containing as low as 17 per cent, and the production of oxidized zinc ores in 1912 greatly increased. Some ore containing as low as 15 per cent was shipped but at a loss. Most of the ore shipped, however, averaged about 30 per cent, and some contained as high as 40 per cent. The average for all shipments was 29.2 per cent.

Owing largely to this increase in price, which allowed several small producers of low-grade ore to ship at a profit, many enthusiastic estimates were made of the vast quantity of ore in reserve; but the rapid decline in price to about 5 cents a pound in the spring of 1913 forced most of the small producers to stop work, and the production for 1913 was less than that for 1912, and only a few properties besides those of the Western Mining Co. at Carbonate Hill were worked throughout the year. Ore containing as little as 24 per cent of zinc, however, could be shipped at a profit during the summer, and in October of that year it was stated that 22 per cent ore could be marketed.[12]

In January, 1914, new smelting rates made it possible to ship carbonate ore containing only 18 per cent of zinc. The average content of ore shipped during that year was 24.3 per cent, and in 1915 the average was 22.48 per cent. In spite of this opportunity to ship lower-grade ores, and in spite of the reported opening of a large body of zinc carbonate ore averaging 25 per cent zinc in the upper levels of the Wolftone mine in 1915,[13] the production of oxidized zinc ores, as shown in the accompanying table, continued to decrease during 1914 and 1915, the decline more than offsetting substantial increases in output of zinc sulphide ore. Owing to the extraordinarily high price of zinc in 1915, however, the total value of zinc was more than double that of 1914.

With the exception of a slight gain in 1916, the production of oxidized zinc ores continued to decline rapidly. The great bodies in Carbonate Hill, which had come from horizons below the Gray porphyry sill in the Blue limestone, had become exhausted, and although another extensive body was found above the Gray porphyry the quantity and grade of ore from it and smaller deposits throughout the district were not sufficient to maintain the output.

The principal mines producing oxidized zinc ore from 1910 to 1924 are listed below. Others were the Clover, Dome, Quadrilateral, Silent Friend, Izard, Matchless, Mikado, Little Sliver, Fortune, Monte Christo, Little Pittsburgh, Carbonate, Rubie, Hawkeye, and Ruby (Weston Pass).

[12] Eng. and Min. Jour., Oct. 18, 1913, p. 761.
[13] Mining Press, Mar. 20, 1915, p. 455.

Mines producing oxidized zinc ores, 1910–1924

	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920	1921	1922	1923	1924
A. Y. and Minnie					×			×		×					×
Belgian														×	
Blind Tom, Iron Silver Mining Co					×	×	×	×	×	×	×	×	×	×	×
Bullion			×												
Blonger			×												
Chrysolite		×	×		×	×	×	×							×
Denver City, Shamus O'Brien							×				×	×	×	×	×
Eliza					×	×	×								
Elk					×	×	×								
Fannie Rawlings			×								×				
Gambetta			×	×		×	×		×						
Highland Chief			×	×	×	×	×								
Ibex (Little Jonny)		×	×	×	×	×	×	×	×		×	×	×	×	×
La Plata (Rickard)			×	×		×									
Lillian		×	×	×		×	×	×	×	×	×	×	×		
Little Chief	×	×	×	×		×	×	×						×	
Little Ellen					×	×	×								
May Queen	×	×	×		×	×	×	×	×		×	×	×	×	
Mikado			×	×											
Minnie Lee						×									
New Dome (Nisi Prius)		×	×	×											
Penrose							×	×	×	×	×	×	×	×	
Ponsardine and Seneca			×	×		×	?								
Rattling Jack		×	×			×	×								
Robert E. Lee				×	×	×	×	×					×	×	×
St. Louis tunnel					×	×									
Small Hopes, Forest City							×	×		×	×	×	×	×	×
Sierra Nevada					×										
Smuggler			×	×	×	×									
Star Consolidated (Morning and Evening Star)		×	×	×	×	×	×	×							
Tucson-Moyer		×	×	×	×	×	?	?	?						
Tip Top and vicinity (Harvard)							×								
Western Mining Co.:															
Mahala		×	×	×											×
Big Chief	×	×	×	×	×	×	×	×							
Brookland, Clontarf (Adams Co.)		×	×	×		×	×	×							
Castleview		×	×	×	×	×	×	×	×						
Evelyn					×	×									
Henriette		×	×	×									×	×	×
Maid of Erin		×	×	×	×	×	×	×							
Wolftone	×	×	×	×	×	×	×	×	×	×	×				
Yak tunnel:															
White Cap			×	×	×	×		?							
Polaris						×									
Dolly B				×		×		×	×			?			×

In the spring of 1914 the Western Zinc Mining & Reducing Co. began the erection of a zinc oxide plant to treat the oxidized ores.[14] This plant, which had a capacity of 50 tons a day and was designed to treat zinc carbonate ore containing 16 per cent or less of zinc, was put into operation in the fall of 1914[15] but was operated for only a short time. In 1915, however, it was successfully operated by the Western Zinc Oxide Co. on low-grade zinc carbonate ores, mainly from the Robert E. Lee mine, and was reported in July to be yielding 150 tons a month of a product containing 70 to 80 per cent zinc and realizing $100 a ton.[16] Since then the plant has been enlarged and has taken nearly or quite the entire output of oxidized zinc ores, all of which have been of comparatively low grade. It has been operated almost continuously except during the severe depression of 1921.

DEVELOPMENTS SINCE 1914

From 1910 to 1914 the mining of sulphide ores was prosperous, but it was eclipsed by the notoriety of the oxidized zinc ores. These sulphide ores came largely from mines served by the Yak tunnel, which in 1912 reached the Diamond mine beneath Evans Gulch, 4 miles from its portal; also from mines of the Iron-Silver Co. in Iron Hill. The average character of the sulphide ores is shown on pages 126–128.

While these mines continued productive plans were perfected to unwater the Downtown and Fryer Hill areas. Unwatering the Downtown area through the Penrose shaft began in 1914 and was completed in 1916, and the mine has since been producing different classes of oxidized and sulphide ores. It was kept open during the strike of 1919 and the depression of 1921, although production was not continuous. In 1924, however, work on the lower levels was discontinued, and in 1925 the mine was closed; but late in 1926 plans were made to unwater the mine again. Unwatering of the Fryer Hill area through the Harvard shaft was completed in 1917, and production of oxidized and sulphide ores proceeded for a time, but the results were disappointing, and in 1918 work was discontinued.

About this time the Graham Park area was also unwatered, and considerable sulphide ore was mined, but

[14] Eng. and Min. Jour., Mar. 28, 1914, p. 676.
[15] Min. and Eng. World, Nov. 14, 1914, p. 92.
[16] Min. Press, July 24, 9115, p. 144.

when the miners' strike occurred early in 1919 and the high cost of operation was leaving no profit to the operators the ground was once more flooded. When times began to improve interests in this area were consolidated, and in 1923 unwatering was once more undertaken under the management of George O. Argall. Shipments of ore were resumed in 1925.

Another project, begun in 1922, is the driving of a tunnel S. 60° E. from the west slope of Canterbury Hill to prospect and drain the ground as far as the north base of Ball Mountain. The portal is 10,077 feet above sea level, and it is planned to pass about 240 feet below the Yak tunnel near the Dolly B shaft. By November 1, 1926, it had been driven 3,400 feet, and near its breast had cut a body of low-grade zinc-lead ore in a barite-quartz gangue. It had been connected with the two Roseville shafts and the Minneapolis shaft.

PRODUCTION FROM DIFFERENT CLASSES OF ORE, 1908–1923

Until the mixed sulphide ores were reached it would have been a relatively simple matter to keep a record of the sources of the gold, silver, and lead, as the ores mined were chiefly lead carbonate ore and oxidized siliceous ore, with a small proportion of iron oxide and iron manganese oxide ores which contained small to considerable amounts of silver chloride. When the mixed sulphide ores were reached, however, the sources of the metals could not be so well determined without detailed statistical records; but no such records were kept for all classes of ore until a system was established by the western offices of the United States Geological Survey. Detailed records of the Leadville ores have been kept since 1908 and are presented in the tables on pages 126–133. (See also p. 330.) During this time, and probably throughout the zinc period, the output of sulphide ores has predominated except in 1912, when the output of oxidized zinc ore reached its maximum. (See fig. 44.) The production from sulphide ores is shown below.

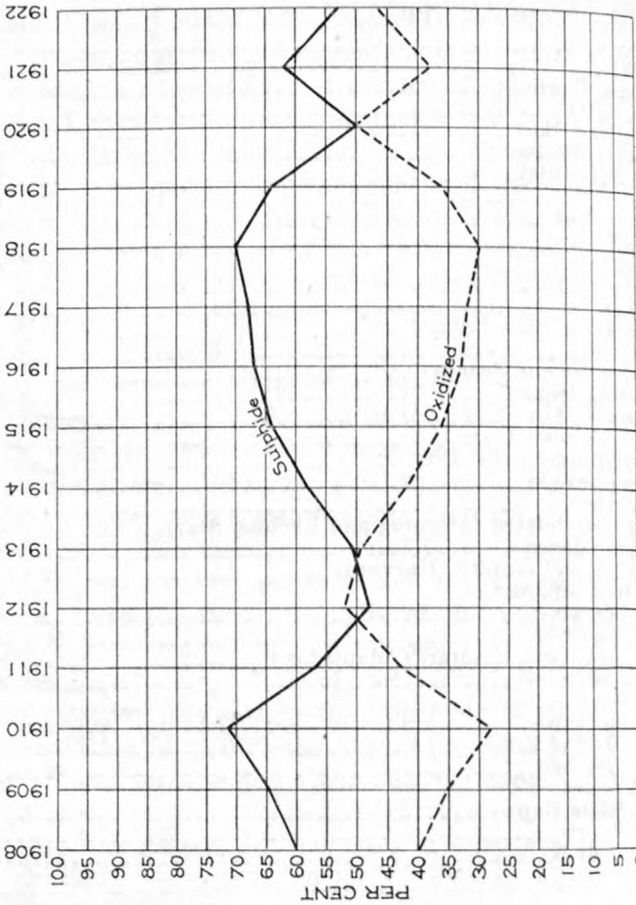


FIGURE 44.—Percentages of sulphide and oxidized ores produced in the Leadville district, 1908–1922

Sulphide ores produced in Leadville districts, 1908–1925

Pyritic ores [a]

Year	Ore (short tons, dry weight)	Recovered contents: Gold (fine ounces)	Silver (fine ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)	Average of original contents: Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)
1908	151, 284										
1909	142, 139										
1910	[b]158, 558										
1911	147, 535	32, 933. 55	1, 970, 054	3, 587, 982	1, 849, 998		0. 22	13. 35	1. 22	0. 63	
1912	127, 575	32, 462. 84	1, 536, 592	1, 748, 246	2, 511, 562		. 254	12. 04	. 69	. 98	
1913	152, 223	23, 744. 01	1, 959, 621	1, 714, 724	3, 989, 755		. 156	12. 87	. 56	1. 31	
1914	174, 610	31, 770. 74	2, 343, 943	1, 720, 872	9, 518, 416		. 182	13. 42	. 49	1. 21	
1915	161, 677	51, 716. 79	1, 560, 191	1, 092, 425	3, 707, 810		. 320	9. 65	. 34	1. 15	
1916	161, 096	54, 574. 15	2, 039, 723	1, 688, 230	3, 154, 198		. 339	12. 66	. 52	. 98	
1917	128, 533	35, 570, 98	1, 247, 574	1, 143, 659	2, 610, 052		. 277	9. 71	. 44	1. 02	
1918	91, 803	5, 754. 37	1, 112, 765	558, 387	1, 475, 416		. 063	12. 12	. 30	. 80	
1919	66, 500	3, 733. 70	664, 276	283, 875	1, 547, 598		. 06	9. 99	. 21	1. 16	
1920	33, 718	2, 337. 70	219, 907	153, 905	1, 319, 004		. 069	6. 52	. 23	1. 96	
1921	40, 337	1, 965. 80	682, 288	829, 282	1, 495, 480		. 049	16. 91	1. 03	1. 85	
1922	37, 365	1, 882. 00	490, 905	402, 357	1, 464, 597		. 050	13. 14	. 54	1. 96	
1923	8, 891	727. 30	129, 729	168, 819	332, 259		. 082	14. 59	. 95	1. 87	
1924	34, 150	9, 648. 60	22, 149	24, 215	34, 047		. 283	. 65	. 04	. 05	
1925 Gold	33, 000	6, 881. 00	2, 429				. 209	. 07			
1925 Silver	13, 047	815. 30	254, 547	30, 000	1, 008, 300		. 062	19. 51	. 11	3. 86	

[a] 1908-1911, includes ore with silica in excess of iron; also small quantities of dry siliceous lead and copper ores; 1912-1917, includes ore with silica in excess of iron; 1918-1923, includes only ore with iron in excess of silica.
[b] Excludes 2,032 tons of copper sulphide ore.

Sulphide ores produced in Leadville district, 1908–1925—Continued

Year	Ore (short tons, dry weight)	Recovered contents: Gold (fine ounces)	Silver (fine ounces)	Copper (pounds)	Lead (pounds)	Zinc (pounds)	Average of original contents[b]: Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)
Siliceous dry gold-silver ores											
1918	25,943	18,422.13	223,279	526,000	293,691		0.710	8.61	1.01	0.57	
1919	21,678	13,935.90	150,472	308,658	132,076		.64	6.94	.71	.30	
1920	19,280	10,614.80	166,487	330,470	471,958		.551	8.64	.86	1.22	
1921	7,446	5,132.50	101,386	222,106	153,457		.689	13.62	1.49	1.03	
1922	10,169	5,968.10	160,473	411,384	174,716		.587	15.78	2.02	.86	
1923	18,973	2,450.40	43,801	56,445	300,718		.129	2.31	.15	.79	
1924	2,212	588.30	16,622	23,535	144,756		.266	7.51	.53	3.27	
1925	1,067	474.40	13,011	27,000	61,300		.495	12.19	1.27	2.86	
Siliceous lead ores											
1910	7,618										
1911	21,632	2,534.95	192,085	92,941	3,481,518		0.11	8.88	0.21	8.05	
1912	13,040	2,109.02	110,092	35,582	4,479,214		.162	8.44	.14	17.17	
1913	10,991	1,703.38	99,225	20,195	2,658,549		.155	9.03	.09	12.09	
1914	17,100	4,989.00	290,906	84,688	5,245,333		.292	17.01	.25	15.34	
1915	1,802	1,567.04	32,154	13,423	451,203		.870	17.84	.37	12.52	
1916	2,208	570.77	63,840	3,779	813,562		.259	28.91		18.42	
1917	3,053	975.61	31,546	14,932	586,760		.320	10.33	.24	9.61	
1918	4,441	1,459.68	37,658	33,545	832,450		.329	8.48	.38	9.37	
1919	907	1,064.91	18,647	11,622	216,427		1.17	20.56	.64	11.93	
1920	411	24.80	2,798	5,109	150,769		.060	6.81	.62	18.34	
1921											
1922											
1923	2,405	441.90	73,176	26,239	395,233		.184	30.43	.55	8.22	
1924	3,032	316.70	27,308	655	521,484		.104	9.01	.01	8.60	
1925	3,057	314.40	29,951	2,000	565,400		.103	6.85	.03	9.25	
Siliceous copper ores											
1910	2,032										
1911											
1912											
1913											
1914	3,902	1,200.18	109,068	344,490	51,992		0.308	27.95	4.41	0.67	
1915	1,627	539.74	51,707	145,783	10,131		.332	31.78	4.48	.31	
1916											
1617	364	83.08	6,800	28.892	2,170		.228	18.68	3.98		
1918							.49	21.92	3.70	.31	
1919	1,860	903.74	40,764	137,600	11,426		.606	24.82	3.93	.33	
1920	2,011	1,219.00	49,920	158,181	13,156						
1921											
1922											
1923	3,716	1,795.50	67,501	309,303	33,653		4.83	18.16	2.82	.52	
1924	1,147	823.90	19,396	62,935	22,806		.718	16.91	2.74	.99	
1925	1,150	740.70	35,454	98,500	48,900		.644	30.83	4.28	2.13	
Zinc-iron-lead ores											
1907	200,197	[d]1,409.26	[d]523,979	([d])	([d])	[e]67,247,381	[f].03	[f]5.00		[f]8.00	[f]23.00
1908	95,306	[d]73.00	[d]145,941	([d])	([d])	[e]23,188,080	[f].03	[f]5.00		[f]8.00	[f]23.00
1909	127,640	[d]838.10	[d]261,792	([d])	([d])	[e]38,637,315	[f].03	[f]5.00		[f]8.00	[f]23.42
1910	163,218	[d]984.58	[d]398,803	[d]45,444	[d]9,559,942	[e]52,056,941	[f].03	[f]5.00		[f]8.00	[f]25.12
1911	79,376	[d]1,250.04	[d]184,726	[d]91,315	[d]8,503,662	[e]26,460,184	[f].03	[f]4.30		[f]7.34	[f]23.29
1912	104,148	[d]2,149.35	[d]463,394	[d]131,239	[d]12,153,436	[e]34,263,116	[f].02	[f]5.55		[f]8.80	[f]24.00
1913	97,704	[d]1,387.25	[d]443,165	[d]77,247	[d]14,102,554	[e]30,502,384	[f].03	[f]4.88		[f]9.39	[f]23.00
1914	111,947	[d]2,319.54	[d]300,505	[d]51,395	[d]10,105,767	[e]21,972,288	[f].03	[f]5.37		[f]8.74	[f]21.20
1915	136,555	[d]1,595.41	[d]404,396	[d]6,008	[d]12,856,824	[e]41,740,312	[f].02	[f]5.00		[f]8.65	[f]22.09
1916	147,295	[d]2,031.07	[d]340,463	[d]1,835	[d]12,922,633	[e]45,833,373	[g].028	[g]5.17		[g]8.37	[g]20.96
1917	148,945	[d]3,510.02	[d]343,277	[d]47,715	[d]10,844,497	[e]38,552,342	[f].033	[f]4.83		[f]7.79	[f]20.00
1918	125,281	[d]2,089.60	[d]302,785	[d]11,490	[d]7,307,290	[e]40,334,218	[f].03	[f]4.33		[f]6.25	[f]24.90
1919	46,967	[d]733.22	[d]112,276	[d]25,058	[d]2,870,173	[e]18,573,049	[f].03	[f]4.11		[f]5.52	[f]28.25
1920	30,899	[d]303.35	[d]68,626	[d]40,004	[d]1,498,581	[e]12,923,696	[f].025	[f]4.00		[f]4.44	[f]27.13
1921	1,292	[h]11.50	[h]2,401		[h]62,188	[i]610,000	[j].009	[j]1.86		[j]2.41	[j]29.38
1922	10,513				[h]1,043,675	[i]5,127,000				[j]4.96	[j]30.48
1923	11,831	[h]64.73	[h]27,811		[h]471,966	[i]2,658,000	[h].006	[h]2.35		[g]2.74	[k]14.04
1924	11,599	[h]647.50	[h]46,321		[h]1,546,164	[i]3,326,000	.056	3.99		[j]7.96	[j]19.45
1925	12,743	[h]28.15	[h]31,550		[h]1,583,000	[i]3,637,000	[h].002	[h]2.48		[j]8.87	[j]19.97

[d] Estimated recovery, as lead and iron concentrates and in zinc residues.
[e] Zinc figured as recovered retort zinc and recovered zinc in zinc oxide.
[f] Average assay of crude ore, mostly milled (lead, wet assay).
[g] Average assay of greater part of original ore for which data were available (lead, wet assay). Average assay of all zinc sulphide was 21.69 per cent zinc.
[h] Recovered in zinc residues. Some lead recovered in leaded zinc oxide.
[i] Zinc in terms of recovered zinc in zinc oxide and leaded zinc oxide.
[j] Average assay of original content; no deductions for loss in smelting. All to zinc plants in 1921 and 1922.
[k] Includes much low-grade dump material milled.

The sulphide ores fall into two main classes—zinc-iron-lead (blende-pyrite-galena) and iron sulphides (both massive and coarsely disseminated pyrite) accompanied by too little lead or copper to be credited by the smelters and little enough zinc to make only a small penalty or to avoid the penalty but enough silver to make shipping worth while. This second main class from 1908 to 1911 included minor quantities of ore containing 4½ per cent or more of lead or 2½ per cent or more of copper, classified as lead and copper sulphide ores. Beginning with 1918 the main class of pyritic ore was further subdivided into siliceous ore in which silica exceeds iron (coarsely disseminated pyrite) and iron pyrites with iron in excess of silica (massive sulphides). Ores containing 4½ per cent or more of lead or 2½ per cent or more of copper were designated lead and copper ores of their respective class, which seems to be confined to the siliceous ore. The siliceous ore is a dry gold-silver ore; the iron pyrites a dry silver ore.

Since detailed records have been kept the total output of dry pyritic ore with excess iron has considerably exceeded that of zinc-iron-lead ore except in 1917 and 1918. The zinc-iron-lead ore has contributed from 2½ to 4 times as much zinc as lead and has been an important contributor of silver.

The iron pyrites ore, with excess of iron over silica, has ranked second among the sulphide ores as a contributor of silver, but its commercial value has depended considerably upon its fluxing properties, which are due to its excess of iron over silica. It has also added to the supply of lead and copper, but the percentage of these metals is too low to be paid for by the smelters, and the same is frequently true regarding gold.

Considerable pyrite ore has also been shipped since 1906 for the manufacture of sulphuric acid. In that year the Western Chemical & Manufacturing Co., which made several products, including sulphuric acid, began buying pyritic gold and silver ore and zinc-iron-lead ore from Leadville, Kokomo, and Red Cliff. The pyritic ore was roasted directly and the residue sold to smelters. The zinc-iron-lead ore was partly roasted, magnetically separated, and wet concentrated. The partly roasted pyrite concentrate was further roasted to make sulphuric acid, and the lead and zinc sulphide concentrates were sold to smelters.

During 1917 and 1918 the powder plant of E. I. du Pont de Nemours & Co. at Louviers used considerable pyrite from Leadville and Red Cliff. Practically all the pyrite ore (as well as the roasted pyrite concentrate) contained some gold and silver, and most of the cinder or residue was shipped to smelters. The pyrite ore was classed with the iron pyrites ore represented on page 126. The quantity of precious metal bearing ore shipped to sulphuric-acid plants was never separately recorded in published reports because it merely went there for roasting. None was shipped after 1921, when pyrite was displaced by sulphur by the acid manufacturers who had been using Leadville ores. During 1918 to 1921 pyrites nearly barren of precious metals, or so low in precious-metal content as to have no valuable residues, or shipped to eastern plants where no attempt was made to save the residues, aggregating 37,358 tons, containing 15,551 tons of sulphur, were sold f. o. b. Leadville for $178,333. This figure represents only a very small part of the sulphur from Leadville utilized for the manufacture of sulphuric acid, but the value of the sulphur in the precious metal bearing pyrite sent to sulphuric acid plants was paid for by a reduction or wiping out of smelting charges.

Barren or nearly barren pyrites produced in Leadville, 1918–1921,[a] for the manufacture of sulphuric acid

Year	Pyrites	Equivalent sulphur[b]	Value
	Short tons	*Short tons*	
1918	2, 947	1, 253	$6, 935
1919	[a]15, 417	6, 756	75, 918
1920	[a]18, 101	7, 169	89, 699
1921	893	373	5, 681
	37, 358	15, 551	178, 333

[a] Large quantities of precious metal bearing pyrite were shipped from 1906 to 1917, and the contents are included in the gold, silver, copper, and lead tables. The value of sulphur for those years should be large, but payment for sulphur was indirect and was expressed in the reduction of freight and of roasting and smelting charges. The sulphuric acid was therefore a valuable by-product. Partly roasted pyrite from magnetic separation of iron from iron-zinc-lead ores was also further roasted to make sulphuric acid and metal-bearing cinders.

[b] The above figures indicate an average content of sulphur in pyrites ore of 42.5 per cent in 1918, 43.8 per cent in 1919, 39.6 per cent in 1920, and 41.76 per cent in 1921. Pure pyrite contains 53.4 per cent.

The siliceous pyritic ore has contributed more gold than all the other sulphide ores and has contained more silver to the ton, but it is far behind the iron pyrites ore in total quantity of silver contributed. It also contains more copper than the iron pyrites ore but not quite enough to be paid for.

The siliceous lead and copper sulphide ores differ from the siliceous pyritic ores only in containing more than 4½ per cent of lead or more than 2½ per cent of copper. Owing to the relatively small quantities mined, however, they do not contribute nearly so much lead and copper to the district's output as the other three classes of sulphide ore.

The siliceous pyrite, lead, and copper ores have come mainly from the lodes and connected replacement deposits in the Breece Hill area, and to a minor extent from veins and replacement deposits along the Tucson-Maid fault zone in Iron and Carbonate hills. The pyrite with excess iron has come mainly from the Yak and Moyer-Tucson mines and in part from the Garbutt, Greenback, Harvard, and Gambetta. The zinc-iron-lead ores have come from the large replacement bodies in limestone in the western half of the district. They commonly contain 2½ to 7 times as much zinc as lead but are the poorest in silver and gold.

The oxidized ores correspond in a general way to the sulphide ores as regards the ratio of iron to silica, but lead and zinc have become separated, and manganiferous ores are of considerable importance. The classes predominating in quantity shipped are siliceous gold and silver, lead, zinc, and iron-manganese ore. Siliceous copper ore and iron fluxing ores are subordinate. "Oxide ores" as classified by the smelters include, besides oxidized ore, ore unaffected by oxidation but containing less than 6 per cent of sulphur. Ore of this kind is present in Leadville but contributes only an insignificant fraction of the output of "oxide ores."

The oxidized siliceous gold and silver ores have been the largest contributors of gold but are far behind the principal sulphide ores in output of silver, copper, and lead. Their content of gold has frequently been higher and their content of silver lower than that of the siliceous sulphide ores. These ores have been subdivided into gold ore and silver ore only since 1920.

Oxidized siliceous gold and silver ores produced in Leadville district, 1908–1925

Year	Ore (short tons, dry weight)	Recovered contents							
		Total				Average			
		Gold (fine ounces)	Silver (fine ounces)	Copper (pounds)	Lead (pounds)	Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)
1908	25, 741	----------	----------	----------	----------	----------	----------	----------	----------
1909	28, 054	----------	----------	----------	----------	----------	----------	----------	----------
1910	21, 280	----------	----------	----------	----------	----------	----------	----------	----------
1911	24, 790	9, 412. 50	105, 620	20, 648	311, 938	0. 38	4. 26	0. 42	0. 63
1912	21, 368	8, 233. 38	108, 485	47, 617	366, 923	. 385	5. 08	. 11	. 86
1913	24, 316	9, 859. 68	127, 375	50, 782	470, 897	. 405	5. 24	. 10	. 97
1914	33, 000	15, 361. 23	166, 159	94, 300	539, 820	. 465	5. 04	. 14	. 82
1915	44, 734	32, 181. 21	150, 257	60, 212	728, 814	. 719	3. 36	. 07	. 81
1916	13, 876	4, 614. 64	81, 680	249, 293	521, 195	. 333	5. 81	. 90	1. 88
1917	10, 233	1, 830. 37	46, 030	57, 191	137, 564	. 179	4. 50	. 28	. 67
1918	6, 271	1, 741. 68	57, 420	7, 594	187, 966	. 278	9. 16	. 06	1. 50
1919	6, 244	2, 769. 23	55, 126	18, 494	141, 967	. 440	8. 83	. 15	1. 14
1920	9, 873	12, 118. 70	101, 282	18, 088	191, 092	1. 233	10. 26	. 09	. 97
1921:									
Gold ore	2, 591	4, 587. 10	15, 829	23, 182	28, 575	1. 770	6. 11	. 45	. 74
Silver ore	1, 426	27. 00	18, 556	3, 373	26, 748	. 019	13. 02	. 12	. 94
1922:									
Gold ore	3, 912	7, 121. 99	27, 320	37, 323	110, 454	1. 821	6. 98	. 48	1. 41
Silver ore	14, 415	234. 70	66, 935	13, 528	535, 990	. 016	4. 64	. 05	1. 86
1923:									
Gold ore	3, 300	5, 567. 03	12, 743	3, 806	60, 571	1. 687	3. 86	. 06	. 92
Silver ore	19, 021	9. 60	67, 428	5, 005	1, 080, 195	----------	3. 54	. 01	2. 84
1924:									
Gold ore	2, 095	26, 852. 54	15, 644	6, 798	65, 969	12. 817	7. 47	. 16	1. 57
Silver ore (mostly old slags)	61, 408	. 90	204, 501	----------	3, 408, 791	----------	3. 33	----------	2. 78
1925:									
Gold ore	1, 303	7, 596. 20	9, 135	6, 500	54, 600	5. 830	7. 01	. 25	2. 10
Silver ore (mostly old slags)	98, 809	17. 40	290, 299	1, 000	4, 783, 900	----------	2. 94	----------	2. 42

The siliceous copper ore differs from the siliceous gold and silver ores in containing more than 2½ per cent of copper. All these ores are mined in the upper levels of the Breece Hill area.

Oxidized copper ore (with excess silica) produced in Leadville district, 1911–1919

Year	Ore (short tons, dry weight)	Recovered contents							
		Total				Average			
		Gold (fine ounces)	Silver (fine ounces)	Copper (pounds)	Lead (pounds)	Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)
1911	1, 215	6. 76	968	190, 727	417	0. 006	0. 80	7. 85	----------
1912	898	96. 64	1, 771	101, 476	2, 486	. 108	1. 97	5. 65	0. 14
1913	64	18. 46	89	7, 037	----------	. 288	1. 39	5. 58	----------
1914	135	10. 70	706	14, 035	----------	. 079	5. 23	5. 20	----------
1915	3, 359	24. 90	5, 252	425, 088	----------	. 007	1. 56	6. 33	----------
1916	8, 520	4, 217. 54	29, 573	639, 672	86, 085	. 495	3. 47	3. 75	. 51
1917	7, 524	2, 408. 00	25, 465	826, 970	199, 478	. 320	3. 38	5. 50	1. 33
1918	3, 898	405. 30	10, 019	402, 060	34, 760	. 104	2. 57	5. 16	. 45
1919	139	----------	110	18, 816	----------	----------	. 79	6. 73	----------

"Metallics" in the Leadville district represent unusually rich bunches of ore in the siliceous gold, silver, and copper deposits. The name was originally given to the pieces of gold that did not pass through the screen in sampling, but its meaning has broadened. They occur mostly in oxidized ore but may also be found in enriched sulphide ore. Shipments of this material average less than 1 ton a year and consist largely of native wire and flake gold, native silver and horn silver, and argentite, separated from ore of ordinary grade. The material includes besides oxidized ore highly enriched sulphide ore and some unusually rich silver-bismuth-gold ore.

Oxidized lead ore, formerly the principal ore mined, has long been subordinate to the principal sulphide ores in quantity mined and in lead, copper, gold, and silver recovered. Its content of lead and its silver-lead ratio (1:20 to 1:40) are much lower than those of the enriched ores mined in the early days, and it doubtless includes ore that formerly could not be profitably mined. Most of it is siliceous ("hard carbonate") and is less desirable from the smelter's standpoint than lead ore with excess iron.

"Metallics" shipped from Leadville, 1909–1925

	Gold (fine ounces)	Silver (fine ounces
1909	2, 973. 66	842
1910	3, 920. 90	1, 307
1911	2, 223. 13	725
1912	1, 657. 66	716
1913	1, 278. 56	350
1914	4, 773. 91	1, 293
1915	4, 178. 75	1, 538
1916	1, 285. 56	310
1917	1, 169. 01	558
1918	780. 74	260
1919	1, 810. 82	587
1920	1, 169. 01	558
1921	608. 58	198
1922	2, 730. 77	750
1923	312. 58	87
1924	5, 655. 12	1, 465
1925	1, 417. 35	112

Oxidized lead ores produced in Leadville district, 1908–1925

Year	Ore (short tons, dry weight)	Recovered contents							
		Total				Average			
		Gold (fine ounces)	Silver (fine ounces)	Copper (pounds)	Lead (pounds)	Gold	Silver	Copper	Lead
						Ounces per ton	*Ounces per ton*	*Per cent*	*Per cent*
1908	24, 616								
1909	27, 504								
1910	[a] 18, 761								
1911	13, 123	4, 317. 97	85, 318	33, 632	1, 934, 868	0. 33	6. 50	0. 13	7. 37
1912	23, 754	4, 470. 20	308, 363	1, 331	4, 931, 803	. 188	12. 98		10. 38
1913	32, 153	5, 548. 97	218, 784	34, 914	6, 152, 882	. 173	6. 80		9. 57
1914	29, 288	9, 314. 94	190, 428	60, 002	5, 227, 960	. 318	6. 50	. 10	8. 93
1915	16, 002	4, 497. 76	87, 933	38, 740	2, 649, 869	. 281	5. 50	. 12	8. 28
1916	19, 716	3, 483. 43	114, 256	27, 585	3, 767, 487	. 177	5. 80	. 07	9. 55
1917	16, 416	2, 242. 04	101, 266	42, 208	2, 858, 848	. 137	6. 17	. 13	8. 71
1918:									
Silica excess	27, 957	3, 319. 05	212, 211	67, 520	7, 494, 803	. 119	7. 59	. 12	13. 40
Iron excess	17, 551	114. 10	85, 284	8, 005	3, 948, 605	. 007	4. 86	. 02	11. 25
1919:									
Lead-copper	653	16. 33	10, 506	75, 923	76, 968	. 03	16. 09	5. 81	5. 89
Silica excess	18, 916	1, 059. 75	172, 817	5, 146	5, 225, 401	. 06	9. 14	. 01	13. 81
Iron excess	1, 087	10. 50	5, 624		172, 702	. 01	5. 17		7. 94
1920:									
Silica excess	17, 826	1, 354. 60	141, 055	92, 361	3, 666, 124	. 076	7. 91	. 26	10. 28
Iron excess	694	68. 80	6, 288	272	119, 452	. 099	9. 06	. 02	8. 61
1921:									
Silica excess	4, 023	2, 072. 00	67, 146		1, 052, 730	. 515	16. 69		13. 08
Iron excess	435		2, 263		106, 464		5. 20		12. 24
1922:									
Silica excess	3, 372	1, 756. 90	26, 503	606	624, 533	. 524	7. 86	. 01	9. 26
Iron excess	3, 569	43. 10	16, 060	2, 975	880, 255	. 012	4. 50	. 04	12. 33
1923:									
Silica excess	11, 345	831. 60	77, 212	41, 274	2, 079, 163	. 073	6. 81	. 18	9. 16
Iron excess	2, 418	61. 20	8, 657		412, 167	. 025	3. 58		8. 52
1924:									
Silica excess	18, 954	1, 484. 50	91, 825	3, 560	2, 967, 086	. 078	4. 85		7. 83
Iron excess	4, 335	46. 60	19, 033	157	683, 047	. 011	4. 39		7. 88
1925:									
Silica excess	23, 826	1, 298. 20	110, 154	5, 200	4, 230, 000	. 054	4. 62	. 01	8. 88
Iron excess	4, 932	62. 80	22, 581		990, 800	. 013	4. 58		10. 04

[a] Includes 60 tons of copper-lead ore.

A complete record of oxidized zinc ore has been kept since mining of it began in 1910. Immense bodies of high-grade ore were mined during the next four years; but after these were exhausted no more extensive high-grade bodies were found, and both the quantity and the grade of ore shipped have been declining almost steadily. At present ore containing as low as 16 per cent of zinc is treated at the local zinc oxide plant, and little is shipped away from the district.

Oxidized zinc ore (carbonate and silicate) produced in Leadville district, 1910–1925

Year	Ore (short tons, dry weight)	Recovered contents (pounds) [a]	Average assay (per cent) [b]
1910	8, 059	4, 310, 500	32. 2
1911	83, 905	45, 143, 658	31. 05
1912	142, 782	71, 682, 667	29. 2
1913	135, 760	63, 340, 473	27. 45
1914	113, 881	46, 791, 046	24. 3
1915	82, 592	30, 684, 552	22. 48
1916	85, 513	30, 174, 903	21. 52
1917	69, 238	21, 116, 726	19. 84
1918	21, 292	6, 351, 683	18. 64
1919	16, 542	4, 592, 170	17. 80
1920	16, 726	5, 830, 835	21. 79
1921	4, 277	1, 200, 000	17. 97
1922	11, 343	3, 876, 000	21. 36
1923	20, 304	6, 732, 000	20. 72
1924	18, 801	5, 796, 000	19. 56
1925	11, 782	3, 823, 000	20. 26
	842707	351,446,168	

[a] Zinc in terms of recovered retort zinc and recovered zinc in zinc oxide.
[b] Average assay of original content; no deductions for loss in smelting. All to zinc plants.

The manganiferous iron-silver ores of Leadville are divided into three commercial classes:

1. Ore that contains sufficient silver and lead to be mined for these two metals. This class is included with lead ore if the lead content is 5 per cent or more, otherwise with dry iron-manganese silver ores. There is very little ore of this class in the district.

2. Ore that contains no lead but some silver and sufficient manganese and iron and little enough silica to be used for the manufacture of spiegeleisen and ferromanganese.

3. Ore that contains too little silver, lead, or manganese to be included in the other two classes but sufficient manganese and iron and little enough silica to be sold as flux to lead and copper smelters. The value of ore of this class depends on the combined iron and manganese content, the silica content, the precious-metal content, and deductions and adjustments of these factors based on temporary demands of the smelters. The greater part of the manganiferous silver ore mined at Leadville belongs to this class.

Before 1917 smelters commonly paid at the rate of 15 cents a unit (per cent) for the excess of combined iron and manganese above 40 per cent after deduction of the siliceous material. They also paid for 95 per cent of the silver content at New York quotations. The deduction of 40 per cent from the combined iron-manganese content was made in lieu of a charge for smelting. Lead was paid for as iron.

Recorded shipments of manganiferous and manganese ores exclusive of those classed as lead ore are shown below. These figures are not included in those on page 112. Records for years earlier than 1891 are incomplete, and no estimate is attempted of the value of ore shipped before that year; but the quantity shipped from Colorado in 1886 to 1890, nearly all fluxing ore from Leadville, was about 300,000 tons.[17]

Manganiferous iron [a] (silver) ores produced in Leadville district, 1891–1925

Year	Ore used in the manufacture of ferro manganese and spiegeleisen				Ore for fluxing (duplicated in other tables)	
	Grade (per cent Mn)	Quantity (long tons, natural weight)	Net value f. o. b. Leadville		(Grade per cent Mn)	Quantity (long tons, natural weight)
			Total	Average		
1891	------	964	$7, 230	$7. 50	------	79, 511
1892	25–38	2, 942	14, 710	5. 00	------	62, 309
1893	30	5, 766	23, 064	4. 00	------	[b] 55, 962
1894	25	7, 022	26, 822	3. 82	------	[c] 31, 687
1895	28–05	13, 464	40, 661	3. 02	------	54, 163
1896	22–35	9, 072	38, 069	4. 20	------	138, 079
1897	27–31	16, 519	39, 565	2. 40	------	149, 502
1898	18–33	18, 848	61, 785	3. 28	------	99, 651
1899	16–43	29, 355	86, 697	2. 95	------	79, 855
1900	18–45	43, 303	205, 256	4. 74	------	188, 509
1901	16–30	62, 385	248, 084	3. 98	------	228, 187
1902	18–32	13, 275	52, 371	3. 95	------	194, 132
1903	------	14, 856	55, 710	3. 75	------	179, 205
1904	15–32	17, 074	54, 104	3. 17	------	105, 278
1905	14-41	45, 837	110, 497	2. 41	------	81, 738
1906	26–36	32, 400	97, 600	3. 01	------	([d])
1907	20–25	41, 694	98, 311	2. 36	8–26	31, 544
1908	22–26	15, 973	39, 468	2. 47	6–22	35, 581
1909	------	12, 905	29, 682	2. 30	------	52, 119
1910	------	------	------	------	5–26	55, 770
1911	------	------	------	------	4–40	41, 753
1912	------	------	------	------	6–24	48, 618
1913	------	------	------	------	2–37	49, 753
1914	21	2, 100	4, 956	2. 36	5–37	37, 781
1915	20–35	15, 956	41, 527	2. 60	5–30	[e] 14, 965
1916	24–46	90, 600	296, 262	3. 27	5–35	[f] 16, 263
1917	19–32	104, 115	267, 284	2. 57	5–37	[g] 20, 600
1918	16–40	103, 855	723, 179	6. 96	5–35	[h] 24, 931
1919	26–39	22, 221	359, 927	16. 20	5–35	[i] 29, 769
1920	19–40	14, 629	152, 170	10. 40	3–22	34, 670
1921	20–41	1, 414	18, 527	13. 10	3–25	10, 819
1922	------	------	------	------	4–18	13, 951
1923	18–38	20, 626	109, 407	5. 30	2–27	10, 376
1924	13–38	25, 270	138, 849	5. 49	13	[j] 4, 484
1925	17–38	5, 893	24, 296	4. 10	5–28	[j] 11, 448
	------	810, 333	3, 466, 070	------	------	2, 322, 963

[a] The larger part of the ore indicated here is manganiferous iron ore. The ore containing over 35 per cent of manganese may be considered manganese ore.
[b] Includes 1,500 tons from Montana.
[c] Includes 1,049 tons from Montana.
[d] Ore for fluxing not recorded.
[e] Includes 796 tons containing less than 5 per cent of manganese.
[f] Includes 1,026 tons containing less than 5 per cent of manganese.
[g] Includes 141 tons containing less than 5 per cent of manganese.
[h] Includes 1,684 tons containing less than 5 per cent of manganese.
[i] Includes 844 tons containing less than 5 per cent of manganese.
[j] Dry weight.

From 1909 to 1914 no ore was shipped for the manufacture of spiegeleisen, but the war caused so great a rise in the price of manganese that the miners were

[17] Hewett, D. F., U. S. Geol. Survey Mineral Resources, 1912, pt. 1, p. 212, 1913. The figures recorded include small quantities of ore from Montana.

attracted to the development and mining of ore of this class for sale to manufacturers of spiegeleisen and manganese. The annual production of spiegeleisen reached a maximum in 1918 but rapidly declined when the war demand ceased. During the war a large quantity of ore containing 30 to 35 per cent of manganese was opened and shipped, but only a comparatively small quantity of manganese ore containing 35 per cent or more of manganese was found.

The contribution of manganiferous fluxing ores to Leadville's output of gold, silver, copper, and lead from 1908 to 1923 is shown below. Besides these ores smaller quantities of iron fluxing ore essentially free from manganese have been shipped since smelters were first established in the district, but a detailed record of shipments separate from those of manganiferous ore has been kept only since 1915. (See below.) The iron ore includes brown oxidized ore from the western part of the district and magnetite-specularite ore from the Breece iron mine. This mine was productive before 1880, until its ore was discarded in favor of brown ore from Fryer Hill. No record of its shipments was kept until 1907, but from 1907 to 1920 it shipped 87,000 short tons of iron ore with a very low content of gold and silver. Recent shipments have contained 0.06 to 0.17 ounce of gold and 2 to 4 ounces of silver to the ton. Below this iron ore was found and mined much siliceous gold-silver ore.

Oxidized iron-manganese (silver) ore for fluxing, produced in Leadville district, 1908–1925

Year	Ore (short tons, dry weight)	Recovered contents								Original average content (per cent)		
		Total				Average						
		Gold (fine ounces)	Silver (fine ounces)	Copper (pounds)	Lead (pounds)	Gold (ounce per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Iron	Manganese	Silica
1908	[a] 111,764	----	----	----	----	----	----	----	----	----	----	----
1909	[a] 91,960	----	----	----	----	----	----	----	----	----	----	----
1910	[a] 82,597	----	----	----	----	----	----	----	----	----	----	----
1911	[a] 64,296	[a] 1,566.16	319,574	----	2,353,112	0.024	4.97	----	1.83	----	----	----
1912	[a] 69,805	[a] 1,799.62	276,016	----	1,702,976	.026	3.95	----	1.22	----	----	----
1913	[a] 61,389	[a] 1,410.03	312,207	1,566	1,720,661	.023	5.09	----	1.40	----	----	----
1914	[b] 48,839	192.45	220,831	34	1,271,781	.004	4.52	----	1.30	----	----	----
1915	[c] 16,761	95.88	91,951	----	403,242	.006	5.49	----	1.20	43.65	14.08	11.10
1916	[c] 18,215	28.03	110,743	----	245,522	.002	6.08	----	.67	43.64	12.27	12.95
1917	[c] 21,447	291.17	114,094	2,666	515,970	.014	5.32	----	1.20	33.85	13.79	13.38
1918	[c] 26,955	291.05	172,475	1,569	783,906	.011	6.40	----	1.45	33.97	12.89	16.16
1919	[c] 33,341	86.41	259,865	1,985	842,365	----	7.79	----	1.26	31.53	14.23	17.51
1920	[c] 37,934	90.70	270,431	----	1,043,668	.002	7.13	----	1.38	29.90	15.68	15.52
1921	[c] 11,684	86.00	97,773	5,724	354,417	.007	8.37	0.02	1.52	31.16	16.26	13.33
1922	[c d] 15,801	30.07	92,505	1,338	649,998	.002	5.85	----	2.06	32.52	13.73	11.80
1923	[c] 12,079	18.30	89,882	----	436,247	.002	7.44	----	1.81	31.50	14.10	16.65
1924	[c] 5,027	8.90	31,084	----	196,062	.002	6.18	----	1.95	36.50	13.00	11.70
1925	[c] 12,822	7.80	91,091	----	535,500	.001	7.10	----	2.09	32.26	14.63	15.22

[a] Includes iron flux and some siliceous gold ore from the Breece Iron mine.
[b] Iron and iron-manganese (silver and some lead) flux.
[c] Iron-manganese (silver and some lead) flux.
[d] Includes 176 tons of iron flux.

Oxidized iron ore for fluxing, produced in Leadville district, 1915–1921 [a]

Year	Ore (short tons, dry weight)	Recovered contents							
		Total				Average			
		Gold (fine ounces)	Silver (fine ounces)	Copper (pounds)	Lead (pounds)	Gold (ounce per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)
1915	5,699	539.55	3,992	556	514	0.095	0.70	----	----
1916	3,879	333.01	2,982	----	----	.086	.77	----	----
1917	6,050	300.33	24,373	6,919	49,161	.050	4.03	0.06	0.41
1918	2,081	----	18,257	3,611	14,296	----	8.77	.09	.34
1919	1,726	85.50	7,063	----	39,388	.050	4.09	----	1.14
1920	1,990	384.00	9,678	507	83,596	.193	4.86	.01	2.10
1921	6,258	82.10	18,471	11,705	234,874	.013	2.95	.09	1.88

[a] Small output in 1922 included with iron manganese flux.

Ores containing valuable quantities of bismuth have occasionally been sold in small amounts, but no systematic records of shipments or bismuth content were kept for several years, and recently producers of bismuth in the United States have been reluctant to disclose the quantity and source of their output. In the Leadville district bismuth has been found in the Florence, Lilian, President, Ballard, Little Prince, Big Six, Highland Mary, and occasionally in a few other mines. The few scattering records of bismuth produced from Leadville ores are as follows:

Bismuth produced in Leadville district

Date	Mine	Price of metallic bismuth per pound	Ore (tons)	Bismuth (pounds)	Value	Source of information
1885	(a)		1			Mineral Industry.
1899	Probably Ballard	1.18			$10,000	Leadville Herald-Democrat.
1900	do	1.37			140,000	Do.
1901	do	1.45	[b] 253.6		22,500	Mineral Resources.
1904	Ballard and Big Six	1.82	[c] 36	5,882	10,705	Mineral Industry.
1905	Ballard [d]	2.14	[e] 9.2	[f] 1,784.8	[f] 3,819	Do.
1906	Two mines [g]	1.25		8,333	12,500	Mineral Resources.
1907	(h)	1.25				
1910	Highland Mary	1.58	(i)		6,320	
1912	do		(j)			
					$205,844	

[a] Locality not given.
[b] 4 to 10 per cent ore.
[c] Ore averaged 8.17 per cent of bismuth; Mineral Resources gives 5,184 pounds, valued at $314.
[d] Mine given in Mineral Resources.
[e] 5.4 to 13.9 per cent bismuth, Mineral Industry, vol. 14, p. 52.
[f] Estimated by taking average of extreme percentages and average annual price of metal.
[g] Names of mines withheld.
[h] Ore mined but not sold.
[i] 11.6 to 15.97 per cent bismuth. Ore yielded "several tons" of metal.
[j] Reported simply as one lot of 15.47 per cent bismuth in the form of carbonate.

These data are sufficient to show that the total value of the bismuth produced from Leadville ores has been only a small fraction of 1 per cent of the total quantity and value of metals derived from the district.

GROWTH OF THE CITY

The growth of the city of Leadville up to 1880 is described by Emmons [18] in the following words:

The nucleus of the present city of Leadville consisted of a few log houses scattered along the borders of California Gulch below the Harrison Reduction Works. In the spring of 1877 a petition for a post office was drawn up by Messrs. Henderson, Meyer, and Wood, which necessitated the adoption of a name for the new town. Mr. Meyer proposed the names of Cerussite and Agassiz, both of which were rejected as being too scientific. Mr. Wood proposed the name of Lead City, to which Henderson objected that it might be confounded with a town of the same name in the Black Hills, and the name of Leadville was finally adopted as a compromise. The rapidity of the growth of this city borders on the marvelous. In the fall of 1877 the population of Leadville was estimated at about 200 persons. The business houses of the town were a 10 by 12 grocery and two saloons. [19] In the spring of 1878 a corporation was formed, which was continued for six weeks, when the town's growth justified its transformation into a city of the second class, Mr. W. H. James being the first mayor and John W. Zollers city treasurer. Within two years Leadville grew to be the second city in the State, with 15,000 inhabitants and assessable property of from $8,000,000 to $30,000,000. In 1880 it had 28 miles of streets, which were in part lighted by gas at an expense of $5,000 per annum. It had waterworks to supply all the business portion of the city, having over 5 miles of pipes laid. It had 13 schools, presided over by 16 teachers, and an average attendance of 1,100 pupils; a high school, costing $50,000; five churches, costing from $3,000 to $40,000; and three hospitals, in one of which 3,000 patients were treated during the year. In 1880 $1,400,000 was expended in new buildings and improvements. It had 14 smelters, with an aggregate of 37 shaft furnaces, of which 24 were in active operation during the census year, and its producing mines may be roughly estimated at 30.

Since that time the number of inhabitants has fluctuated considerably. In 1890 it had fallen to 10,384, but in the next 10 years it rose again to 12,455, only to fall back in 1910 to 7,508. In 1920 it was 4,959. A considerable decrease in population had taken place in 1919, owing to the depression that began soon after the end of the World War. Continuation of the depression through 1921 doubtless caused further decrease.

During the 44 years that have passed since the first geologic report of Emmons was published the city, in spite of the fluctuation in its population, has gradually spread over a wider and wider area. Nothing will more strikingly reveal this fact than a comparison of the photograph taken by Emmons in 1880, which forms the frontispiece of the first Leadville report (pl. 4 of this report), with the one taken in 1912 (pl. 1).

During the period from 1889 to 1907 the workings of the mines extended beyond the Carbonate and Pendery fault zone and spread beneath the city streets as far west as Harrison Avenue. Shafts and dumps appeared within the city blocks, so that many a high

[18] U. S. Geol. Survey Mon. 12, pp. 14-15, 1886.
[19] A local census placed the population in 1877 at 5,040.

cribbed-up waste heap (see pl. 1) stood side by side with dwellings, and the disposal of waste became a serious problem, for a dump could not be extended beyond the limits of the surface property of the mine, nor could it be permitted that buildings should be overwhelmed by the growing accumulations of débris. To one looking eastward over the city the gallows frames vie in prominence with the steeples of churches and other high buildings and exceed them in number. (See pl. 1.)

POWER

Throughout the larger part of the history of the Leadville district steam has been the source of power for hoists, compressor plants, and mills, and to a very small extent it is still in use at one or two of the mines.

Custom electric-power service was introduced in Leadville in 1907 by the Leadville Light & Power Co., a subsidiary of the Central Colorado Power Co. Prior to this time custom electricity was available for lighting only, except for two or three small power installations in the town and an interchange of power service between adjoining mines. Until the summer of 1909 the Leadville Light & Power Co. operated with its own steam plant in California Gulch near the portal of the Yak tunnel. The capacity of this plant was 3,000 kilowatts. In July, 1909, the Central Colorado Power Co. began to operate its hydroelectric power plant, replacing the steam-plant service in Leadville with service from a substation on its high-tension lines. The Central Colorado Power Co. and the Leadville Light & Power Co. were later reorganized and consolidated as the Colorado Power Co. In September, 1924, the Colorado Power Co. was absorbed by the Public Service Co. of Colorado.

The hydroelectric station, known as the Shoshone station, operates on diverted water from Grand River and is about 12 miles east of Glenwood Springs. The transmission line extends from the Shoshone plant eastward, generally following the line of the Colorado Midland Railway over Hagerman Pass to Leadville, thence northeastward over Fremont Pass to Summit County, thence eastward over Argentine Pass (altitude 13,000 feet) into and through Clear Creek County, and thence to Denver. Current from the high-tension line is distributed by means of substations and local distribution systems. Substations are located at Denver, Idaho Springs, Dillon, and Leadville. The Leadville substation comprises three 1,500 kilovolt-ampere transformers with one spare unit; these step down to 6,600 volts for distribution. The distribution lines are copper circuits on wooden poles. The Leadville network of distribution lines extends westward to the Sugar Loaf mining district and to the mining district at the head of Upper Halfmoon Gulch, just across a divide from the Lackawanna mining district, northward to the upper reaches of Big Evans Gulch, and eastward to the head of Iowa Gulch. Three-phase 60-cycle current is delivered to the customer at a potential of 440 volts, the company providing the necessary transformers. The rates for power service are uniform over the entire system. Public-utility service in Colorado is under the control of a commission with which the rates of all custom power companies must be filed. The laws are particularly severe in penalizing any discrimination between customers. The power customer has six months in which to ascertain which of the schedules is particularly adapted to his requirements, and thereafter he operates under that schedule. The compressor rate is available where a compressor is the predominating load, and the hoist rate where a mine hoist is the predominating load.

With the exception of two large mines whose owners are unwilling to undertake the expense of electrification and the abandonment of a very considerable steam installation, practically all power users in the Leadville mining district in recent years have purchased their power from the Colorado Power Co. In general, in the Leadville district good steam coal can be obtained at $3 to $4 a ton, the price depending on the location.

In January, 1910, the company's operating records for Leadville show 1,743 horsepower connected load, a peak of 1,300 kilowatts on the substation, and an output to the distribution network for the month of 477,327 kilowatt-hours. In December, 1914, the corresponding figures were 6,569 horsepower connected power load, 2,350 kilowatts substation peak, and an output of 1,202,780 kilowatt-hours.[20]

CHRONOLOGIC SUMMARY

In order that the principal events in the history of Leadville may more easily be passed in review the following chronologic summary has been prepared. The information has been culled from many sources.

1842–1859. Valley visited by trappers and individual explorers.

1845. Frémont enters and passes through upper Arkansas Valley.

1858. Organized prospecting expeditions from Auraria, Ga., in June find gold in Cherry Creek and on South Platte River, near present site of Denver. Rush to "Pikes Peak" region begins.

1859. On January 7 Jackson finds placer gold in Chicago Creek, and on May 6 Gregory finds decomposed oxidized outcrop of gold lodes on North Clear Creek. Rush to "western Kansas" continues. Gold-bearing gravel deposits found on northern border of South Park, in Tarryall Creek, on the Platte near Fairplay, and on the tributaries of Blue River near the present town of Breckenridge. Gold discovered at junction of California Gulch and Arkansas River by Slater and others. S. B. Kellogg comes to Colorado after 10 years' experience in placer mining in California.

1860. Deposits found in a valley leading from Iowa Gulch. California Gulch preempted in 100-foot claims for 7 miles.

[20] Information obtained from Colorado Power Co.

California mining district organized by Slater, Currier, and five others, on April 12. Kellogg and Tabor enter California Gulch on April 26. Placer gold excitement grows. Probably 10,000 people at work by July 1. Discovery claim, above A. Y. and Minnie mine, produced $65,000; other claims did as well.

1861. Lake County organized as one of original 17 Colorado counties by Territorial legislature. (It has been cut down several times to present size.) Production of placers decreases, and population of Oro City begins to dwindle. Ditch for carrying on sluice mining built from Evans across head of California Gulch.

1864. Oro City abandoned.

1865. California Gulch almost abandonded.

1866. Only 150 permanent residents in Lake County.

1867. A few prospectors only left in Oro City.

1868. In June Printer Boy vein on Printer Boy Hill discovered by Mullen and Smith; Five-Twenty and Pilot veins located. In August stamp mill built at Oro City to treat ore from Printer Boy mine. Lower Printer Boy mine located.

1869-1874. Period of depression. California district nearly abandoned.

1871. Homestake mine, on Homestake Mountain, in Sawatch range, opened. Placer mining continued in California Gulch with decreasing yield. A 5-stamp mill erected on the Five-Twenty property.

1873. Several rich gold strikes in California Gulch.

1874. Placers on higher ground in California Gulch developed. Stevens and Wood find carbonates.

1875. Chlorination works built by Breece in California Gulch for treatment of gold ore from Berry tunnel. Smelter at Malta, 10 tons capacity (two roasting furnaces and one blast furnace), under construction, expecting to treat Homestake ore and other silver ore which it was hoped would be developed. Wood and Stevens locate claims on contact between Blue limestone and White porphyry on Rock and Iron hills, covering large portions of Iron Silver Mining Co's. property. Work begun on present Rock claim (Dome Hill) in the fall.

1876. Shamrock and Carbonate mines, on Carbonate Hill, located. J. H. Dana mine, on Long & Derry Hill, located by Abe Lee. Rich ore found in croppings of Iron and Bull's Eye claims, on Iron Hill. A. Y. mine, on Iron Hill, located. A. R. Meyer makes first shipment of 200 to 300 tons of carbonate ore from Rock mine, on Dome Hill, to St. Louis, Mo. Camp Bird and Charlestown claims located on North Iron Hill by Gallagher Bros. Long & Derry mine located by Long & Derry. Colorado becomes a State. Lizzie smelter begins operations at Malta.

1877. Petition for post office filed, and name of Leadville adopted on January 18. Ore discovered on Fryer Hill by George Fryer. Little Pittsburgh mine, on Fryer Hill, located a month later by Rische and Hook for H. A. W. Tabor. Tabor buys Chicken Bill's "salted" ground for $40,000 and, with associates, under title of Tabor, Borden & Co., develops it and finds it to be very valuable. Crescent, Yankee Doodle, Catalpa, Evening Star, Morning Star, and other mines on Carbonate Hill opened. Census by local town board on December 24 showed population of 5,040. Leadville smelter begins operations.

1878. Smelter of La Plata Mining & Smelting Co. "blown in" in June. Leadville made a city of the second class. Sampling works of August R. Meyer & Co. and Eddy, James & Co. start work. Grant smelting works begin operations in September. Harrison Reduction Works (St. Louis Smelting & Refining Co.) begin operations in October.

1878-1884. Iron-Silver mine the leading producer.

1879. Chaffee County made from a part of Lake County by State legislature. Leadville second largest city in Colorado; population 15,000; assessable property, $8,000,000 to $30,000,000; made a city of the first class. Morning Star very large producer. Little Pittsburgh Consolidated Mining Co. incorporated, covering Little Pittsburgh, New Discovery, Dives, Union, and Winnemuck claims. Amie, Dunkin, Matchless, and other mines on Fryer Hill begin producing. Tabor, Borden & Co.'s property purchased by Chrysolite Consolidated Mining Co., capitalized at $10,000,000, including the Carboniferous, Chrysolite, Fairview, and All Right claims. Pendery-Glass Mining Co. organized. Evening Star produces largely. Robert E. Lee vein discovered in winter (January?). Carbonate ore discovered on Little Ellen Hill, and Little Ellen mine opened. Highland Chief mine opened on north slope of Breece Hill. Pendery shaft strikes second or Gray porphyry contact. American smelter erected by American Mining & Smelting Co. in California Gulch; begins smelting in May. Denver, South Park & Pacific Railroad reaches Buena Vista in the spring. Ore struck in Breece iron mine, on Breece Hill. California smelter erected and begins smelting in June. Billing & Eilers smelter begins operations in May. Ohio & Missouri smelter erected in Big Evans Gulch; begins operations in June. Gage, Hagaman & Co.'s smelter and Raymond, Sherman & McKay's smelter begin operations in June. Elgin smelter erected by Elgin Smelting Co. and begins smelting in June. Cumming & Finn's smelter begins operations in July. Little Chief smelter begins operations in August. Adelaide smelter begins operations during the year.

1880. Henriett mine begins producing (?). Miners walk out on strike May 26; martial law declared by Governor Pitkin June 13. Strike terminates June 18. First train run over Denver & Rio Grande Railroad reaches Leadville August 2. Two desperadoes, Frodsham and Stewart, lynched, and period of extreme lawlessness brought to an end November 20. Several ore-buying companies active; also 11 or 12 smelters yielding bullion and four stamp mills operating during the year.

1882. Arkansas Valley Smelting Co. formed, by consolidation of Billing & Eiler's Utah smelter and the A. R. Meyer & Co.'s sampling works; largest smelter in Leadville. Grant smelter destroyed by fire.

1883. Six large smelters in operation. Little Jonny shaft down 120 feet. Breece iron mine the only producer on Breece Hill. Adams Mining Co. incorporated, including Clontarf, Brookland, and Moyamensing claims.

1884. Manville smelter put into operation. Smelters at Leadville still taking most of the ore, but those of Denver and Pueblo increasing their purchases. Several mills active. Little Jonny producing lead-silver ore. Iron Hill continues to be largest producing center, but deposits on Carbonate Hill regarded as chief lead reserve.

1885. Sulphides struck in New Pittsburgh group. Smelter competition pronounced. Four stamp mills begin operations in April on gold ores: Oro mill, 25 stamps; First National, 10 stamps; Seven-Thirty, 5 stamps; Lilian, 20 stamps. Mixed sulphide ores first mined for lead and silver; no market for zinc. Concentration plant erected at Iron-Silver mine in April. Concentration plant installed at Wolftone mine August 15. F. L. Bartlett begins experiments at Portland, Maine, on treatment of lead-zinc sulphides, which resulted in establishment of a zinc-oxide plant at Canon City six years later. Silver Cord strikes sulphides September 12. California Gulch placers produce $60,000 in gold during the year. Concentrating plants in use to treat zinc-lead ores; designed to make high-grade lead concentrates from low-grade zinc-lead sulphides; the zinc-sulphide concentrates are allowed to accumulate, and later (1899-1901) large quantity shipped to Wales and Belgium; 1900-1902, domestic smelters succeed in treating ore and concentrates and drive European buyers from market; 1907-1914, large quantity of zinc concentrates re-treated by magnetic separation at Canon City and Pueblo.

1886. Concentration plant erected at Col. Sellers mine in January. Project of drainage tunnel from Malta eastward first suggested. Leadville monograph published. Alice placer bought May 1 by Leadville Tunneling & Mining Drainage Co. for draining all Leadville mines.

1887. Colorado Midland Railway reaches Leadville, and first train run into city September 3.

1889. First work started in Downtown district beneath the city of Leadville.

1890. Large deposit of copper-bearing sulphide ore found in Henriett and Maid of Erin properties.

1891. Ten shafts sunk within city limits of Leadville, opening up Downtown district. Ore encountered in Penrose, Gray Eagle, Lazy Bill, and Star of Hope shafts. American Zinc Lead Smelting Co. (Bartlett process) started operations at Canon City. John Campion finds gold ores in Little Jonny claim.

1892. Center of mining activity shifts to Downtown district. July 2, plans drawn for drainage tunnel from Malta to drain Leadville mines (often discussed and debated again as years went by but not yet started in 1925). November 26, Little Jonny mine shipping copper sulphate ores. New smelting plant errected by Bi-Metallic Smelting Co. on site of old La Plata smelter.

1893. Sudden fall in price of silver causes shutdown on most of lead-silver mines July 15, and vigorous prospecting for gold ores results. Gold from Breece Hill properties begins to make gold output of Lake County important. Gold production rises from \$250,000 to nearly \$1,000,000. On September 23 mine owners and miners agree on a reduction of wages until silver rises to 83½ cents a fine ounce.

1894. Gold production increases from \$900,000 to \$1,500,000 Gold producers include Ibex Co., comprising Little Jonny, Uncle Sam, Little Stella, and others; Little Winnie, Nevada, Little Ella, Valley, Midnight, Australian, Virginius, Fanny Rawlings, St. Louis (Colorado Prince and Miners Boy), Eliza, Highland Chief, Nettie Morgan, and Great Hope. Resurrection and Garbutt were among the promising prospects. Yak Mining, Milling & Tunnel Co. incorporated.

1895. Extensive developments in Downtown district in Gray Eagle, Pocahontas, Bon Air, Gazelle, and other mines. Work on Yak tunnel started by enlarging the first 3,000 feet of the Silver Cord single-track tunnel to double-track. The next 1,842 feet to the face of the Silver Cord tunnel remained single-track, but from that point a double-track tunnel was cut.

1896. Strike of 1,600 miners June 21; later spread until nearly all mines in the district were closed. Militia called out September 20 to protect property and quell disorder.

1897. March 9, strike declared off by miners' union and strikers return to work at old wage scale.

1898. October 22, work begun in unwatering mines of the Downtown district, flooded during the strike.

1899. Snowstorm in January to March for 57 days causes blockade and ties up many of the mines. In April unwatering of mines in Downtown district practically completed through efforts of a pumping association composed of practically all leasing companies and owners of territory in the Leadville basin; 15,000,000 gallons of water a day handled. Two-month smelter strike occurred during the summer. Leadville very active; producers worked to the limit, and much exploration work undertaken. Nearly all lead smelters in the Rocky Mountain States taken over by the newly organized American Smelting & Refining Co. Ibex workings aggregate nearly 45 miles.

1900. Leadville very active. Highest gold production in history of the district. Zinc industry grows, and treatment of lead-zinc ores receives attention. A semipyritic smelter started in November, 1899, by the Boston Gold-Copper Smelting Co. is operated continuously through 1900. Leasing system predominates.

1901. New zinc concentrating mills at Minnie and Resurrection mines. A cyanide mill erected to attempt to treat gold ore from the Garbutt and Little Jonny.

1902. Ohio & Colorado Smelting Co. completes smelting plant at Salida. Magnetic separation mills built at Canon City, Pueblo, and Denver.

1903. Magnetic separation plant erected at Resurrection mine. Milling plant for low-grade sulphides erected at Arkansas Valley Smelting Co.'s plant. Fifty-ton concentrating mill erected at Ballard mine.

1905. Rho (frequently spelled Rowe) magnetic separation mill erected at mouth of Yak tunnel, replacing the old Yak concentrating mill.

1906. Damascus, A. Y. & Minnie, Adams, and Rho mills in operation.

1907. Financial panic in the fall causes partial cessation of mining activity in the district. Only Rho mill active. Downtown mines allowed to fill with water. (Compare 1916.)

1908. Rho, Adams, and Leadville District (new) mills active.

1909. Adams mill closed. On January 1 Yak tunnel reaches a point 3 miles from portal. May 15, first wire-rope tramway in Leadville installed at Tucson mine on Iron Hill. August 14, first recognized body of zinc carbonate ore opened in Robert E. Lee mine. September 25, Robert E. Lee begins shipments of zinc carbonate ore (unsuccessful). October 30, Yak tunnel reaches Resurrection Shaft No. 2, nearly 3½ miles from portal.

1910. Zinc carbonate ore found in old workings of Amie, Henriette, Maid, Wolftone, Morning Star, Evening Star, Big Chief, Castle View, Amie, Iron Silver, and Fryer Hill mines. Heavy shipments to about 1915. Carbonate of zinc ore discovered in Lime and Stevens shafts October 29.

1911. Rho mill closed. Zinc carbonate ore discovered in Ibex mine April 8.

1912. Leadville Mines Pumping Co. signs contract to unwater mines of East Fryer Hill, May 18. Zinc carbonate ore found September 7, in La Plata mine, on Dome Hill. Yak tunnel winze on Diamond ground, 4 miles from portal of tunnel on October 26. Year shows maximum yearly output of zinc carbonate ore.

1913. Drop in price of zinc slowed up production of zinc carbonate.

1914. A 50-ton zinc oxide plant built for treatment of zinc carbonate ore containing 16 per cent or less zinc. Operated only short time in 1914. Leadville District mill remodeled, and flotation equipment added. Operated on lead-zinc ores from Leadville and Red Cliff. Unwatering of Downtown mines planned and installation of equipment begun at Penrose shaft by Downtown Mines Co., a consolidation of large group of mines of lower Carbonate Hill and upper part of area within the city limits of Leadville. Iron-manganese ore shipped from the Star mines was first shipment for manufacture of spiegeleisen or ferromanganese since 1909.

1915. Water in Penrose shaft (Downtown) lowered from 238 to 700 feet below collar. Up to the end of 1915 this unwatering had not affected water in Wolftone and other shafts on Carbonate Hill to any extent. Plans formed to unwater mines in Fryer Hill. Claims consolidated and pumps installed at Harvard shaft by U. S. Smelting, Refining & Mining Co. Zinc oxide plant, unsuccessful in 1914, treated 16 to 20 per cent (some small purchases of even lower grade) zinc carbonate ore from April, 1915, onward. Considerable interest shown in development work on Prospect Mountain. Derry Ranch dredge, on Arkansas River at mouth of Box Creek, 12 miles below Leadville, operated for first time. This placer production first for Lake County since early placer mining in California Gulch; continued in 1916–1920, 1923, and 1924. Lead and silver production continued to decrease, but gold from Breece Hill increased heavily.

1916. The 50-ton zinc oxide plant operated on low-grade ore. (Operated continuously 1916–1925, with one short interval of idleness in 1921.) Unwatering of Fryer Hill mines completed, and zinc carbonate and iron sulphide ores shipped. Downtown mines, allowed to fill with water in 1907, again unwatered, and produced large quantities of oxide of lead, zinc, iron-manganese, and other ores from 1916 to August, 1923, when pumps were again removed from the lower levels.

1917. Greenback and Mikado shafts in Graham Park unwatered, and ore shipped; Mikado working deep-seated ore bodies of Venus claim and Marian group of claims (Iron-Silver). October 13, Moyer mine practically exhausted of ore that could be mined at profit, and pumps pulled; mine closed after almost 20 years of service. Zinc carbonate shipments decrease considerably. Production of gold ores of Breece Hill also decrease.

1918. Zinc shipments further decrease. Tucson closed in July, ore of present commercial grade being exhausted. Operations by U. S. Smelting Co. on Fryer Hill abandoned in June, though lessees continue through year. Work begun in July of clearing old Pyrenees shaft (more than 1,200 feet deep); enlargement to three compartments planned by Iron-Silver Co. Greenback mine closed during summer. Wolftone mine closed December 1. Drop in price of zinc in December; was first stage in big depression, but Mikado and Yak kept open to avoid prohibitive cost of closing and reopening. War brings first shipments of pyritic ore barren of precious metals to sulphuric acid plants in Colorado and to eastern plants, as distinguished from pyrite carrying precious metals shipped since 1906 for making sulphuric acid with return of cinders to lead smelters. (Barren pyrite shipments continued in 1919 and 1920.)

1919. All metal mining adversely affected in January and February by high cost of operating and low prices and poor demand after World War. Short labor strike in April resulted in closing several mines, including those operated through Mikado shaft.

1920. Complete cessation of all zinc shipments in November. The 50-ton zinc oxide plant doubled in size; new unit not used till 1922, whereupon old unit was idle.

1921. Very little production of zinc during year cuts gross production seriously, because it affects also production of lead and silver. Probably the worst year of Leadville's history.

1922. Improvement general, including resumption of zinc-ore shipments in November. (See also 1920.)

1923. Expiration of Pittman Act silver purchases (July 1) cuts silver production.

MINING DEVELOPMENT

EXTENT OF WORKINGS

The amount of underground exploration in the Leadville district is difficult to estimate with any approach to accuracy, for although many of the mine maps are complete so much entirely unrecorded work has been done by owners and lessees and by prospectors in a small way that measurement of mine maps must necessarily fall far short of the truth. It undoubtedly amounts to many hundreds of miles and may now equal if indeed it does not exceed that of any other mining district in the United States. The wide distribution of the ore deposits over the entire area and the comparatively shallow depths at which they lie in nearly all parts of the district have naturally led to their attack at a large number of different points, with the result that most of the district is honeycombed with workings. In places where ore deposits have been richest, as on Fryer, Carbonate, Iron, and Breece hills, the workings are of course greatest in extent and complexity. On the northwest slope of Carbonate Hill so great has been the amount of underground work that the dumps have all run together in one great mass of débris, and it almost seems that more of the hill is above ground than has been left below.

The workings represented in Plate 13 include 1,329 shafts, 155 tunnels, and 1,628 prospect holes, and to these must be added many more now caved in and obscured or covered by dumps. Although the restriction of the ores to the sedimentary formations has resulted in shallow shafts, and the footage of shafts is therefore relatively small compared with the lateral exploration, it forms a surprisingly large total. Records of the geology in 411 of the 1,329 mapped shafts have been obtained. Some conception of the aggregate amount of shaft work may be gained from these 411 shafts, about one-third of the total number. The total footage in these 411 shafts was 35.5 miles in 1901 and has been vastly increased since, as exploration has been pushed to deeper horizons. It would not be surprising if the aggregate length of all the shafts, tunnels, and prospect holes in the district proved to be about 75 miles.

Of the amount of drifting, tunneling, stoping, and other underground explorations even a rough estimate is impossible, but it obviously is vastly in excess of the total amount of shafting.

As early as 1884, eight years after the discovery of lead carbonate ore bodies, an estimate of the amount of development work in 60 of the principal producing mines amounted to 356,248 feet, or 67.5 miles.[21] At that early date the workings of one mine alone, the Chrysolite, amounted to 9.1 miles. The extent of the workings has, of course, been enormously increased since 1884. In 1925 the workings of a single mine, the Ibex, on Breece Hill, had an aggregate length of 50 miles.

Were it possible to form an approximate estimate of the aggregate cost of all excavation it is probable that the total would form here, as in other mining districts, a notably large percentage of the gross value of the total metallic product of the district, as it would necessarily include a vast amount of unsuccessful and totally unprofitable exploration.

RELATION OF EXPLORATION AND DEVELOPMENT TO GEOLOGIC STRUCTURE

PROGRESS OF DISCOVERY

The localities at which ore bodies were successively discovered are naturally those where the ore cropped out. With one exception, that of Fryer Hill, the deposits first discovered were outcrops; but outcrops

[21] Director of the Mint Ann. Rept. for 1884, p. 231.

were few owing to the concealment of the principal ore-bearing beds beneath White porphyry and to the extensive covering of bedrock by glacial deposits and "wash." From west to east the outcrops are located on the west slope of Carbonate Hill, at the south end of Carbonate Hill, near California Gulch, in California Gulch between Rock and Iron hills, on Long & Derry Hill, on Printer Boy Hill, on the north slope of Breece Hill, and in Evans Gulch on the south slope of Little Ellen Hill.

In addition to these localities at which the ore is exposed at the surface two other localities where it reached bedrock surface beneath "wash" and "lake beds" were the seat of chance discovery. The first two outcrops discovered were in the neighborhood of the placer mines, as would be expected; but these discoveries were closely followed by or simultaneous with those on Carbonate Hill, Little Ellen Hill, and the west brow of Iron Hill. Of the two chance discoveries made by workings that penetrated the wash, one was made on Fryer Hill under purely fortuitous circumstances, as described on page 117. The other appears to have been in the vicinity of the Argentine tunnel, where the wash is thin and the ore comes nearly to the surface.

From the outcrops exploration was pushed inward and downward along the contact farther and farther beneath the overlying porphyries. In this way mining progressed eastward from the west brows of Iron Hill and Carbonate Hill and the point of discovery on Fryer Hill, northeastward from the southwest slope of Little Ellen Hill, and southward in the Argentine tunnel.

The work progressed from the outcrops rapidly during the period between 1876 and 1900. Not until 1889 was work pushed westward from the brow of Carbonate Hill and downward beneath the city of Leadville, but by 1891 a large number of shafts had been sunk in this part of the district, and new and extensive ore bodies were opened up. Although the outcrop on the north slope of Breece Hill, where the Little Jonny mine is located, was mined in its upper portion in comparatively early years, the exact dates are not known. The outcrop dipped southward so steeply into a little-known and deeply buried portion of the district that it was not until 1893 that extensive exploration was carried downward toward the south and reached the very extensive ore bodies which have since made the Ibex mine so famous.

The center of the greatest mining activity has shifted a number of times. In the early eighties Fryer Hill and Carbonate Hill figured most largely. Iron Hill and Little Ellen Hill occupied somewhat subordinate although very important positions. In the early nineties the center of mining activity and interest shifted to the Downtown district, beneath the city of Leadville. In 1893 it shifted again to the vicinity of the Ibex mine, on Breece Hill. Since 1905 interest has centered chiefly in deeper workings in the sulphides on Iron Hill and in Graham Park, notably the Silver Cord and Iron Silver Mine Co., and the siliceous gold ores of Breece Hill. From 1910 to 1914 the zinc carbonate ores of Carbonate Hill and western Graham Park overshadowed the other ores, but the sulphide ores have furnished the steadier output.

METHOD OF OPENING MINES IN "BLANKET" ORE BODIES

Nearly all the outcrops mentioned on page 117 were "blanket" ore bodies or replacement deposits in limestone beneath a capping of porphyry. As the ore horizon coincided with the limestone-porphyry contact it was commonly called the "contact"; and after several ore horizons had been discovered, that between the Blue limestone and the overlying White porphyry became known as the "first contact," and lower horizons were numbered in downward succession. The early developments were all along the "first contact," which commonly had an eastward dip as a result of postmineral faulting and tilting.

Exploration at first followed the "contact" inward and downward from the outcrop along inclines, and levels were run at successive vertical intervals.

Some of these old inclines in Carbonate Hill, Iron Hill, and Little Ellen Hill are shown in Plate 43. Drifts at successive levels followed the contact, and as it was necessary to maintain the proper grade and at the same time not depart from the undulating and in places exceedingly irregular contact, these drifts usually followed sinuous and wandering courses, thereby materially increasing the distance over which ore had to be trammed to reach the main shaft. Owing also to the undulating nature of the contact it was usually impossible to keep inclined shafts at a constant slope, for if that were done they would either penetrate the overlying porphyry or depart from the contact into the limestone below. Some efforts to maintain an even slope took inclines so far into the overlying porphyry or underlying limestone that exploratory winzes or raises were necessary to find the contact. Consequently the slope was generally changed many times in the downward course, and the shafts were difficult to maintain.

From the so-called contact drifts crosscuts were driven backward toward the mouth of the incline and raises put up to the contact, which became successively higher as distances were gained from the main level. An additional source of trouble with these inclines lay in the nature of the porphyry near the contact. This rock is usually soft and claylike along the contact for great distances from the outcrop and makes heavy swelling ground, which must be closely timbered and is even then difficult to support. For these reasons inclines were always more or less unsatisfactory, for they were difficult to keep in repair, were expensive to operate and maintain, were of limited hoisting capacity, and involved longer distances for underground tramming than the more direct approach.

As inclined shafts reached greater depth and thus became more unsatisfactory, and as the increasing knowledge of the geologic occurrence of the ore involved less uncertainty, vertical shafts were sunk some distance back from the outcrops, and many of the old inclines were abandoned. At first these shafts were sunk only to open up ore bodies whose presence had been sufficiently demonstrated by inclines; but presently they were also sunk in considerable numbers for exploratory purposes by companies owning ground on the dip beyond that owned by the companies owning the outcrop. Though some of the old inclines continued to be used for many years after the superiority of vertical shafts had been demonstrated, they were practically abandoned at a very early stage of Leadville's history, and by 1885 it had become a rule of thumb with the miners to start a shaft almost anywhere in the porphyry and sink to the contact.

The method of procedure used with vertical shafts is simple, and though frequently varied in detail is the same in its broader features throughout the district. A station is often cut at the contact and exploratory drifts run from it, but unless the contact is inclined so that crosscuts can be run beneath the ore body at a considerable angle to its strike stoping is not carried on from this level. If no contact level is started the distance of the uppermost level below the porphyry contact is governed by the inclination of the contact and the position of the ore body. If much ore lies on the up-dip side of the shaft the station of the uppermost level may be cut well within the porphyry cap and drifts may be run through the porphyry into the limestone through and beneath the ores. If the ore sought lies on the down-dip side of the shaft the first level is started well below the contact and driven outward until the contact is cut. A similar course is followed on each succeeding level. Except where ore is encountered on the level, raises are put through the limestone to the contact above. In general raises put up for mining do not extend much more than 60 feet, but raises for exploring the contact and locating the ore bodies may be extended upward for 100 feet or more. From the tops of raises short exploratory drifts are frequently run along the contacts to locate ore bodies, but extensive exploration is rarely carried on from any individual raise. In some places intermediate levels having no connection with the shaft are run from raises, but this practice usually arises from an incomplete knowledge of the form and position of the ore when the development was planned. Square sets are used in all stopes, but in places where the ground is very heavy solid cribs of timber are sometimes employed.

Subsequent to the exploitation of the ores of the first or upper contact, vertical shafts were carried deeper and more contacts at successively lower horizons were found. (See p. 188 and pl. 59 for description of contacts in different localities.) Plate 9, *A*, shows the main working shaft of the Wolftone mine, a vertical shaft about 1,500 feet east of the outcrop of the contact. The "first contact" was cut in the shaft at a depth of about 650 feet, and the Cambrian quartzite in the footwall of the Tucson-Maid fault was reached at the bottom of the shaft. Plate 44, *A*, shows the Pyrenees (Rialto) shaft, as formerly equipped, located where the White porphyry was deepest. The shaft was sunk for 1,065 feet to the "first contact."

Where an ore body followed up the dip was found to be cut off at the footwall of a fault, and the significance of the fault was understood, development proceeded in a different way. The ore was traced down the fault until its position on the footwall side was determined; then it was followed up the dip of the contact, the development perhaps meeting workings that had been driven downward from an outcrop. Exploration along the fault was conducted either by an inclined shaft along the footwall, or by a vertical shaft started on the hanging-wall or downthrown side and passing through the fault into the footwall. Short crosscuts were driven from either shaft to explore the fault zone.

Several notable examples are worthy of mention, as a correct interpretation of the geology has in large measure afforded the courage required for this method of procedure. One of these is the Mikado mine, at the northwest end of Iron Hill. (See pl. 21, section J–J'.)

Considerable rich ore was first found immediately beneath the "wash" on the upthrown side of the fault, near the Camp Bird tunnel, one of the first points of discovery in the district. This ore, worked by the open-cut method, was cut off sharply on the west by the Iron fault, and at the suggestion of the superintendent, Mr. Chadbourne, a shaft, the Mikado No. 1, was sunk on the downthrown side of the Iron fault about 450 feet to the west of its outcrop, to develop the possible continuation of ore in that direction. The shaft penetrated the overlying White porphyry at a depth of 260 feet and reached ore and the sedimentary formations. Workings soon developed the presence of the Mikado fault, 400 feet west of the Iron fault and of much greater throw. The ore on the bench between the faults was in turn cut off sharply against the Mikado fault. In 1890 a second shaft, the Young America or Mikado No. 2, was sunk nearly 500 feet west of the old shaft. This cut the fault and then entered the granite. Dragged-in ore was found along the fault and was mined through levels run east from the shaft above its intersection with the fault and west below the intersection. The shaft did not follow the fault surface because of the soft ground and great flow of water. The lowest of the west levels at a depth of 1,000 feet encountered the limestone on the western or downthrown side of the fault, but no ore was developed.

A third deep shaft, the R. A. M., was sunk about 350 feet south-southwest of the Mikado No. 2. (See pl. 19.) This shaft likewise cut the Mikado fault and penetrated the granite, and extensive developments on the most deeply buried portion of the "contact" were later carried on through it.

During this development the workings in the Wolftone, Robert Emmet, and other neighboring mines were being extended downward on the dip of the several contacts, and the exploration down the dip then joined that proceeding upward from the fault.

Perhaps the most successful example of development down the dip of faults is that of the McKeon shaft, in South Iron Hill. A large shoot of ore mined at the old Iron incline was followed westward to its outcrop. The lower portion of the outcropping ore body bent downward along the Iron fault. A large amount of dragged-in ore was found in the fault, and an inclined shaft was carried down in the footwall toward the west. Ore was then discovered on successive lower benches between the main Iron fault and a series of smaller parallel faults on the "first contact" until the lowest level was reached, and thence it continued west on the Satellite workings. (See section E–E′, pl. 24.)

The historically most interesting of the examples of development of this kind is that which led to the discovery of the Downtown district, where ores have been mined directly beneath the city of Leadville. The first development in this neighborhood was on the outcrop of the "first contact" on the west side of Carbonate Hill, where the contact dips gently eastward from the Carbonate fault zone beneath the White porphyry cap that extends eastward to the Iron fault. Access was first gained to the ore bodies by means of inclines on the contact, of which the more extensive were the Combination, Carbonate, Yankee Doodle, and Crescent. Eastward progress on the "first contact" was then gained by a row of vertical shafts east of the inclines. The next step in the development was the sinking of vertical shafts at or near the mouths of the inclines, still east of the Carbonate-Pendery fault zone. In these shafts a "second contact" beneath a sheet of Gray porphyry was discovered in the Blue limestone. This contact in turn was followed eastward. For that purpose inclines were driven along it from the bottoms of vertical shafts, notably those of the Lower Henriett and Waterloo mines. The "second contact" was also opened up in the Lower Evening Star, Forsaken, Halfway, and Harker mines.

A third series of ore bodies was in like manner discovered below the Parting quartzite in the White limestone, and subsequently ore was even found below that member in the Lower or Cambrian quartzite itself. All of this development was on the upthrown side of the Carbonate-Pendery fault group.

A new stage in the exploration was then initiated by the sinking of shafts within and on the west or downthrown side of the Carbonate-Pendery fault group. Some of these, such as the Meyer and Yankee Doodle, were located too far east and encountered the fault on its west dip a short distance below the surface. They were therefore compelled to follow the fault downward in inclines from their bottoms in search of the downthrown part of the "first contact." Other shafts were more fortunately located at greater distances from the fault and continued down until the "first contact" was reached. It was soon discovered that instead of a single fault there were a series of parallel and intersecting faults, which constitute the Pendery group. Each of these faults threw the contact a step farther on the west, and between them a series of ore-bearing benches were found. The occurrence of ore on these benches demonstrated that ore could be reasonably looked for beneath the city, and deeper shafts were sunk at successively greater distances westward until they encroached upon the limits of the city itself. Among these larger shafts were the Penrose, Bon Air, Lazy Bill, Weldon No. 2, Star, Pocahontas, Coronado, and Capitol. With their successful completion came the mining in the Downtown district, beneath the city of Leadville. With the legal problems involved in the rights to mine beneath the city and the conflicting claims concerning surface and mining rights, the removal of waste rock, etc., this report is not concerned, but these problems have constituted no negligible factor in the westward migration of exploratory work.

DRAINAGE TUNNEL PROJECTS

What may be called a third stage in the development of the Leadville district a stage that became possible only after geologic conditions had been fully demonstrated, was that involved in the driving of long tunnels to accomplish the threefold purpose of drainage, exploration, and development. Only one of these projects has so far been carried to a successful completion, although sundry short adit tunnels of a purely exploratory character, or for the purpose of opening a particular deposit, have been driven. The Yak tunnel, one of the most successful ventures in the Leadville district, was started by A. A. Blow and at first was known as the Blow tunnel. The plan was the direct result of knowledge of geologic conditions. By reason of the series of north-south faults by which eastward-dipping sedimentary rocks are successively stepped upward toward the east, this adit tunnel was intended to penetrate the several ore-bearing contacts not once but many times, the number depending upon the number of faults intersected. From its portal in the overlying White porphyry on the west side of the Iron fault it crossed the fault and successively intersected the Lower quartzite, White limestone, Parting quartzite, Blue limestone, and White porphyry, thus exploring each contact successively and repeating the process after the next fault had been crossed. Drainage was at the same time furnished to greater depth than had yet been attempted in any other mine. It is doubtful if the original plan for this tunnel anticipated the complex conditions introduced by the Breece Hill mass of porphyry, but its penetration of this mass has again enabled it, by crossing the Weston fault, to explore the successive formations of the Ibex region and those in the vicinity of the Resurrection shafts by crossing them at an angle to the dip. The geologic information thus furnished has been invaluable, not only for scientific study but for a clearer understanding of the possibilities of the district.

The manner in which the Yak tunnel has prospected the Leadville region may be understood more clearly by consulting the special Yak tunnel section of Plate 15. Had the tunnel been much lower the ore bodies developed, which have unfortunately been mainly below the tunnel level, might have been more easily operated and drained; but a much longer adit would then have been necessary, and throughout the greater part of its length the tunnel would have cut only Lower quartzite and granite, which would have made it vastly less satisfactory as an exploratory project.

The system adopted by the managers has been to drive a series of branches or "laterals" on the tunnel level. Some of these branches have been connected with the bottoms of the main working shafts or with some portion of the workings of neighboring mines; others have been carried for purposes of exploration and development into ground owned, leased, or otherwise controlled by the tunnel company. From these laterals a series of winzes have been sunk through which ore bodies have been mined. Other ore bodies, above the tunnel level, have been mined through raises. Drainage arrangements have been made with many of the companies benefited.

Laterals connecting directly with the Horseshoe, Rubie, North Mike, South Mike, Ibex No. 4, Little Winnie, Resurrection No. 1, Fortune, Resurrection No. 2, and Dolly B have been driven, and others are projected connecting with a very large number of workings on Iron Hill, Breece Hill, and Little Ellen Hill. In addition six working winzes have been sunk by the company. These are the White Cap, Cord, Mike, Willard, My Day, and Diamond.

Another long drainage tunnel was at one time projected but never carried to completion. This tunnel was to have started with its portal at Malta at an altitude of 9,569 feet (old U. S. Geological Survey datum). Without making allowances for grade this would have made the tunnel level 764 feet below the Yak and 946 feet below the collar of the Maid-Combination shaft, with which it was originally designed to connect. The estimated length was 21,000 feet to the Maid shaft. For the Downtown district and Fryer Hill and the region to the east such a tunnel would have been satisfactory, as it would have been well up within the sedimentary formations. Beyond the Pendery fault it would have passed through granite, and though perhaps valuable and satisfactory for drainage and the operation of known bodies of ore, as a means of exploration it would have furnished little information of value. Work was started on this tunnel in 1892 by the sinking of a series of shafts at intervals along the proposed course, and the project has often been revived in the newspapers, but no further work has been done.

The Canterbury Hill tunnel, begun in 1922, is mentioned on page 325.

DEPTH OF MINE WORKINGS

The depth of the Leadville mines is definitely limited by geologic conditions. Practically all the workable ore deposits are confined to the comparatively thin covering of sedimentary rocks and their included porphyries that overlie the basal granite. Shafts and other underground workings are therefore likewise confined to this series except where structural conditions have made a passage through granite desirable to approach a faulted or otherwise depressed ore body. In a few places fissure veins extend downward into the granite, and shafts have been sunk into this formation to exploit them, but so far the yields of the lodes have been disappointing and will probably never justify exploration to any considerable depth into the granite. For these reasons most of the Leadville shafts are relatively shallow, and by far the greater number of them are less than 1,000 feet deep. The shallowest working shafts are generally near the outcrop of one of the "contacts." The deepest are those intended to reach down-faulted segments of ore bodies.

The sedimentary rocks which contain the ore-bearing contacts range from the base of the Weber (?) formation down to the pre-Cambrian granite and have an average aggregate thickness of 560 feet. By omitting the Lower or Cambrian quartzite, which only here and there carries ore minerals in commercial quantity (see p. 188), this thickness is reduced to 400 feet. The thickness of material that must be penetrated by the deepest shafts is very much increased by overlying and included bodies of porphyry of varying but in places great aggregate thickness and by a variable amount of glacial débris. In the northeastern part of the district the aggregate thickness is further increased by a cover of "Weber shales" and "Weber grits," which in the far northeast corner attain a depth of 1,200 feet.

The maximum possible depth of mining for the blanket ores may be determined with considerable accuracy for each block of faulted ground from the geologic sections on Plates 14–17, 20, 21, 23–26, and 28. From these sections it appears that without exploration of the southeastern part of the district, where the formations are very deeply buried beneath porphyry of Ball Mountain and where exploration has not yet been carried to any considerable depth, mining can never be extended much deeper than 2,000 feet. It is possible that veins may be discovered that will make it seem desirable to carry explorations deeper into the underlying granite, but as most veins in the quartzite have so far proved disappointing it is not believed that deep working will ever constitute an important phase of mining in the Leadville district. The one possible exception may be in Ball Mountain, where the geologic structure is yet unknown and where ore-bearing contacts may be more than 2,000 feet deep.

PROSPECTING AND DIAMOND DRILLING

Prospecting in the Leadville district for unopened ore bodies is carried on by shafts and tunnels and by diamond drilling. When the position and character of a contact are known vertical shafts may be sunk to this contact and drifts driven along it for exploration. The fact that the rocks and the included ore bodies lie in positions inclined at relatively low angles to the horizontal makes the risk of sinking vertical shafts for exploration relatively small. In those portions of the area where ore bodies are closely spaced the sinking of shafts without knowledge of the existence of ore bodies below is a common procedure, inasmuch as a certain amount of ore is always to be found at one or more of the contacts. Much of this exploratory shaft sinking has been successful. Some has resulted in failure, but this has generally been in relatively little known territory.

When the vertical shaft has been sunk through the overlying porphyry to the ore-bearing horizon drifts are usually driven along the contact so as to maintain grade. Such drifts rarely follow any given direction. The ore bodies are so irregular in horizontal extent that one direction is usually as good as another.

A great deal of money has been spent at Leadville in diamond drilling, and much of it has been wasted by inaccurate identification of the drill cores. The purpose of the drilling has of course been either to find ore or to determine the shape and size of ore bodies. Where ore has been intersected by the drill it is of course easily recognized, and an assay gives definite information as to its value. Where it has not been so intersected the nature and position of the rocks cut by the drill are the only guides to the probable occurrence of ore bodies, and they need to be determined with great care and accuracy. Within the limits of a core, limestone, shale, porphyry, granite, and quartzite are often exceedingly difficult to distinguish correctly. This is particularly true of the distinction between shale and porphyry. Were the drill cores always examined by someone with geologic experience accurate determinations could be made. Many difficulties could thus be averted, and geologic information that would be invaluable for the development of the property could be obtained. This has rarely been done. The determination of the formations cut has until recent years been intrusted to utterly unskilled men, and innumerable drill records have thus been rendered worthless. Often interpretations of two drill holes located a few feet apart have shown impossible differences in the character and thickness of the rocks encountered. Some records of drill holes in the Iron Hill area at first appeared incompatible with the geology until the existence of the Tucson-Maid reverse fault was proved. Failure to detect the presence of this fault from the evidence in the records reflects more on those who were interested in geologic structure than on those who interpreted the drill cores; but in some other places faulty or questionable drill records have rendered the interpretation of geologic structure uncertain.

Most of the drilling has been done from underground workings. A few diamond-drill holes have been put down from the surface in relatively little explored portions of the district. Such are the Edith, My Day, Spurr, Aladdin, and Anchorage drill holes; but these are exceptional. It is common procedure to sink diamond-drill holes from the bottoms of shafts after the shafts have been carried to varying distances from the surface. It is difficult to justify this procedure, as the added expense of sinking the shaft before the diamond-drill hole was begun resulted in no additional information. Presumably, however, the practice is chiefly the result of discouragement. A shaft is sunk in a certain locality with the idea of reaching the contact or ore-bearing limestone parting at some supposedly limiting depth. After the shaft has been driven to this depth and is still in porphyry, either the finances of the company become too slender to permit further sinking of the shaft or the miners become discouraged. Having already spent considerable money, the company feels that a drill hole will give the necessary information as to lower rocks at the least cost. Some diamond-drill holes are put down from the bottoms of shafts that are producing ore at higher horizons, but these are to be regarded as simply part of a systematic policy of drilling carried on elsewhere in the mine of the company.

The drilling from underground workings has been of great prospective value. The relatively great horizontal extension of the ore bodies and the low angle at which they lie make vertical holes a very satisfactory method of procedure, and many ore bodies have been discovered in this manner. In addition, geologic information as to the position of the contacts, intrusive porphyry bodies, faults, and other structural features is of much value in planning the method by which ore bodies may be most profitably approached and exploited.

Uniform spacing of drill holes is not necessary. Exploratory diamond-drill holes in the Yak tunnel, for instance, are not located at regular intervals but are driven in those portions of mines where geologic sections appear to indicate that masses of ore may be discovered. In many places geologic sections indicate that diamond-drill holes would be of relatively little value, as formations in which there is no possibility of the existence of ore are known to be present both above and below the drift or stope. Irregular spacing is also due to the somewhat irregular nature of the workings. Although the location of diamond-drill holes appears to be governed in part by the actual geologic indications, it is perhaps mostly controlled by the conception of the meaning of such indications that is held by the superintendent or foreman who is carrying on the work, and the reasons for his conception are not always easily perceptible.

Where ore bodies are abundant, as in the Iron-Silver properties and the R. A. M.-Wolftone group of mines, drill holes may be close together. In such places they are put down after the ore has been discovered, to determine the size, shape, and value of the mass. Many holes are driven vertically upward and downward from the same point. Horizontal holes are rarely if ever used. Rarely inclined holes are driven, when it is desired to make a hole at right angles to the dip of the sedimentary formations.

An examination of Plate 45 shows that the ore shoots at the different horizons are not regularly superposed. Ore bodies operated from above therefore furnish no necessary clue to the position of those that may be expected below.

CAPITALIZATION AND DIVIDENDS

Only scattered records on the capitalization of the Leadville mines are available and no analysis of financial conditions is therefore possible. The tables below, however, present an interesting summary of statistics for the early years of the district's history. They have been compiled from the report of the Director of the Mint for 1884, and from the Engineering and Mining Journal for 1885–1892, with some additional information furnished by the writer.

Capitalization of 37 prominent Leadville mines in 1884

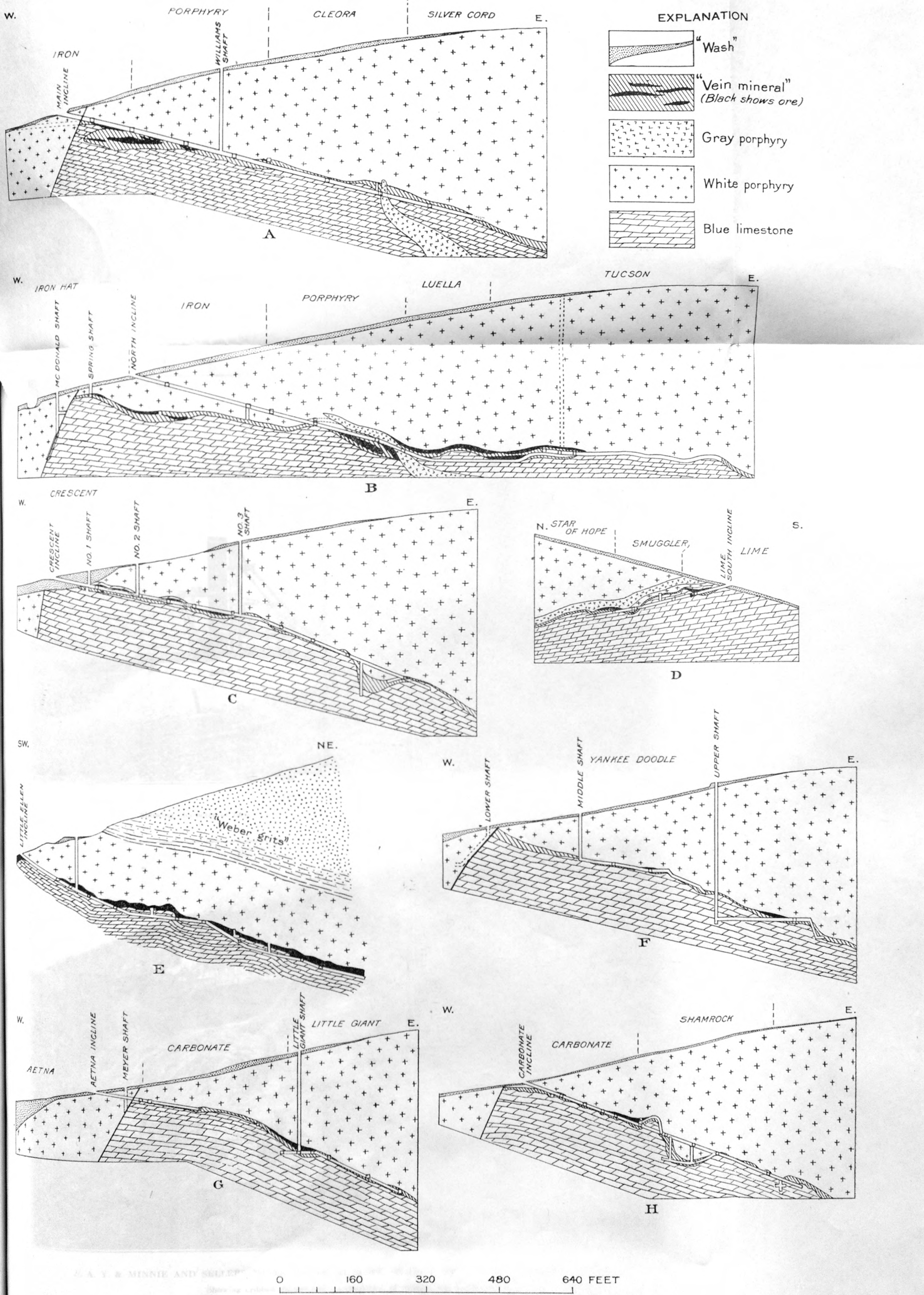
Name	Location	Capitalization
Adams Mining Co	Carbonate Hill	$1, 500, 000
Aetna (Meyer Mining Co.)	Carbonate Hill	220, 000
American Mining & Smelting Co.	Little Ellen Hill	3, 500, 000
Amie Consolidated Mining Co.	Fryer Hill	5, 000, 000
Argentine	Iron Hill	2, 500, 000
Agassiz Consolidated Mining Co.	Carbonate Hill	2, 500, 000
Allegheny Co	Yankee Hill	800, 000
Argent Mining Co	Rock Hill	5, 000, 000
Breece Mining Co	Breece Hill	5, 000, 000
Carbonate Hill Mining Co	Carbonate Hill	2, 000, 000
Catalpa Mining Co	Carbonate Hill	3, 000, 000
Chrysolite Silver Mining Co	Fryer Hill	10, 000, 000
Climax Mining Co	Fryer Hill	2, 000, 000
Crescent Mining Co	Carbonate Hill	3, 000, 000
Denver City Consolidated Mining Co.	Yankee Hill	5, 000, 000
Dunkin Mining Co	Fryer Hill	5, 000, 000
Emmet Mining Co	Rock Hill	5, 000, 000
Evening Star Mining Co	Carbonate Hill	500, 000
Forepaugh (Enterprise Mining & Prospecting Co.).	Fryer Hill	800, 000
Iroquois	Carbonate Hill	5, 000, 000
Iron-Silver Mining Co	Iron Hill	10, 000, 000
Iron Hill Consolidated	Iron Hill	2, 500, 000
Iowa Gulch Mining Co	Yankee Hill	6, 000, 000
Highland Chief Consolidated Mining Co.	Breece Hill	2, 500, 000
Lee Basin Mining Co	Yankee Hill	5, 000, 000
Leadville Consolidated Mining Co.	Carbonate Hill	4, 000, 000
Little Pittsburgh Consolidated Mining Co.	Fryer Hill	20, 000, 000
Little Chief Mining Co	Fryer Hill	10, 000, 000
La Plata Mining & Smelting Co.	California Gulch	2, 000, 000
Morning Star Consolidated Mining Co.	Carbonate Hill	1, 000, 000
Mike & Starr Gold & Silver Mining Co.	Breece Hill	1, 000, 000
New Pittsburgh	Yankee and Fryer hills	20, 000, 000
Robert E. Lee Silver Mining Co.	Fryer Hill	10, 000, 000
Silver Cord Combination Mining Co.	Iron Hill	4, 480, 000
Small Hopes Mining Co	Yankee Hill	5, 000, 000
Smuggler Consolidated Mining Co.	Iron Hill	600, 000
Terrible Mining Co	Iron Hill	125, 000

Dividends paid by certain Leadville mines

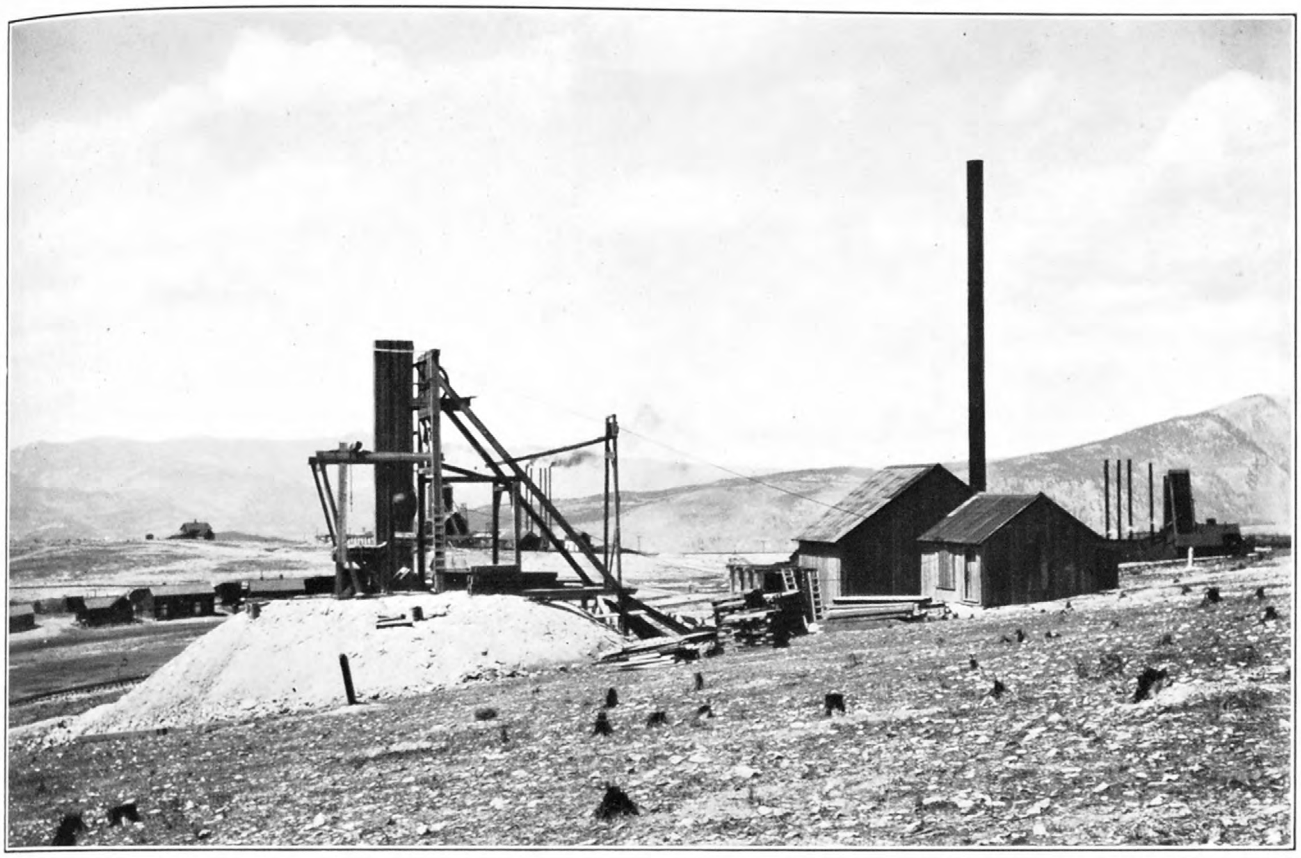
Mine	Total earlier than 1884	1884	1885	1886	1887	1888	1889	1890	1891	1892	Total to end of 1892
Adams		$82, 000	$217, 000	$240, 000	$15, 000				$75, 000	$10, 000	$639, 000
Bangkok-Cora Bell	$29, 510							$15, 000			44, 510
Carbonate Hill	60, 000	10, 000									70, 000
Catalpa	240, 000	30, 000									270, 000
Chrysolite	1, 600, 000	50, 000									1, 650, 000
Dunkin	210, 000	10, 000			30, 000	$100, 000	$40, 000				390, 000
Eclipse (?)	10, 000				10, 000						20, 000
Evening Star	1, 400, 000					12, 500	25, 000				1, 437, 500
Iron-Silver	1, 400, 000	100, 000		300, 000	300, 000	300, 000	100, 000				2, 500, 000
Leadville Consolidated.	216, 000	20, 000	20, 000	40, 000	20, 000						316, 000
Little Chief	740, 000	40, 000				20, 000		20, 000			820, 000
Little Sliver	200, 000										200, 000
Maid of Erin	288, 825								419, 175		708, 000
Mary Murphy	17, 500				70, 000	87, 500					175, 000
Morning Star	525, 000	25, 000	25, 000	125, 000	75, 000	50, 000	50, 000		50, 000	100, 000	1, 025, 000
Rialto (?)									32, 250	18, 000	50, 250
Silent Friend									600, 000		600, 000
Silver Cord	225, 000						45, 000				265, 000
Small Hopes	937, 500	800, 000		775, 000	600, 000		25, 000	25, 000		62, 500	3, 225, 000
Ward							20, 000				20, 000
Whale									5, 000		5, 000

The 37 mines listed in the first table show an aggregate capitalization of $160,705,000, or an average of $4,186,250, which is high. That the mines of the district as a whole were far from returning the total amount of nominal capital by 1884 appears at once by comparison of the total capitalization of these 37 mines, only a little over half of the productive mines of that year, with the total value of the metallic production to the end of 1884, which is $88,835,425. If allowance is made for expenses it is obvious that had all the stock been sold the mines might be regarded as very much overcapitalized. Even at the end of 1892, only 2 of the 12 mines for which both capitalization and dividends are recorded had returned dividends in excess of the nominal capitalization. These were the Evening Star and Morning Star. How far overcapitalization was real depends of course on the amount of capital stock actually sold as compared with that held in the treasury and on the price at which it was sold. It is probable that for some mines the larger proportion of the stock had been actually sold either at or above par. The Little Pittsburgh is perhaps an example. With a capitalization of $20,000,000 this mine was profitable during its first year, 1879, and paid dividends to its stockholders amounting to $100,000 a month, but in 1880 the market price of the stock fell off enormously, largely on account of the inability of the company to pay interest on so heavy a capitalization after the first rich bonanzas had been exhausted and on account of the concentration of all energies on production to the exclusion of development. For many of the mines but little of the stock has been sold in the open market, and as the mines were acquired by location and not by purchase, they have been exceedingly profitable. The capitalization of such mines is purely nominal and has no necessary relation to the amount of money invested.

Notable among the mines for which both capitalization and total dividends are known is that of the Iron Silver Mining Co. This company was organized in 1880 with a capital stock of $10,000,000 in shares of $20 par. In 32 years, or to the end of 1912, the company had paid $4,650,000 in dividends. It is improbable that the initial investment in this property was large, although there is no means whatever of ascertaining what it was, and it is presumable that the mine has been a very profitable venture.

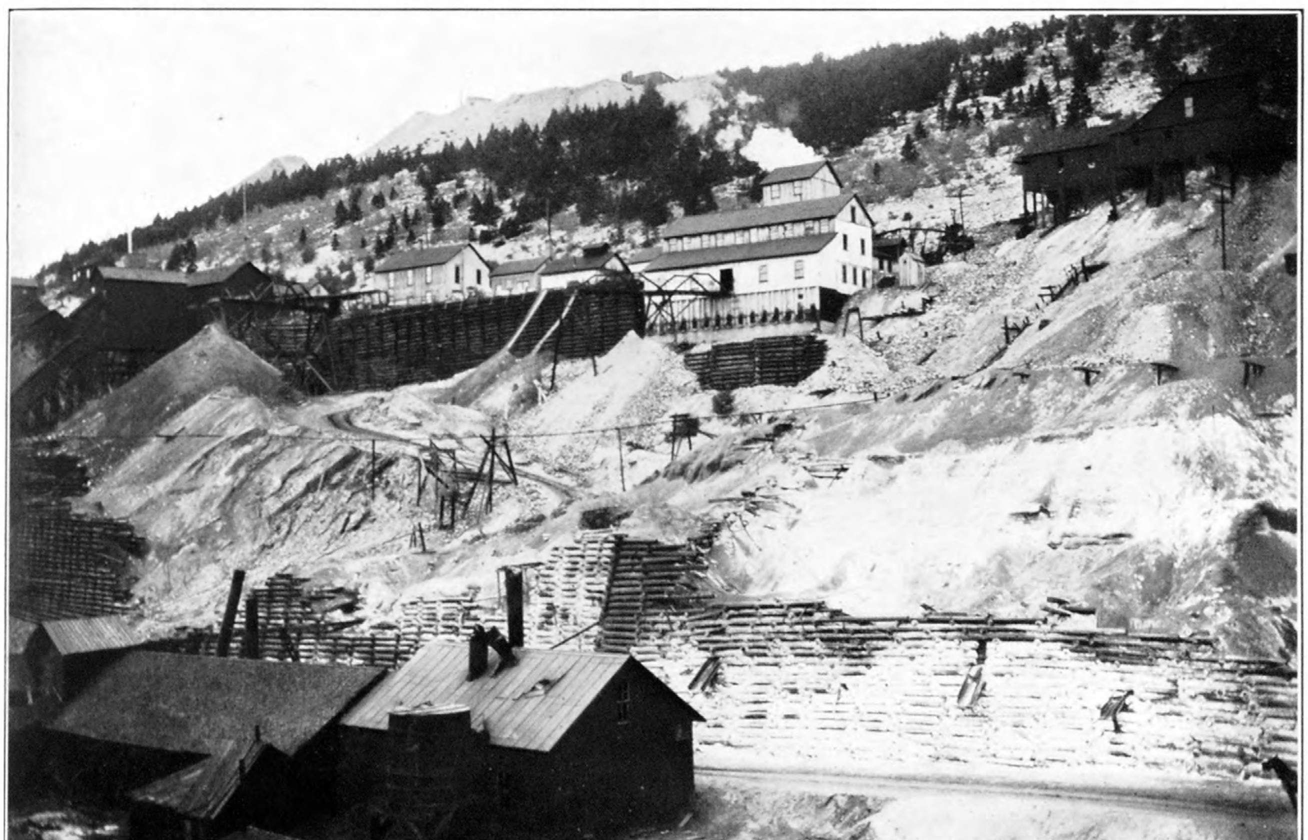


SECTIONS OF PRINCIPAL INCLINED SHAFTS IN LEADVILLE DISTRICT



A. PYRENEES (RIALTO) SHAFT

Showing character of head frame and sinking equipment in common use in Leadville district



B. A. Y. & MINNIE AND SELLERS MINES, ON SOUTH SLOPE OF IRON HILL, FROM CALIFORNIA GULCH

Showing cribbed dumps and accumulation of tailings and waste

CHAPTER 8. CLASSIFICATION AND MINERALOGY

The distribution and general forms of the ore bodies that have been mined within the Leadville district are shown on Plate 45. A few ore bodies of considerable size have been mined to the east and south of this area, particularly near the head of Iowa Gulch and where the gulch is crossed by the Weston fault, but too little is known of their outlines for them to be adequately represented.

The ore bodies may be classified according to form into (1) veins or lodes, (2) stockworks closely related to veins, (3) replacement deposits or "blankets," and (4) placers. The first two classes occur principally in siliceous rocks, and the third in carbonate rocks, though there are exceptions to both rules. The placers are now of historical interest only and are not further considered except incidentally in the discussion of the occurrence of gold. Classification may also be based primarily upon the genetic relations of the ores and their constituent minerals and secondarily upon the metals and gangue present. A combination of these classifications is necessary for an adequate understanding of the ores and is dependent upon a knowledge of the ore and gangue minerals.

MINERALS IN THE LEADVILLE DISTRICT

An alphabetic list of the ore and gangue minerals occurring in the Leadville district is given below.

Minerals in the Leadville district

Name	Chemical formula	Page on which detailed description is to be found [a]
Allanite	$Ca_2[Al.OH](Al,Fe,Ce,La,Di)_2[SiO_4]_3$.	
Alunite	$K_2O.3Al_2O_3.4SO_3.6H_2O$	176
Anglesite	$PbSO_4$	164
Ankerite	$(Ca,Mg,Fe)CO_3$	176
Apatite	$(Ca,F)Ca_4P_3O_{12}$	
Aragonite	$CaCO_3$	175
Argentite	Ag_2S	167
Arsenic	As	171
Arsenopyrite	FeAsS or $FeS_2.FeAs_2$	151
Augite	$CaMgSi_2O_6$ with (Mg,Fe) (Al,Fe)O_2Si_6.	
Aurichalcite	$2(Zn,Cu)CO_3.3(Zn,Cu)(OH)_2$	157
Azurite	$2CuCO_3.Cu(OH)_2$	166
Barite	$BaSO_4$	176
Biotite	$(H,K)_2(Mg,Fe)_2Al_2SiO_3O_{12}$	
Bismuthinite	Bi_2S_3	169
Bismutite	$Bi_2O_3.CO_2.H_2O$	170
Bornite	Cu_3FeS_3 or Cu_5FeS_4	166
Bromyrite	AgBr	167
Calamine	$(ZnOH)_2SiO_3$	158
Calcite	$CaCO_3$	175
Caledonite	$(Pb,Cu)SO_4.(Pb,Cu)(OH)_2$	164
Cerargyrite	AgCl	167

[a] Minerals for which no page is given are either not described in the text or are described only in the chapter on igneous rocks (pp. 43-59).

Minerals in the Leadville district—Continued

Name	Chemical formula	Page on which detailed description is to be found
Cerusite	$PbCO_3$	163
Chalcanthite	$CuSO_4.5H_2O$	166
Chalcedony	SiO_2	172
Chalcocite	Cu_2S	166
Chalcophanite	$(Mn,Zn)O.2MnO_2.2H_2O$	159
Chalcopyrite	$CuFeS_2$	165
"Chinese talc" (see Kaolin).	$(Al_2Si_2O_7.2H_2O)$	174
Chlorite	Hydrous silicate of iron, magnesia, aluminum.	
Chrysocolla	$CuSiO_3.2H_2O$	166
Clay	Mixtures of kaolin, alunite, and sericite (which see).	174
Clay (zinciferous)	Kaolin in which some aluminum is replaced by zinc.	160
Copper (native)	Cu	166
Dechenite	$PbO.V_2O_5$	164
Descloizite	$4(PbZn)O.V_2O_5.H_2O$	164
Diopside	$CaMg(SiO_3)_2$	173
Dolomite	$CaMg(CO_3)_2$	175
Embolite	Ag(Cl,Br)	167
Epidote	$H_2O.4CaO.3(Al,Fe)_2O_3.6SiO_2$.	167
Ferric sulphate (basic) near utahite.	$Fe_2O_3.SO_3.2H_2O$	155
Freibergite	$4(Cu_2S,Ag_2S)._3Sb_2S$	166
Galena	PbS	162
Gold (native)	Au	168
Goethite	$Fe_2O_3.2H_2O$	155
Goslarite	$ZnSO_4.7H_2O$	162
"Gray copper" (tetrahedrite).	$Cu_8Sb_2S_7$ or $4Cu_2S.Sb_2S_3$	166
Hedenbergite	$CaFe(SiO_3)_2$	173
Hetaerolite (wolftonite).	$2ZnO.2Mn_2O_3.H_2O$	158
Hematite	Fe_2O_3	150
Hornblende	$Ca(Mg,Fe)_2(SiO_3)_2$ with some $(Mg,Fe)(Al,Fe)_2SiO_6$ and $Na_2Al_2(SiO_3)_4$.	
Hydrozincite	$3ZnO.CO_2.2H_2O$	157
Hypersthene	$(Mg,Fe)SiO_3$	
Iodyrite	AgI	167
Jarosite	$K_2O.3Fe_2O_3.4SO_3.6H_2O$	155
Kaolin	$2H_2O.Al_2O_3.2SiO_2$	174
Kaolin (zinciferous)	Kaolin in which some aluminum is replaced by zinc.	160
Kobellite	$Pb_2(Bi,Sb)_2S_5$ or $2PbS.Bi(Sb)_2S_3$.	169
Lanarkite (bismuthiferous).	$(Pb,Bi)SO_4.PbO$	171
Lillianite	$3PbS.Bi_2S_3$	169
Leverrierite	$H_2O.Al_2O_3.SiO_2$	174
Limonite	$2Fe_2O_3.3H_2O$	155
Magnetite	Fe_3O_4	150
Malachite	$CuCO_3.Au(OH)_2$	166
Manganosiderite	$(Fe,Mn,Mg)CO_3$	151
Marmatite (zinc-iron blende).	$(Zn_3Fe)S$	156
Massicot (litharge)	PbO	163
Melanterite	$FeSO_4.7H_2O$	155
Microcline	$KAlSi_3O_8$	24
Minium	Pb_3O_4	163
Muscovite	$KH_2.Al_3(SiO_4)_3$	172
Nicholsonite (zinciferous aragonite).	$(Ca,Zn)CO_3$	175

Minerals in the Leadville district—Continued

Name	Chemical formula	Page on which detailed description is to be found
Orthoclase	$KAlSi_3O_8$	
Opal	$SiO_2.nH_2O$	172
Paragonite	$NaH_2Al_3(SiO_4)_3$	172
Plagioclase	$x(NaAlSi_3O_8)y(CaAl_2Si_2O_8)$	
Plumbojarosite	$PbO.3Fe_2O_3.4SO_3.6H_2O$	165
Psilomelane	H_4MnO_5	156
Pyrite	FeS_2	150
Pyrolusite	MnO_2	156
Pyromorphite	$(PbCl)Pb_4P_3O_{12}$	164
Quartz	SiO_2	171
Rhodochrosite	$MnCO_3$	176
Rhodonite	$MnSiO_3$	173
Rutile	TiO_2	
Schapbachite	$PbAg_2Bi_2S_5$ or $PbS.Ag_2S.Bi_2S_3$	169
Sericite	$KH_2Al_3(SiO_4)_3$	172
Serpentine	$H_4Mg_3Si_2O_9$	173
Siderite	$FeCO_3$	151
Silver (native)	Ag	168
Smithsonite	$ZnCO_3$	157
Sphalerite	ZnS	156
Sulphur	S	176
"Talc (Chinese)." (See Kaolin.)		174
Tetrahedrite ("gray copper").	$Cu_8Sb_2S_7$	166
Titanite	$CaTiSiO_5$ or $CaO.TiO_2.SiO_2$	
Topaz	$(Al,F)_2SiO_4$	
Turgite	$2Fe_2O_3.H_2O$	155
Vanadinite	$(PbCl)Pb_4V_3O_{12}$	164
Vivianite	$Fe_3P_2O_8.8H_2O$	155
Wad	Mixtures of oxides, chiefly of manganese, with water.	156
Wolftonite. (See Hetaerolite.)		158
Wollastonite	$CaSiO_3$	172
Wulfenite	$PbMoO_4$	164
Wurtzite (?)	ZnS	246
Zircon	$ZrSiO_4$	

CLASSIFICATION OF MINERALS ACCORDING TO ORIGIN

The minerals in the foregoing list, considered genetically, fall into two distinct groups of differing mode of origin—minerals of the rocks and minerals of the ore deposits.

In the first group are included not only those minerals of which the country rocks were originally composed before the ore deposits were formed but those which have been developed from them by the action of surface waters. Such minerals are entirely independent of ore deposition but may be regarded as gangue minerals where unreplaced remnants of country rock have been inclosed by ore bodies. These minerals are sufficiently considered in the foregoing descriptions of sedimentary and igneous rocks.

The second group includes minerals formed by ascending ore-forming solutions (hypogene minerals) and other minerals derived from them by the action of descending waters (supergene minerals). All the minerals of this group are arranged in the table opposite according to the principal metals contained and the relative temperatures at which they were deposited. A few minerals which have been deposited through a great range of temperature or which contain more than one valuable metal are represented in more than one place. Manganosiderite is listed under both ore and gangue, as the oxidized manganese ore has been mainly derived from it, but it is the principal gangue mineral accompanying much of the sulphide ore.

As originally formed, the ore deposits and the altered wall rocks by which they are inclosed contained only primary or hypogene minerals. As erosion proceeded they were brought nearer and nearer to the surface until they came within reach of downward circulating waters. Different minerals are affected to different degrees by these waters. Some, like quartz and barite, are only slightly attacked, but most of the minerals are decomposed with comparative rapidity, and their constituents are either converted at once into oxidized minerals, which remain in the oxidized zone, or are dissolved and carried below the limits of oxidation, where they may be redeposited, usually as sulphides, in the secondary sulphide or sulphosupergene zone. The more abundant hypogene minerals are comparatively few and mostly of simple chemical composition; the supergene minerals include more than 50 species, some of which have relatively complex composition.

The subdivision of the hypogene minerals according to temperatures is based on the classification proposed by Lindgren[1] in 1907 and elaborated by W. H. Emmons[2] in 1908 from the results of subsequent experimental work, particularly at the Carnegie Geophysical Laboratory and local field observations. Certain minerals are particularly significant. For example, wollastonite, according to Doelter,[3] crystallizes between the approximate limits of 1,100° and 400° C., and according to Allen and White,[4] it changes to a different crystal form (pseudowollastonite) at 1,190°. At Leadville wollastonite has been found only as a constituent of metamorphic limestone close by or inclosed in Gray porphyry in the Breece Hill area, where the temperature must have been much higher than in limestone away from the contact. Pyroxene, probably diopside or enstatite, or perhaps an olivine, forsterite or monticellite, now altered to serpentine, has similar significance; magnetite and specularite are most abundant where the temperature at the time of deposition must have been high, although they are also found in small quantity where the temperature was never high enough to permit the crystallization of such silicates as wollastonite and pyroxene.

The other hypogene minerals are much less diagnostic. Manganosiderite in small quantity fills interstices among magnetite grains close to contacts with Gray

[1] Lindgren, Waldemar, The relation of ore deposition to physical conditions: Econ. Geology, vol. 2, pp. 105–127, 1907.

[2] Emmons, W. H., A genetic classification of minerals: Econ. Geology, vol. 3, pp. 611–627, 1908.

[3] Doelter, C., Min. pet. Mitt., vol. 25, pp. 89–92, 1906.

[4] Allen, E. T., and White, W. P., Am. Jour. Sci., 4th ser., vol. 21, p. 89, 1906.

Minerals of the ore deposits

[Brackets indicate that the mineral is rare or its occurrence doubtful]

		Ore minerals										Gangue minerals			
		Iron	Manganese	Zinc	Lead	Copper	Silver	Gold	Bismuth	Arsenic	Tungsten	Silica	Alumina	Lime, magnesia, and manganese	Other
Supergene minerals	Oxidized (oxysupergene[a]) zone.	Limonite. Turgite. Goethite. Hematite. Jarosite. Basic sulphate. Melanterite. Vivianite.	Pyrolusite. Psilomelane. Wad. Mixed. Earthy oxides and hydroxides. Chalcophanite. Heterolite.	Smithsonite. Hydrozincite. Aurichalcite. Nicholsonite. Calamine. Chalcophanite. Hetaerolite (wolftonite). Zinciferous kaolin. Goslarite.	Cerusite. Anglesite. Plumbojarosite. Pyromorphite. Wulfenite. Vanadinite. Dechenite. Descloizite. Minium. Massicot (litharge).	Malachite. Azurite. Chrysocolla. Chalcanthite. Native copper.	Native silver. Embolite. Cerargyrite. Bromyrite. Iodyrite.	Native gold.	Bismuthite. Caledonite. Bismuthiferous lanarkite. Unidentified bismuth minerals.			Chalcedony. Opal. Quartz.	Kaolin. Leverrierite. Alunite. "Chinese talc."	Calcite. Aragonite.	Barite. Suphur.
	Sulphide enrichment (sulphosupergene[a]) zone.	Marcasite?			Galena?	Chalcocite. Chalcopyrite? Bornite.	Native silver.	Native gold.		Native arsenic.					
Hypogene minerals	Low temperature (epithermal[a]) zone, 50°–150° C.														
	Moderate-temperature (mesothermal[a]) zones, 150°–300° C.	Pyrite. Siderite. Arsenopyrite.	Manganosiderite. Rhodochrosite?	Sphalerite (marmatite).	Galena.	Chalcopyrite. Tetrahedrite?	Argentite. Freibergite and argentiferous tetrahedrite. Tennantite. Lillianite.	Native gold.	Bismuthinite. Lillianite. Kobellite. "Schapbachite."	Arsenopyrite. Tennantite.	Scheelite. Wolframite.	Quartz. Jasperoid.	Sericite (muscovite and paragonite).	Calcite. Dolomite. Manganosiderite. Siderite. Rhodochrosite? [Rhodonite]. Chlorite. Epidote. Serpentine.	Barite.
	High-temperature (pyrometasomatic[a] and hypothermal[a]) zones, 300°–800° C.	Magnetite. Pyrite. Hematite (specularite).										Quartz.	Sericite.	Manganosiderite. Diopside. Olivine. Wollastonite. Epidote.	

[a] Names proposed by Waldemar Lindgren (A suggestion for the terminology of certain mineral deposits: Econ. Geology, vol. 17, pp. 292–294, 1922).

porphyry, a relation suggesting deposition at high temperature; but it is most abundant in places well removed from the main center of intrusion, where the temperature must have been lower. Pyrite also is intimately associated with magnetite but is most abundant away from the main intrusive center, and veins containing it cut masses of magnetite, indicating that although pyrite may begin to crystallize at high temperature it is for the most part formed at moderate temperature. The close association of pyrite and quartz with each other in the Penn and Ibex mines and with the tungsten minerals wolframite and scheelite in the South Ibex stockwork of Breece Hill suggests crystallization at rather high temperature.

Zinc blende and galena, although in small part closely associated with high-temperature minerals, are more abundant in veins formed subsequently to these and are by far the most abundant in the "blanket" bodies replacing limestone, most of which lie far from the area containing high-temperature minerals. This relation suggests that reaction of the ore-bearing solutions with limestone may have had more influence than degree of temperature on the deposition of blende and galena. In the mixed sulphide ores of Leadville, however, these two minerals, whether they replaced siliceous rock or limestone, crystallized later than the bulk of the pyrite. It appears, therefore, that where deposition was chiefly controlled by decrease in temperature blende and galena were in the main deposited at a somewhat lower temperature than pyrite, although there was a small amount of overlap in the periods of deposition, and that where saturation with wall-rock material was the principal controlling factor in rendering the ore minerals insoluble blende and galena represent a higher degree of saturation than pyrite. Although blende and galena have commonly been regarded as capable of deposition through a wide range of temperature, their paragenetic relations in the Leadville ores class them as diagnostic of moderate temperature. Where blende and galena occur together the galena as a whole has crystallized later than the blende. Intergrowths of argentite and bismuthinite have been found that are later than galena, but as bismuth is rare except in the oxidized ore occurring in the vicinity of Breece Hill, its genetic relations are obscure.

Barite is most abundant in places well removed from the high-temperature center, and secondary dolomite free from considerable amounts of iron and manganese is most conspicuous in the vicinity of the replacement bodies in limestone. Both of these minerals in the Leadville district, therefore, indicate moderate to somewhat low temperature. Calcite is rare as a gangue mineral in the hypogene ores but where found is of later growth than dolomite.

Quartz represents a very wide range of temperature. It is associated with the high-temperature minerals and is abundant both as well-crystallized quartz and as dense masses (jasperoid) associated with the pyritic veins in the Breece Hill area and vicinity. It is abundant in parts of the replacement ore bodies in limestone, particularly as jasperoid, and is also associated with barite. Even beyond the limits of workable deposits, extensive ledges of jasperoid or "flint" may be found. (See fig. 10.)

Sericite is a close companion of quartz and is especially characteristic of those veins or replacement deposits in siliceous rocks which contain minerals suggestive of rather high to rather low temperature. Epidote is found in a few places replacing carbonate rock and associated with distinctly high-temperature minerals. It is also found with chlorite and sericite in altered siliceous rocks along or near ore bodies, and all three of the minerals there represent hydration of the rock through a considerable range of temperature. In such rocks quartz and sericite are most abundant close to veins or to replacement bodies connected with them, and chlorite mingled with epidote and calcite (propylitic rock) becomes abundant a short distance away. Chalcopyrite and gold are most prominent in ore bodies in siliceous rocks or in immediately adjacent limestones in Breece Hill and vicinity, but in the mixed sulphide ores they crystallized later on the whole than pyrite and much of the zinc blende. Thus their distribution in space suggests deposition at rather high to moderate temperature, whereas their paragenetic relations suggest moderate to somewhat low temperature; but reaction with siliceous rocks through a considerable range of temperature is evidently the principal controlling factor in their deposition. Other minerals listed in the accompanying table are present in too small quantity to be diagnostic.

This evidence, so far as it goes, indicates that the workable hypogene ore bodies, other than those consisting of magnetite and specularite, were formed within the range of moderate temperature, 300°–150° C., although some of the pyritic veins may have been formed at somewhat higher temperature. No minerals distinctly diagnostic of low temperature have been found in noteworthy amounts. As shown on page 41, the ore bodies were formed at a depth of about 10,000 feet, and a normal temperature gradient of 1° C. per 100 feet of depth would imply a temperature 100° C. higher than that of the surface. That the existing temperature must have been somewhat higher than this is indicated alike by the presence of many sills of then newly intruded porphyry and by the character of the ore minerals themselves.

At some places, as already implied, minerals indicative of high temperature are confusingly associated with those indicative of moderate temperature, but confusion decreases with detailed study of the ores. In the Penn, Comstock, and Ibex mines, in Breece Hill, masses of high-temperature minerals were fractured and later filled by veins and impregnations of the moderate-temperature minerals. Of the high-temperature minerals magnetite was evidently very stable when invaded by the later solutions. In several places it has been shattered and recemented by quartz and dolomite. It has also been found as inclusions in pyrite. Plate 47, *C,* illustrates a metamorphic shaly limestone in which magnetite was deposited as minute grains, generally of crystalline outline, arranged in well-marked dark layers parallel to the original stratification. Later mineralization introduced pyrite and some quartz. The pyrite occurs in cubes or clusters of cubic grains impregnating the rock. Nearly all the pyrite grains inclose grains of magnetite, showing that the pyrite, although capable of replacing the other minerals of the rock, had little or no effect on the

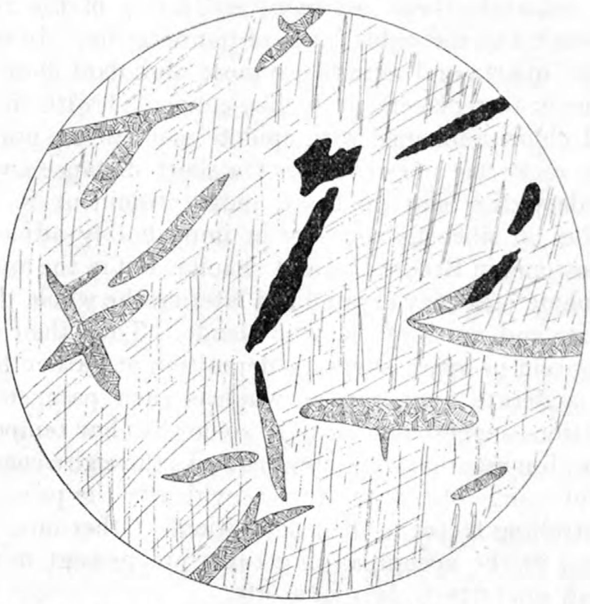


FIGURE 45.—Crystals of specularite formed during early high-temperature phase of mineralization replaced in part by pyrite of a later phase of mineralization

magnetite. This condition is in marked contrast to that existing in the porphyries, in which the magnetite originally present was replaced by pyrite when the rock was permeated by solutions near veins and replacement bodies formed at moderate temperature.

In contrast to the stability of magnetite in the high-temperature deposits are the replacement of specularite by pyrite (pl. 46, *C,* and fig. 45) and the thorough alteration of pyroxene or olivine to serpentine (fig. 50).

Sericite is abundant in certain shaly limestones that were partly replaced first by high-temperature minerals and later by moderate-temperature minerals, resulting in an aggregate of magnetite, serpentine, manganosiderite, sericite, quartz, and pyrite. No trace remains of the minerals replaced by sericite. They may have constituted the original shaly matter of the rock or, as Irving suggests, are metamorphic (high-temperature) minerals derived from the shaly matter.

Where zinc blende is associated with magnetite bodies, it is extremely scarce in their central parts but abundant around their edges. This indicates either that solutions no longer able to deposit magnetite began to deposit zinc blende as part of a continuous process, or that some time after the magnetite had formed, fissuring admitted a new supply of solution at moderate temperature, which deposited the zinc blende.

COMPARISON OF MINERALOGY OF ORES AT LEADVILLE AND ELSEWHERE IN COLORADO

As shown in the chapter on igneous rocks (pp. 54–55), the Leadville district is one of several which lie within the "porphyry belt" of central Colorado and the deposits of which are genetically associated with monzonitic intrusions. The deposits of the "porphyry belt" have been reviewed by Lindgren,[5] whose work supplies the basis for the accompanying comparative table of the minerals of each district. The minerals are arranged according to the prevailing temperature range of deposition, and a few, deposited through a great range of temperature, appear at more than one place within a single column. Minerals attributed to sulphide enrichment are also shown, as their distinction from hypogene minerals is not everywhere certain; but minerals formed by oxidation are omitted, as they have little or no bearing on the genesis of the hypogene ores.

The mineral character of the deposits in these districts is summarized below.

The ore deposits of Boulder County are exclusively veins. Lindgren distinguishes three classes—sulphide veins, tungsten veins, and telluride veins. The sulphide veins contain quartz, blende, galena, chalcopyrite, and some molybdenite. No statement appears as to the depth at which these were formed. The tungsten veins contain molybdenite, quartz, fluorite (?), very abundant sericite, calcite, and a little pyrite, besides wolframite which probably is of the variety ferberite. Lindgren regards these veins as formed at moderate depth by recent thermal activity. To the minerals of the tungsten veins George[6] adds ferberite, scheelite, galena, and sphalerite. He also mentions magnetite, which, however, is probably a constituent of the original rocks. The tungsten minerals have more recently been studied in detail by Hess and Schaller,[7] who regard them as generally indicative of high temperature, although they do not state specifically that the tungsten veins of Colorado belong to the high-temperature (hypothermal) rather than the moderate-temperature (mesothermal) class. The telluride veins consist of quartz, chalcedony in large amount, roscoelite, barite, molybdenite in abundance, pyrite, sericite, and adularia. Lindgren considers these veins to have been formed at shallow depth.

[5] Lindgren, Waldemar, Mineral deposits, 2d ed., pp. 617–622, 1919.
[6] George, R. D., Colorado Geol. Survey First Rept., pp. 9–103, 1908.
[7] Hess, F. L., and Schaller, W. T., Colorado ferberite and the wolframite series: U. S. Geol. Survey Bull. 583, 1914.

Zone	Approximate range of temperature of formation (°C.)	Approximate pressure	Range of depth (feet)	Mineral	Monarch	Anthracite and Crested Butte	Aspen	Homestake, Sugarloaf, and Twin Lakes	Leadville	Alma	Tenmile	Red Cliff	Montezuma	Breckenridge	Georgetown	Gilpin County	Idaho Springs	Boulder County veins: Tungsten	Boulder County veins: Sulphide	Boulder County veins: Telluride
Zone of sulphide enrichment (sulphosupergene).	0–100		From lower limit of complete oxidation to a varying depth below ground-water leve.	Argentite	×	×	×		×	×			×		×		×			
				Calcite			×													
				Chalcedony						×										
				Chalcocite	×				×											
				Chalcopyrite					×?											
				Gold					×								×	×		×
				Polybasite											×		×		×	
				Proustite		×							×							
				Pyrargyrite		×				×			×		×					
				Silver		×	×		×	×			×		×					
				Stephanite	×	×				×			×							
				Sulphantimonides							×									
Primary zone. Hydrothermal deposits. Shallow (epithermal) vein zone.	50–150	Moderate	1,500–4,000	Adularia																×
				Altaite																×
				Amalgam																×
				Argentite																×
				Barite																×
				Bismuth																×
				Calaverite																×
				Chalcedony																×
				Coloradoite																×
				Jasperoid																×
				Lionite																×
				Marcasite		×					×									×
				Melonite																×
				Molybdenite																×
				Nagyagite																×
				Native tellurium																×
				Petzite																×
				Pyrargyrite																×
				Pyrite																×
				Quartz																×
				Roscoelite																×
				Sericite																×
				Sylvanite																×
Middle (mesothermal) vein zone.	150–300	High	4,000–12,000	Alabandite						×			×							
				Anhydrite						×										
				Argentite		×	×		×	×			×		×		×			
				Arsenopyrite		×			×							×				
				Barite		×	×		×	×	×		×	×	×		×			
				Bismuthinite					×					×						
				Calcite		×	×		×	×	×			×		×	×	×		
				Chalcedony					×											
				Chalcopyrite		×		×	×	×		×	×	×	×	×	×		×	
				Dolomite			×		×		×	×								
				Enargite						×						×				
				Ferberite														×		
				Fluorite		×				×					×	×		×?		
				Freieslebenite		×														
				Gadolinite						×										
				Galena		×	×	×	×	×	×	×	×	×	×	×	×	×	×	
				Gersdorfite				×												
				Gold													×			
				Hessite								×			×	×				
				Hübnerite														×		
				Jamesonite						×										
				Lollingite		×														
				Magnesite											×		×			
				Manganosiderite				×	×			×	×	×						
				Marcasite		×														
				Molybdenite														×	×	
				Pearceite			×													
				Polybasite			×								×	×	×		×	
				Proustite		×							×							
				Pyrargyrite		×				×			×		×				×	
				Pyrite		×		×	×	×		×		×	×	×	×	×		
				Quartz		×	×	×	×	×	×	×	×	×	×	×	×	×	×	
				Rhodochrosite		×			×	×				×			×			
				Rhodonite					×											
				Scheelite				×	×									×		
				Schirmerite															×	
				Sericite				×	×	×		×				×				
				Siderite		×				×		×			×	×	×			
				Smaltite		×														
				Sphalerite		×	×	×	×	×	×	×	×	×	×	×	×	×	×	
				Stephanite		×				×			×						×	
				Stibnite						×										
				Sulphantimonides							×									
				Tellurides											×					
				Tennantite			×			×					×	×	×		×	
				Tetrahedrite		×	×	×		×					×	×			×	
				Uraninite		×										×				
				Warrenite		×														
				Wolframite					×									×		
				Zinkenite						×										
Deep (hypothermal) vein zone.	300–500	Very high	12,000–15,000	Galena	×															
				Magnetite	×		×							×				×		
				Manganesian garnet															×	
				Pyrite	×															
				Pyrrhotite	×						×								×	
				Specularite										×						
				Sphalerite	×															
Emanation deposits. Contact-metamorphic (pyrometasomatic) conditions.	300–800	Very high	3,000–30,000	Andradite	×															
				Calcite	×															
				Chromite						×										
				Epidote					×											
				Fluorite	×															
				Galena	×															
				Magnetite	×				×	×										
				Pyroxene					×											
				Pyrrhotite	×															
				Quartz					×											
				Specularite	×				×											
				Tremolite	×															
				Wollastonite					×											
Magmatic deposits. Pegmatitic (pneumotectic) conditions.	575+	Very high	3,000–30,000	Bornite	×															
				Chalcopyrite	×															
				Feldspar	×															
				Gannite	×															
				Molybdenite	×															
				Muscovite	×															
				Quartz	×															
				Sphalerite	×															

Farish[8] mentions as constituents of the telluride veins petzite, sylvanite, and free gold.

The deposits in the vicinity of Central City, Gilpin County, are gold-bearing veins. Of the minerals listed in the table pyrite and quartz are by far the most abundant, and sericite is abundantly developed in the altered siliceous wall rock. The polybasite may be due to sulphide enrichment. No minerals characteristically formed at shallow depth and no high-temperature minerals are found in this group. They therefore appear to belong to the deposits formed at intermediate depth or at moderate temperature.

In the Idaho Springs district, which adjoins the Central City district, the deposits are of similar character. The native gold present appears to be secondary, and polybasite and argentite are regarded by Spurr as at least in part secondary.

In the deposits of the Georgetown district much of the argentite, pyrargyrite, and polybasite are believed by Spurr to be of secondary origin, but from the descriptions given it seems that at least some of these minerals must be primary. No high-temperature minerals and none distinctive of the shallow-vein zone are present. On the other hand, the presence of tetrahedrite and tennantite suggests that the deposits were probably formed at no greater than moderate depth.

The deposits of the Montezuma district contain the persistent minerals, quartz, zinc blende, galena, and chalcopyrite, and a considerable proportion of barite, argentite, proustite and pyrargyrite, which suggest moderate to rather low temperature. From descriptions that have been given of the rich silver minerals it is uncertain whether they are due entirely to enrichment or are in part of primary origin. If primary, they indicate the zone of moderate depth. This indication appears to be confirmed by the absence of any distinctively high-temperature minerals.

The veins in the Breckenridge district differ from the veins at Leadville in mineralogy only in containing small quantities of the high-temperature minerals magnetite and specularite, which suggest that the ore deposits of the district were formed well down toward the bottom of the zone of moderate temperature. In this respect they show a striking contrast with the telluride veins of Boulder County, which, being of later age, were perhaps produced after the erosion had removed the larger portion of the superincumbent rocks.

The veins and replacement deposits mined in the Tenmile district occur in formations 2,500 to 3,000 feet stratigraphically higher than those containing the deposits at Leadville, but they are identical in mineral composition with the Leadville deposits except for the presence of considerable pyrrhotite in the Michigan mine[8a] and the presence of marcasite. The ores of the Tenmile district, therefore, most probably represent the zone of moderate temperature, although the pyrrhotite suggests a close relation to the zone of high temperature.

The deposits of the Alma district include veins and replacement bodies which contain the same principal minerals as those of Leadville but also several others, including secondary sulphides. Minerals suggestive of high and low temperature zones are present, and it appears, in the absence of more specific data regarding their occurrence, that the deposits were formed throughout a considerable range of temperature, which may have extended beyond both of the arbitrary limits of the zone of moderate temperature.

In the Red Cliff district the principal minerals in the veins and replacement bodies and the formations containing them are the same as those at Leadville. Their paragenesis is also similar, and they are regarded as representative of the zone of moderate temperature. No distinctive high-temperature minerals have been found, but the telluride hessite has been reported, which suggests an approach toward low temperature.

The veins in the small districts across the Arkansas Valley west of Leadville are in siliceous rocks and are very similar in mineral composition to the Leadville deposits of the zone of moderate temperature. The ore bodies of the Aspen district differ particularly from those of Leadville in the scarcity of pyrite, the greater prominence of barite and dolomite, and the abundance of the rich silver minerals, which indicates that they were deposited somewhat farther from their source than those at Leadville; but they suggest the zone of moderate rather than low temperature. Microscopic tourmaline recently found by Adolph Knopf[9] indicates local deposition at rather high temperature. The small veins of the Crested Butte district are commercially unimportant, but their mineralogy suggests deposition at moderate to rather low temperature.

The ores of the Monarch district, described by Crawford,[10] are nearly or quite all of the high-temperature zone. Some of the deposits are of pegmatitic character, though the ore minerals may be of later origin than the pegmatitic minerals; other deposits, in limestone, contain typical contact-metamorphic minerals; still others, notably on Monarch Hill, contain no mineral diagnostic of high temperature, with the possible exception of specularite, but Crawford is inclined to regard them on the whole as equivalent to the deep-vein or high-temperature zone. The depth at which the ores were formed was at least 7,000 feet, without allowance for Mesozoic and uppermost Paleozoic strata that may have been entirely eroded since the ores were deposited. The genetic relation of ores to intrusive quartz monzonite is evidently more definitely established in the Monarch district than in the

[8] Farish, J. B., Am. Inst. Min. Eng. Trans., vol. 19, pp. 547-553, 1890.

[8a] Information from H. S. Brown, of the American Metal Co., in letter from C. W. Henderson to G. F. Loughlin dated Aug. 5 1925.

[9] U. S. Geol. Survey Bull. 785, p. 22, 1926.

[10] Crawford, R. D., Colorado Geol. Survey Bull. 4, pp. 212-227, 1913; also personal communication dated Oct. 23, 1922.

others. The Leadville district is the only other in which high-temperature minerals are at all prominent. The deposits at Aspen also were formed beneath a thick cover of strata but farther from their ultimate source. The deposits north and northeast of Leadville, as Lindgren[11] has stated, were formed beneath thinner and thinner covers, and those in the vicinity of Boulder have features indicative of the low-temperature zone.

IRON MINERALS

IN THE SULPHIDE ZONE

MAGNETITE

Magnetite (Fe_3O_4) occurs mostly in large, irregular masses as much as 300 feet in length and 80 feet in both width and thickness. (See pl. 68 and sections

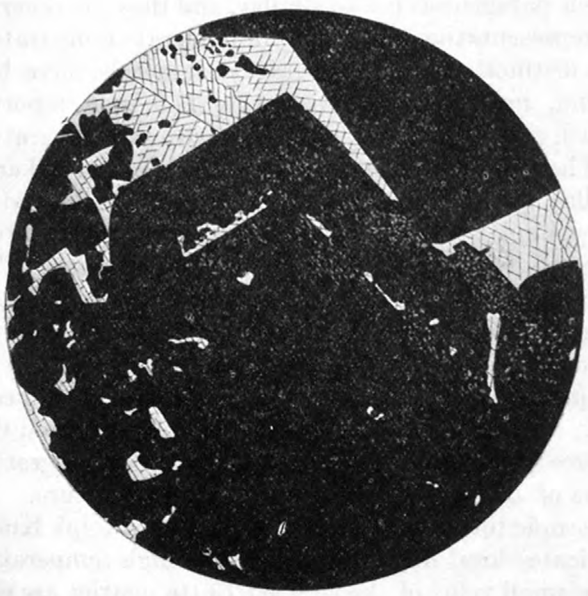


FIGURE 46.—Thin section of magnetite with interstitial manganosiderite and zonal inclusions of the same mineral. Zonal aggregates of pyrite are also present Magnified about 50 diameters

on pl. 28.) These masses are dark gray to black and fine to medium grained. Single grains are 0.1 to 1 millimeter in diameter. The massive magnetite in places is spotted with manganosiderite, and where this mineral has been dissolved out the resulting cavities are lined with magnetite crystals. The crystals of magnetite are best developed where the manganosiderite is relatively abundant. Many of the crystals inclose one or more zones of manganosiderite near their margins (fig. 46).

Around the margins of the large masses magnetite is found as fine bluish-black streaks along bedding planes and as disseminated grains, particularly in shaly limestone (pl. 47, *C*, and fig. 47). A specimen of massive magnetite tested by W. F. Hillebrand in the chemical laboratory of the United States Geological Survey was found to be entirely free from titanium, chromium, aluminum, magnesium, phosphorus, and zinc; but considerable phosphorus is recorded in the analysis on page 178.

Microscopic magnetite has also been found in the Tucson mine partly replacing manganosiderite, whose color is correspondingly darkened. This magnetite is developed along the cleavage planes of manganosiderite grains. Whether this association is to be interpreted as indicating an approach to contact-metamorphic conditions or as a later alteration of manganosiderate is uncertain.

SPECULARITE (HEMATITE)

Although hematite (Fe_2O_3) occurs abundantly in all the ores of the Leadville district, it is much less abundant than the hydrated oxides. In the high-temperature ores the dark-gray crystalline variety, specularite, is occasionally found, although it is subordinate in quantity to the magnetite. Specularite is found in the contact-metamorphic ores of the Ibex mine, but it is not usually present in those portions of the ore which contain appreciable amounts of magnetite. In the siliceous jasperoid, which is closely associated with the magnetite ore and which has usually a characteristic vuggy or cavernous appearance, numerous minute scales of specularite set at all angles to one another are observable. As this mineral is so characteristic of high-temperature deposits in general, the fact that so little of it occurs in the Ibex, Breece Iron, and Comstock mines is somewhat surprising. Specularite replacing dolomite or manganosiderite (?) has been found in the Wolftone mine. (See pl. 46, *B*.)

Besides the variety specularite, of hypogene origin, hematite is present in red earthy to compact masses of supergene origin. The red variety is found in great quantity, however, in the outcrops of iron ore at the Breece Iron mine, where it forms a dull, dark-red compact, tough material, which has evidently resulted from the oxidation of magnetite.

PYRITE

Pyrite (FeS_2) is the most abundant of the primary ore minerals in the Leadville district. It is locally prominent in contact-metamorphic deposits and is abundant in the veins and blanket ore bodies. It also impregnates nearly all the porphyry masses and other country rocks. In most of the ores it is the predominating mineral, and in some portions of the blanket ore bodies and veins it is the only sulphide present. More commonly, however, it is mingled with the other sulphides—sphalerite, galena, and chalcopyrite—and may be totally absent from shoots of high-

[11] Lindgren, Waldemar, Mineral deposits, p. 621, 1919.

grade zinc blende and also from local masses of practically pure galena. In the porphyries it is generally associated with sericite, which forms microscopic fringes around pyrite grains. In all these modes of occurrence and throughout the district the pyrite is characteristically associated with quartz.

Pyrite occurs in large masses of grains without crystal outline, but isolated grains and those that line cavities generally show distinct and typical crystal form. In the large masses the grains range in size from those of such extreme fineness that the mass has a velvety appearance up to grains half an inch in diameter. Cavities in these masses are lined with well-shaped pyrite crystals, which vary in size with the coarseness of grain of the mass. Some of the well-formed crystals are 12-faced (pentagonal dodecahedrons), and some are cubes. All have characteristic striated faces. The larger crystals attain sizes of 1½ inches and more, and the largest found are cubes measuring 4 to 5 inches on an edge. The large well-formed cubes are found mostly in shaly strata and in the "Weber grits" of the Ibex mine and vicinity. The largest of all were found in the South Ibex stockwork. A striking feature of the crystals of this ore body was the presence of parallel ridges, composed of smaller and smaller superposed layers with rounded tapering ends, which resembled Gothic windows in outline. These ridges are unusually large and incompletely developed examples of the striations that are characteristic of pyrite crystals.

Some well-formed pyrite crystals are surrounded by finer granular aggregates of the same mineral, formed at a later stage of deposition.

In the Wolftone mine a considerable quantity of pyrite was found with radiating structure suggestive of marcasite, but chemical tests proved it to be pyrite. The surfaces of many of these radiating pyrite crystals are coated with pyrite crystals of more ordinary form. The radiating aggregates are irregularly mingled with masses of galena and zinc blende and in places are cut by veinlets of these minerals, particularly galena.

Pyrite unrelated to ore deposition may be present as fine to microscopic crystals in the different country rocks, but none has been positively identified. The bluish color of some of the unaltered shale and limestone may be due in part to inclusions of these minute crystals within the translucent mineral grains of the rocks.

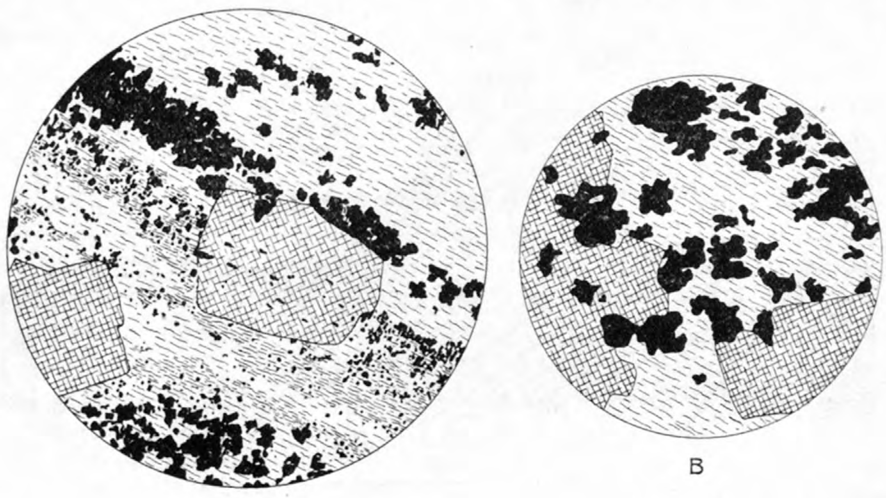


FIGURE 47.—Photomicrographs of thin sections of lean magnetite ore from seventh level of Ibex mine

ARSENOPYRITE

Arsenopyrite ($FeAsS$ or $FeS_2.FeAs_2$) or mispickel, the silver-white arsenical pyrite, has been reported from the Moyer mine and was also discovered in the Tucson mine, where it formed a lens 5 feet long, 3 feet wide, and 1 foot thick, parallel with the pitch of the ore shoots in the Tucson fault. Well-developed crystals of it were orthorhombic prisms terminated by basal plane but with no pyramid faces. So far as known these are the only occurrences of arsenopyrite discovered in the Leadville district.

SIDERITE AND MANGANOSIDERITE

Siderite ($FeCO_3$), though abundant at Leadville, was not recognized for a long time, although recognized in several other districts in neighboring parts of the State. It was first adequately described by Philip Argall[12] in 1914.

Two varieties of siderite accompany the sulphide ores. One is a relatively pure iron carbonate, which

[12] Argall, Philip, Siderite and sulphides in Leadville ore deposits: Min. and Sci. Press, July 11 and 25, 1914.

occurs in flat rhombs or disklike crystals of light to dark-brown color on the walls of cavities; the other with a high content of manganese, which forms large granular masses usually around the margins of sulphide ore bodies. The crystals of the first variety range from a sixteenth of an inch or less up to half an inch in diameter. The larger sizes are unusual at Leadville, though common in the similar sulphide ores at Red Cliff (Gilman), 28 miles to the north (pl. 47, *D*). Some of the larger crystals have curved edges, and in this respect resemble dolomite crystals. The conspicuous crystals of siderite are perched on edge upon the sulphide crystals, but close inspection and microscopic study show that some of them are intergrown with galena, the latest of the sulphides to form, and that some interstitial siderite is found among the massive mixed sulphides. It evidently crystallized later than all the sulphides except galena, and continued to crystallize after the deposition of galena had ceased.

Argall showed that siderite accompanying sulphide ores ("vein siderite" in contrast to sedimentary siderite or spathic iron ore) contains considerable manganese. He cited no analyses of the cavity-coating siderite from Leadville, however, presumably because crystals large enough for analysis were difficult to obtain.

The massive variety is by far the more abundant in the Leadville district. Its content of manganese, though variable, is high enough to classify it as manganosiderite [(Fe, Mn, Mg)CO_3]. It occurs in abundance in the Downtown, Fryer Hill, Carbonate Hill, and Iron Hill areas and is present in the Ibex mine on Breece Hill and other Leadville mines, either intimately mingled with sulphides or replacing the original limestone or dolomite, forming an envelope or casing of variable width around the sulphide bodies. The replacement has usually been so complete that all the original rock structures are preserved, and the mass of manganosiderite so closely resembles the unaltered White limestone that the boundary between the two is not easily found without systematic quantitative determinations of iron and manganese.

The manganosiderite is usually light gray, but much of it shows a very slight yellowish and some a pinkish tinge. It is coarsest grained where mingled with the sulphides, and single grains there range from 1 millimeter to more than 5 millimeters in diameter. The larger grains show a marked rhombohedral cleavage and their faces are slightl curved. In the envelopes that surround ore bodies and in the isolated masses, within ore bodies, of what at first appear to be residual masses of limestone it occur: as fine-grained aggregates of irregular grains from .05 to 1 millimeter in size.

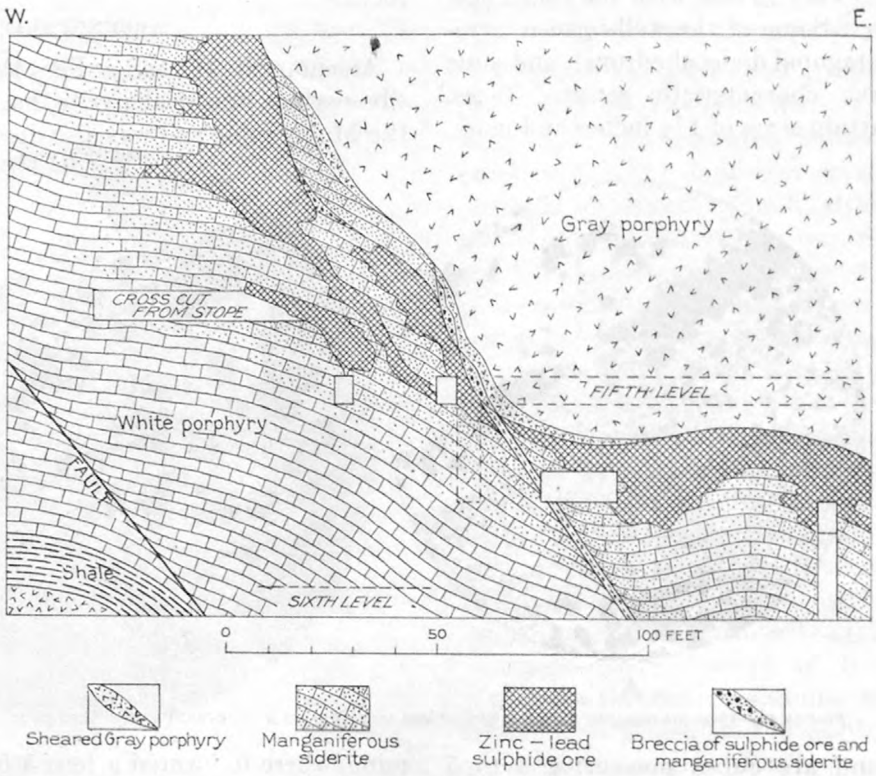


FIGURE 48.—Cross section showing relations of manganosiderite to sulphide ore and limestone, fifth level, Tucson mine. (After Philip Argall)

These aggregates are interrupted by thin layers of greenish-gray shale that mark the original bedding of the limestone. (See pl. 48, *D*.)

Determinations of iron and manganese made by Argall are here quoted with his remarks:

In various places in the Tucson mine the beds of siderite are of such wide extent as to suggest sedimentary deposition. Observing a drift closely following the strike of the beds in such a locality, samples were taken at intervals of 20 feet along one particular bed and assayed with the following result:

Sample	From fissure (feet)	Iron (per cent)	Manganese (per cent)	CaO (per cent)	Insoluble (per cent)
A	40	24. 3	16. 2	1. 8	16. 6
B	60	5. 2	3. 1	19. 6	25. 2
C	80	3. 4	1. 2	24. 1	13. 2

A second place was chosen where ore was mined along a "flat" in the footwall country of a fissure where, on reaching the limits of the pay ore, a crosscut had been extended through the siderite into the unreplaced limestone following the bedding. Samples here gave the following results:

Sample	Feet	Iron (per cent)	Manganese (per cent)	CaO (per cent)	Insoluble (per cent)
A	10 from ore	26. 6	18. 9	0. 6	29. 6
B	20 from ore	19. 4	21. 0	. 7	19. 2
C	30 from ore	16. 7	20. 1	1. 2	25. 0
D	40 from face of crosscut, top.	4. 2	3. 2	19. 6	20. 0
E	40 from ore, floor of crosscut.	3. 6	2. 8	23. 0	18. 0

These samples conclusively showed that practically complete siderite replacement of the limestone extended 30 feet beyond the termination of the zinc-lead ore [see fig. 48], extending as a "flat" from the fissure, and then gradually faded out in 10 feet, as shown in samples D and E. In fact, the change in the crosscut is so gradual and imperceptible that no person with the unaided eye could determine in the mine the limestone from the siderite. * * * Consequently the siderite has, perhaps, been mistaken for White limestone, both by the miners and by the visiting scientists.

Plate 47, *A*, illustrates the massive manganosiderite. Under the microscope the mineral closely resembles dolomite in color, cleavage, and lack of distinct crystal boundaries but has stronger absorption and higher index of refraction. It is usually clear and contains no inclusions, although it is cut by many later veinlets of quartz and sericite with pyrite, sphalerite, and galena and is likewise replaced by crystals of these minerals, single or in clusters. Where vugs are present, however, they are lined with crystals of manganosiderite (pl. 48, *A*) that grew later than the bulk of the sulphides and therefore correspond to the siderite crystals already described. It is impossible to separate these small drusy crystals sufficiently from the massive mineral to determine any difference in chemical composition, and their indices of refraction are too nearly equal to indicate such a difference. It appears on the whole that manganosiderite crystallized throughout a great part of the period of ore deposition and through a considerable range of high to moderate temperature. It apparently acted as an advance guard of the sulphides, replacing the limestone first, only to be replaced itself by the sulphides (pl. 48, *C*) and carried into the limestone around them, where it was again deposited by replacement.

Argall,[13] from his study of the manganosiderite masses in the Tucson mine, concluded that they were in part of contact-metamorphic origin and in part introduced through deep-seated fissures. The evidence in favor of contactmetamorphic origin consisted of the position of the manganosiderite along the contact of a large irregular sheet of Gray porphyry (fig. 48) and its association with comparatively small aggregates of magnetite and specularite. Argall also refers to the association of chloritic material and suggests that it may have been derived from contact-metamorphic pyroxene; but the chloritic material may represent remnants of original shaly matter in White limestone. The close association with magnetite (p. 150 and fig. 46) and specularite points to deposition in high temperature, but the scarcity or absence of associated silicates and the occurrence of masses of manganosiderite away from intrusive contacts (for example, at Red Cliff, where no intrusive rocks have been found associated with the ores) indicate that its temperature of deposition may extend from the lower end of the contact-metamorphic (pyrometasomatic) range well through that of the intermediate (mesothermal) vein zone.

A complete chemical analysis of massive manganosiderite from the Tucson mine is given in the table below. Beside it is the corresponding calculated mineral composition in column 1; also the calculated mineral composition of another massive specimen from the Tucson mine and a sample of crystals from Gilman (Red Cliff), Colo. Partial analyses quoted from Philip Argall's paper are given in the second table.

[13] Argall, Philip, op. cit., p. 32.

Analyses and mineral composition of manganosiderite

1					2	3
Chemical analysis		Calculated mineral composition				
	Per cent		Calculated from analysis	Carbonates recalculated to 100 per cent		
SiO_2	10.08	Quartz	6.48		[a] 4.22	0.9
Al_2O_3	3.16	Sericite:				
		Muscovite	.80			
Fe_2O_3	None	Paragonite	6.88			
FeO	26.80	$FeCO_3$	43.15	51.49	68.22	56.5
MgO	4.04	$MnCO_3$	31.97	38.15	20.53	21.3
CaO	.08	$MgCO_3$	8.48	10.12	7.00	13.4
Na_2O	.57	$CaCO_3$	.20	.24	.16	.7
K_2O	.08	Pyrite	.84			.5
H_2O-	.22	?Water+[b]	.52			
H_2O+	.89	Water−	.22			
TiO_2	Trace.	?P_2O_5[c]	.47			
CO_2	33.14		100.01	100.00	100.13	93.3
P2O5?	.47					
FeS_2	.84					
MnO	19.71					
BaO	Trace.					
	100.08					

[a] Insoluble.
[b] Part may be in sericite, in excess of the muscovite-paragonite formula.
[c] If P_2O_5 is combined with Fe, Mg, Mn, or Ca there will be a corresponding excess of CO_2.

1. Manganosiderite replacing White limestone 4 feet beneath sulphide ore body, seventh level, Tucson mine. Analyst, J. G. Fairchild, U. S. Geol. Survey.

2. Fine-grained manganosiderite from "horse" between two sulphide bodies in Blue limestone, third level, Tucson mine, 250 feet N. 10° E. from shaft. Average of two analyses. The specimen from which this was taken was intersected by many seams of sulphide, and scattered grains of sulphide were likewise abundant in it. These were all carefully removed before the analysis was made, so that practically clean material was available. Four grams of pure material was thus obtained, which was dried at 100° C. for one hour. Analyst, Dr. W. M. Bradley, Sheffield Scientific School, Yale University.

3. Fresh crystals from sulphide zone at Gilman (Red Cliff), Colo., collected by J. A. Ettlinger. Mineral composition calculated from a commercial analysis by J. W. Hawthorne, chemist of the Empire Zinc Co.

Partial analyses of manganosiderite [a]

	1	2	8	9	10	11	12	13	14
Insoluble	19.60	21.20	19.60	21.20	19.20	4.40	2.00	18.10	28.40
Iron [b]	23.07	21.80	13.00	21.80	19.40	25.60	28.10	29.70	17.20
Manganese	20.70	21.10	20.70	21.10	21.00	12.60	9.90	5.40	11.70
MgO	1.40	2.40							
CaO	.30	.40	.47	.40	.70				
Lead	1.50	.60							
Zinc	.30	.30							
Iron carbonate [b]	47.86	45.23	47.72	45.23	40.25	53.11	58.30	61.62	45.68
Manganese carbonate	43.36	44.20	43.36	44.20	43.99	26.40	20.74	11.31	24.51
Magnesium carbonate	2.94	5.04							
Calcium carbonate	.54	.71	.84	.71	1.25				

[a] Quoted from Argall, Philip, Siderite and sulphides in Leadville ore deposits: Min. and Sci. Press, July 11 and 25, 1914.
[b] Includes a small quantity of iron present as sulphide and oxide.

Nos. 1 and 2 each contained 0.04 ounce of gold to the ton, and No. 1, 0.08 of silver.

From these analyses it appears that the iron is generally present in greatest amount and that magnesia is a persistent minor constituent. The small amount of calcite may be due wholly to infiltrated calcite or to minute quantities of unreplaced rock and need not be considered a part of the mineral. If the carbonates are regarded as isomorphous mixtures of siderite, rhodochrosite, and magnesite molecules the formulas for the two relatively complete analyses may be written as follows:

Analysis 1. $4FeCO_3.3MnCO_3.MgCO_3$.
Analysis 2. $7FeCO_3.2MnCO_3.MgCO_3$.

Microscopic examination of the sample represented by analysis 1, at the top of this page, revealed quartz and a small quantity of finely divided sericite and pyrite in veinlets and irregular patches in the manganosiderite, and recalculation of the analysis agrees very closely with the microscopic evidence. The predominance of the paragonite (soda mica) molecule over the muscovite (potash mica) molecule in the sericite is particularly noteworthy and raises a question as to the relative amounts of these two molecules in sericite throughout the district. The excess water of composition (H_2O) is more likely to be in the sericite than in any other mineral. The P_2O_5 was neglected in the calculation, as no mineral of which it is a constituent could be identified.

The sulphide ores shipped from the district to smelters are very low in manganese carbonate and give no adequate idea of the large amounts of this mineral present in the masses of low-grade ore and practically barren manganosiderite that border the high-grade shoots and are occasionally found within them.

IN THE OXIDIZED ZONE

MELANTERITE

The hydrous ferrous sulphate, melanterite ($FeSO_4 + 7H_2O$), is a very common mineral in the Leadville mines but has been deposited by surface waters that have been active since the development of the workings has been carried on. It incrusts the walls of drifts and also forms stalactites and stalagmites of considerable size. When fresh the mineral is green and transparent, but on exposure to air and light it gradually turns to a white chalky powder.[9] It is generally found well within the sulphide zone, and in the oxidized ores its place is taken by ferric sulphates and oxides.

VIVIANITE

Vivianite ($Fe_3P_2O_8 + 8H_2O$) occurs in small quantity in all the oxidized ores of the district. It is not uniformly disseminated, however, but occurs as indigo-blue to bluish-green flat prismatic crystals, some small and some very large. The prism faces are generally striated. It is found most abundantly in the oxidized portions of the magnetite-pyrite ores of the contact-metamorphic class. Here it forms solid aggregates, single crystals, crystalline druses lining cavities, or masses embedded in loose infiltrated clay.

BROWN IRON OXIDE

Brown to yellowish earthy hydrous oxides, generally referred to as limonite and goethite, accompanied by the red hydrous oxide, turgite, form a large part of the oxidized ores of the district and also appear as stains and coatings on rocks and siliceous ores. They have resulted chiefly from the decomposition of pyrite and ferruginous zinc blende, to a somewhat similar degree from the decomposition of siderite, and to a slight degree from the decomposition of magnetite. They also result from the alteration of the hornblende and biotite in weathered eruptive rocks, which are correspondingly stained brown.

These iron oxides are mingled with manganese oxides in all proportions. As the proportion of manganese increases the brown or reddish-brown color changes to a very dark brown, and finally to black. These oxides are also mingled with kaolin, producing the light-yellowish ocherous varieties, which are not readily distinguished from jarosite and other basic ferric sulphates.

One of the commoner varieties of brown iron oxide in the district is commonly known as "liver-colored rock." This is a dense flinty material of yellowish-brown color, having a conchoidal fracture and containing a large proportion of admixed silica. Much of it is sprinkled through with irregular blotches and particles of massive cerusite, and is often spoken of as low-grade hard carbonate ore. The earthy material and the "liver-colored rock" are the most abundant varieties of brown iron oxide in the district. None of the botryoidal and fibrous varieties have come to the writers' attention.

JAROSITE AND BASIC FERRIC SULPHATES

Ricketts,[14] Emmons,[15] and Hillebrand [16] have described the occurrence of abundant basic sulphates of iron in the oxidized ores. Ricketts described basic ferric sulphate as forming a bed or layer lying beneath the richer bodies of lead carbonate in Carbonate Hill. The material is an ochery yellow, rather loose and earthy substance, resembling dry clay in some places and light-colored limonite in others. It contained considerable though varying quantities of lead sulphate, evidently in the form of plumbojarosite, which had not then been recognized as a distinct mineral species.

Three analyses of this material quoted from Emmons and one quoted from Ricketts are given below:

Analyses of basic sulphates

	1 Maid of Erin	2 Morning Star	3 Lower Waterloo	4
SiO_2	None.	0. 30	0. 36	Trace.
Fe_2O_3	46. 70	42. 98	44. 40	40. 22
Al_2O_3	None.	. 20	. 23	1. 11
CaO	. 06	. 64	None.	
MgO	. 06	None.	None.	
K_2O	5. 33	6. 31	. 15	
Na_2O	1. 68	. 83	. 37	
H_2O	10. 54	10. 12	8. 99	11. 20
PbO	4. 27	8. 27	19. 50	29. 98
Bi_2O_3	. 08	None.	None.	
As_2O_5	. 46	. 42	. 39	
P_2O_5	. 08	1. 58	. 11	
SO_3	30. 53	27. 81	25. 07	18. 02
Cl	. 02	. 26	. 04	} . 27
Ag	. 0048	. 0036	. 075	
Au	Trace.	None.	None.	
	99. 8148	99. 7236	99. 685	100. 80

1–3. Emmons, S. F., U. S. Geol. Survey Mon. 12, p. 550, 1886
4. Ricketts, L. D., The ores of Leadville, p. 36, 1883. Exact locality not specified; Waterloo, Morning Star, or Evening Star mine.

[14] Ricketts, L. D., The ores of Leadville, p. 36.
[15] Emmons, S. F., U. S. Geol. Survey Mon. 12, p. 549, 1886.
[16] Hillebrand, W. F., idem, p. 607.

The first two analyses represent mainly mixtures of jarosite ($K_2O.3Fe_2O_3.4SO_3.6H_2O$) and a basic ferric sulphate, with minor quantities of plumbojarosite, pyromorphite, and other compounds; the third and fourth represent mainly plumbojarosite.

MANGANESE MINERALS

IN THE SULPHIDE ZONE

Manganese in the ores of Leadville is present mainly as manganosiderite, described on pages 151–155. A few occurrences of rhodochrosite (manganese carbonate) and one or two doubtful occurrences of rhodonite (manganese silicate) have also been reported. The sulphide, alabandite, has not been found in the Leadville district, although reported by G. M. Butler[17] from the Alma district, on the east slope of the Mosquito Range. Before the casings of manganosiderite around the sulphide ores were recognized, the opinion had been held by several that the manganese in the extensive bodies of "black iron" or oxidized iron-manganese ore was derived in part at least from alabandite; but alabandite is rarely found in considerable quantity. The only evidence of the existence of manganese as sulphide is presented in the three chemical analyses of ferruginous zinc blende (marmatite) quoted on page 157. In these analyses manganese isomorphous with zinc and iron ranges from 1.3 to 3.7 per cent.

IN THE OXIDIZED ZONE

In the oxidized ore of Leadville manganese occurs abundantly as oxides and hydrated oxides. In much of this material it is difficult if not impossible to determine the exact mineral species to which the earthy manganese oxides belong. Pyrolusite, though not seen by the writers, was detected by Emmons in his original investigation, but psilomelane and wad are doubtless the oxides present in greater abundance. The difference between the last two minerals is chiefly in the degree of hydration, and it is probable that they occur together abundantly in the oxidized manganese ores. Pyrolusite and probably manganite are also present. Away from the ore bodies black oxide of manganese commonly forms dendritic or fernlike growths on fracture surfaces. Manganese is also present in hetaerolite and chalcophanite, which are grouped among the zinc minerals of the oxidized zone.

PSILOMELANE AND WAD

Stalactitic and mammillary forms of black to dark steel-gray psilomelane (H_4MnO_5, generally impure, hence composition doubtful) are often found but are much less common than the black, impure, earthy variety of material which is commonly known as wad.

[17] Colorado Geol. Survey Bull. 3, p. 240, 1912.

This material occurs mixed in all proportions with the iron oxides. It frequently contains admixed chalcophanite where the ore carries appreciable amounts of zinc.

PYROLUSITE

The black dioxide of manganese, pyrolusite (MnO_2), occurs mixed in all proportions with the iron oxides and with the other oxidized minerals. It is so intimately mingled with the psilomelane that the two can rarely be distinguished from one another. It is very abundant in the mines of the Downtown district and Carbonate Hill but is less prominent in the more siliceous ores of Breece Hill and vicinity. Crystals of pyrolusite were identified by Emmons, and most of the manganese ores were assumed by him and also by Ricketts to be in the form of the dioxide. Later investigations by G. M. Butler and J. D. Irving, however, showed that much psilomelane is present.

ZINC MINERALS

IN THE SULPHIDE ZONE

SPHALERITE (ZINC BLENDE)

With the exception of pyrite, sphalerite or zinc blende (ZnS) is the most abundant mineral in the Leadville ores. It constitutes a large percentage of many of the blanket ore bodies and the lodes but occurs very sparsely in magnetite-pyrite contact-metamorphic ores.

The sphalerite is in several places segregated into certain portions of an ore body and constitutes a high-grade zinc ore, but more commonly it is intimately mixed with pyrite and galena. The most abundant variety of zinc blende is granular and massive, with a dark-brown to nearly black color and a resinous luster. The grains are without crystal boundaries except where they project into cavities. In the finest-grained material they are less than 0.01 millimeter in diameter and from that they range up to 2 millimeters. The coarser-grained masses contain numerous vugs lined with sphalerite crystals, most of which are twinned. In some large vugs the crystals attain diameters of more than half an inch. These large crystals were common in the Moyer, Tucson, A. Y., Minnie, and adjoining mines of southern Iron Hill.

The zinc blende mined in the Leadville district is not pure but is the dark-brown to nearly black variety marmatite, which, as shown by the chemical analyses below, contains a high percentage of iron. This iron content has made magnetic concentration of the blende possible. Three analyses by Warwick are quoted on page 157.[18]

[18] Bain, H. F., U. S. Geol. Survey Mineral Resources, 1905, p. 384, 1905.

Chemical analyses of ferruginous zinc blende (marmatite)

	Adams	Col. Sellers	Yak
Zinc [a]	52.8	47.6	45.1
Sulphur	34.7	35.7	36.4
Iron [b]	12.1	14.8	17.8
Silica	.2	.4	.2
	99.8	98.5	99.5

[a] Includes cadmium which varied from 0.1 to 0.35 per cent.
[b] Includes manganese which varied from 1.3 to 3.7 per cent.

Allen and Crenshaw,[19] in their discussion of the physical chemistry of sphalerite and wurtzite, have analyzed several varieties of sphalerite ranging in content of iron from 0.15 to 17.06 per cent.

Recalculations of the analyses usually show that the iron is present not as mechanically mixed and finely divided pyrite but as FeS, presumably in some form of combination with the ZnS. Some samples of sphalerite contain as high as 20 per cent of iron.

IN THE OXIDIZED ZONE

SMITHSONITE

Smithsonite ($ZnCO_3$) is the most abundant of all the oxidized zinc minerals and forms large blanket bodies, replacing the limestone and also the manganosiderite of the primary mineralization. The bulk of the zinc obtained from oxidized ores is derived from smithsonite. Two varieties are especially common at Leadville. One is a dense, compact gray to brown massive rock with sparsely scattered irregular cavities (pls. 49, *D*; 50, *C*, *D*). It is impure and contains varying amounts of the isomorphous iron, magnesia, and manganese carbonate molecules. It strongly resembles slightly altered limestone and was for many years mistaken for limestone. The other is a fine drusy variety, mostly light brown but in part also colorless to white, or occasionally pale green, generally found lining cavities in the dense variety (pl. 50, *A*, *B*). This drusy variety at several places forms thin layers alternating with a black mineral (hetaerolite?) and locally with ferric oxide. Botryoidal and fibrous varieties are comparatively rare. Although pure smithsonite should contain 52 per cent of metallic zinc, the presence of impurities considerably reduces the zinc content so that the carbonate ore mined rarely contains more than 40 per cent and ranges down to 15 per cent.

A third variety, comparatively uncommon at Leadville, has a cellular structure (pl. 51, *F*). It occurred on the second level of the Wolftone mine and formed an extensive layer from 18 inches to 3 feet thick immediately beneath a mass of sulphides 10 feet thick, which was in turn overlain by a roof of porphyry. This structure is caused by the intersection of numerous thin plates of crystalline smithsonite and is believed to have been developed by deposition in shattered limestone, the intervening fragments of which were subsequently dissolved.

[19] Allen, E. T., and Crenshaw, J. L., Am. Jour. Sci., 4th ser., vol. 34, p. 347, 1912

HYDROZINCITE

Hydrozincite, a basic zinc carbonate ($ZnCO_3.ZnO_2H_2$), has been reported to occur here and there as a dull-lustered white, soft, earthy alteration product of smithsonite.[20] In the workings accessible to Loughlin, however, the only earthy white material found in the oxidized zinc ores proved, on testing, to be zinciferous clay described on pages 160–162.

AURICHALCITE

Aurichalcite is a basic carbonate of zinc and copper ($2(Zn,Cu)CO_3.3(Zn,Cu)(OH)_2$) whose zinc content ranges, according to different analyses, from 50 to 59 per cent and whose copper content ranges from 15 to 22 per cent. The pure mineral, according to Penfield,[21] contains 53 to 54.4 per cent of zinc and 20 to 21.2 per cent of copper. The mineral is of pale-green to sky-blue color, of pearly luster, and very soft; it occurs in drusy coatings or divergent tufts of columnar or needle-like crystals.

The only deposits of aurichalcite noted by Loughlin in Leadville were in two small stopes above the first level of the Ibex No. 1 (Little Jonny claim). Here the aurichalcite occurs as pale bluish-green crystals forming druses or cavity fillings in light-brown zinc carbonate ore. (See pl. 52, *A*.) In thin section (pl. 52, *B*) the cavity fillings were found to consist of a mixture of aurichalcite and calamine. The calamine predominated, forming diverging groups of bladelike crystals, in and through which were scattered tufts of fine needlelike to fibrous crystals of aurichalcite. A thin rim of drusy smithsonite separated the calamine and aurichalcite in places from the massive brown ore. One of the pockets was found to have a matrix of nearly or quite isotropic silica, in which the crystals of aurichalcite and calamine were embedded. The silica preserved to some extent the granular texture of the massive carbonate ore, proving that it had grown in part, or been enlarged, by replacement of the massive ore, and indicating that the zinc in the calamine and aurichalcite had been, at least in part, derived from the zinc in the massive ore. The source of the copper is not apparent, but its presence is not surprising, as the original sulphide ores in the vicinity contain considerable copper. It is said that ore of this variety from the Ibex No. 1 has run as high as 4 per cent copper, but that no allowance for the copper is made by the ore buyers. Ore of a similar kind is said to have been mined in the Rattling Jack claim, whose shaft is a short distance southeast of the Ibex No. 1 shaft.

[20] Butler, G. M., Some recent developments at Leadville, second paper, The oxidized zinc ores: Econ. Geology, vol. 8, p. 8, 1913; reprinted in Colorado School of Mines Quart., vol. 8, April, 1913.

[21] Penfield, S. L., On the chemical composition of aurichalcite: Am. Jour. Sci., 3d ser., vol. 41, pp. 106-108, 1891

A few microscopic needles of aurichalcite were found in a thin section (pl. 52, *C*) of a calamine-quartz vein cutting low-grade reddish-brown zinc ore in the Belgian mine (Fenton's lease in 1913). Here also the aurichalcite grew simultaneously with the calamine; the two zinc minerals grew inward from the sides of the vein, and their terminations are embedded in a central filling of chalcedonic quartz. Some of the aurichalcite needles are bent, and fragments of calamine blades, which may have been broken from the margins, are inclosed in the central portion of the vein, suggesting that there was a sluggishly flowing fluid (or gelatinous) silica during or just after the growth of the aurichalcite and calamine crystals.

The fact that these were the only occurrences of aurichalcite noted in the district indicates that the mineral is a very minor constituent of the general run of the oxidized zinc ores. Its relative abundance in the Ibex, which lies in the copper-gold belt, is significant, and its occurrence in considerable quantities is doubtless limited to this belt.

CALAMINE

Calamine ($H_2Zn_2SiO_5$) occurs typically in fine to coarse druses of white to colorless bladed crystals (pl. 49, *A*, *B*), or in aggregates of diverging crystal groups, which may partly or completely fill cavities (fig. 63). Sheaflike aggregates, composed of crystals welded along their brachypinacoids, are occasionally found. The crystals in these cavities are tabular parallel to the brachypinacoid, which is vertically striated. Many of the crystals are terminated by a blunt point formed by two macrodomes; others by a sharper point where the blunt macrodomes are subordinate to steep macrodomes. Less commonly the nearly flat brachydomes predominate, producing a blunt chisel-like termination, and in a few specimens the "chisel edge" was seen to be truncated by the basal pinacoid. One small pyramid face was noted by Butler.[22] Prism faces are present but not conspicuous. The calamine also fills small fractures, in a few of which it is accompanied by amorphous or microcrystalline silica. In one exceptional specimen, found by R. S. Fitch on the dump at the Adams shaft, August, 1913, calamine crystals are coated with minute quartz crystals. The calamine crystals have grown upon both massive and drusy smithsonite and on red and brown iron oxides and black manganese oxides. (See Hetaerolite.) They may inclose small particles of the iron and manganese minerals and be correspondingly darkened in color. They are also found in pockets or fractures in limestone near zinc carbonate ore bodies, and some veinlets cut hetaerolite and zinciferous clay, both of which are described below. One specimen, found on the May Queen dump, was so filled with brown oxide of iron as to have a brown opaque appearance, and only its crystal habit gave a clue to its identity. In this and certain other specimens the calamine appears to have grown, at least in part, by the replacement of brown massive smithsonite ore along cavities or fractures. In still other specimens, where the calamine rests upon other drusy minerals or fills a network of fractures inclosing sharply angular fragments of brown carbonate ore, the calamine was unquestionably deposited by infiltrating waters without detectable replacement.

HETAEROLITE ("WOLFTONITE")

The mineral hetaerolite was not recognized at Leadville until the development of the oxidized zinc ores was begun. It was at first believed to be a new species and was therefore named wolftonite,[23] after the mine in which it was found, but further study proved it to be hetaerolite. It is composed principally of oxides of zinc and manganese, with smaller amounts of silica and water. Opinions differ as to its chemical formula. The mineral was first described by Moore[24] in 1877 from a specimen found at the Passaic zinc mine, Sterling Hill, near Ogdensburg, Sussex County, N. J. Moore described the physical properties and occurrence of the mineral and stated it to be a zinc hausmannite ($ZnO.Mn_2O_3$)[25] but published no analyses. It occurred in association with chalcophanite in ocherous limonite, the chalcophanite usually forming a thin coating over it.

In 1910 Palache[26] studied a new lot of material from Franklin Furnace, N. J., and agreed with Moore that the hetaerolite was a zinc hausmannite. He assigned it to the tetragonal system of crystallization and stated that it had an indistinct cleavage. The material was analyzed by W. T. Schaller, of the United States Geological Survey (see column 1 on p. 159), and shown to contain small amounts of silica and water, the water being attributed to a slight admixture of chalcophanite.

In 1913 Ford and Bradley[27] gave a description and analysis of a specimen of the Leadville hetaerolite, taken from the Wolftone mine. They described it as a rare vug-filling mineral, having a radiating mammillary structure, whose outer surfaces are generally smooth and rounded. The mineral showed a splintery fracture, and individual splinters showed a prismatic structure. Under the microscope the finest fragments were birefringent and had an extinction parallel to the prism edges, but no further indication of its crystal form could be discovered. Its hardness was found to be between 5.5 and 6, and its specific gravity was determined as 4.6. Its luster was submetallic, its color

[22] Butler, G. M., Some recent developments at Leadville, second paper, The oxidized zinc ores: Econ. Geology, vol. 8, p. 7, 1913.

[23] Butler, G. M., op. cit., p. 8.

[24] Moore, G. E., Preliminary notice of the discovery of a new mineral species: Am. Jour. Sci., 3d ser., vol. 14, p. 423, 1877.

[25] The formula for haumannite is Mn_3O_4 or $MnO.Mn_2O_3$.

[26] Palache, Charles, Contributions to the mineralogy of Franklin Furnace, N. J.: Am. Jour. Sci., 4th ser., vol. 29, pp. 177–187, 1910.

[27] Ford, W. E., and Bradley, W. M., On hetaerolite from Leadville, Colo.: Am. Jour. Sci., 4th ser., vol. 35, pp. 600–604, 1913.

dark brownish to black, with a bright varnish-like exterior, and its streak dark chocolate-brown. It was infusible but on charcoal with sodium carbonate gave the characteristic zinc oxide coating and with fluxes gave the color reactions indicative of manganese. It was easily dissolved in hydrochloric acid, giving off chlorine gas. In the closed tube it yielded water but did not give off oxygen. The index of refraction of hetaerolite was determined by Ford and Bradley to be above 1.78. It was determined by E. S. Larsen, of the United States Geological Survey, from material collected by Loughlin to be 2.19 and 2.22.

The mineral is of widespread occurrence in the oxidized zinc deposits of Leadville, though Loughlin saw no specimens equal in size to those obtained in one part of the Wolftone mine. It was also found by Philip Argall on the fourth level of the Tucson mine, filling small fractures in manganosiderite, well below the levels where oxidized zinc ores have been mined.[28] The mineral occurs mostly as thin drusy bands, alone or alternating with smithsonite, around cavities; also as fillings of small fractures, or as linings of fractures that are centrally filled with calamine or zinciferous clay. Its surface may be exposed, or it may be covered by calamine druses, the crystals of hetaerolite appearing to end abruptly where those of calamine begin. In some specimens small central clusters of distinct hetaerolite crystals grade outward into black stains that spot or mottle a considerable part of the brown carbonate ore. This relation leads to the suggestion that all the black manganese oxide stains and spots in the zinc carbonate ores may be incipient segregations of hetaerolite and not of psilomelane, as would at first be supposed. Wherever seen these black stains bear the same paragenetic relations to the later smithsonite and to calamine as the undoubted occurrences of hetaerolite. Locally hetaerolite may be the most conspicuous mineral in the ore, giving it a black or brownish-black color. In one specimen of this character, from the Tucson mine, the hetaerolite crystals are very distinct, having grown along intersecting fractures and inclosing dark-brown soft, earthy material of low zinc content. In other specimens of similar color the mineral is not visibly crystallized. The Tucson specimen strongly indicates that the hetaerolite was formed by the segregation of zinc and manganese from the massive carbonate ore, which left a residue composed largely of iron oxides. This origin is also suggested by several other specimens, some of which contained undoubted hetaerolite and others only the black stains.

In column 1 below is an analysis made by W. T. Schaller[29] of hetaerolite from Franklin Furnace, N. J.; in columns 2 and 3 are analyses of the Leadville hetaerolite made, respectively, by W. M. Bradley[30] and by Chase Palmer, of the United States Geological Survey; and in column 4 a partial analysis by G. Haigh.[31]

Analyses of hetaerolite

	1	2	3	4
Mn_2O_3	60.44	MnO 50.34	49.13	45.9
O	----	5.99	5.50	----
Fe_2O_3	.77	----	.67	5.9
ZnO	33.43	37.56	37.66	37.1
CaO	----	Trace.	Undet.	----
SiO_2	1.71	2.69	2.91	[a]2.0
H_2O-	2.47	4.36 (H₂O− and H₂O+)	3.78	4.7
H_2O+	1.42			
	100.24	100.94	99.65	95.6

[a] Insoluble.

In discussing analysis 2, Ford and Bradley state that the structure of the mineral was such as to suggest that the silica is due to the presence of calamine, and that if so about 10 per cent of calamine is present—a large amount to escape discovery; but they thought that the fibrous structure of the hetaerolite might well conceal this amount. By recalculation, with allowance for the calamine, analysis 2 is found to correspond closely to the formula $2ZnO.2Mn_2O_3.H_2O$. Recalculation of analysis 1, including H_2O but not SiO_2, yielded the same formula, which Ford and Bradley conclude should be the formula for hetaerolite, instead of $ZnO.Mn_2O_3$, as stated by Moore and later by Palache; but they add that "it may be that the exact composition of hetaerolite can not be settled until purer material can be analyzed."

The best specimens collected by Loughlin show the hetaerolite to be a distinctly earlier growth than calamine, and the purest material, when crushed to a fine powder and examined under the microscope, gave no indication of calamine, even fine specks of which should be easily distinguishable from hetaerolite. Chemical analysis (column 3 in the preceding table) shows it, however, to be practically identical with the material analyzed by Bradley (column 2). G. M. Butler[32] has expressed the conviction that the silica is an essential constituent of the mineral but has not suggested a corresponding formula. Nevertheless, the fact that silica and the excess of ZnO over that necessary for the ratio $2ZnO.2Mn_2O_3.H_2O$ are in the same ratio as in calamine is certainly significant, although just what the significance is must for the present be left to speculation.

CHALCOPHANITE

Chalcophanite, like hetaerolite, is a manganese-zinc oxide, with the formula $(Mn,Zn)O.2MnO_2.2H_2O$, containing about 21 per cent of zinc oxide.[33] It is closely

[28] Specimen taken in June, 1914, and sent to Loughlin for identification.
[29] Palache, Charles, op. cit., p. 180.
[30] Ford, W. E., and Bradley, W. M. op. cit., p. 602.
[31] Haigh, G., partial analysis quoted by Ford and Bradley.
[32] Written communication.
[33] Dana, J. D., System of mineralogy, 6th ed., p. 256.

associated with hetaerolite, both at Franklin Furnace, N. J., and at Leadville, Colo. It differs from hetaerolite in certain physical and chemical properties. In some specimens collected by Loughlin at Leadville it forms druses of minute tabular crystals of the rhombohedral system, coating botryoidal surfaces and filling cracks in hetaerolite. In others it forms foliated crusts coating brown smithsonite and covered in turn by calamine druses. (See pl. 49, *C*.) Dana states that it also forms stalactitic and plumose aggregates. It hardness, as given by Dana, is only 2.5; its specific gravity 3.91. Its luster is metallic and brilliant, its color bluish black to iron-black; and its streak chocolate-brown. In the closed tube it gives off water and oxygen and exfoliates slowly, and its color changes to a golden bronze. Before the blowpipe a similar change of color takes place, accompanied by slight fusion on thin edges, and it is this bronzy appearance that has given rise to the mineral name.

Since the above paragraph was written specimens of Leadville chalcophanite collected by F. B. Laney have been studied by Ford,[34] whose description verifies the properties above mentioned. He found that very thin plates under the microscope are sufficiently transparent to give a negative uniaxial interference figure.

ZINCIFEROUS CLAY

Three varieties of zinciferous clay have been recognized in the Leadville mines—white, brown, and black. The white and brown are the most abundant. The white clay (pl. 51, *A*) is very similar in appearance to kaolin and is one of the materials included under the local name "Chinese talc." The fresh material, however, is harder (about 3) and of more waxy luster than kaolin and does not slake or become plastic even when immersed in water for several days. Its fracture is conchoidal. Weathered or leached portions of it are of earthy appearence and slake readily in water. It has been found at the base of porphyry sheets in the Waterloo[35] and New Dome mines, forming in the latter a layer 1 to 2 feet thick that separates the sill from an underlying body of reddish-brown zinc carbonate ore. It has also been found in the Yankee Doodle mine, where it forms a layer about 2 feet thick immediately beneath a thin bed of silicified shale. These occurrences are of sufficient size to be called small ore bodies. Here and there are fissure deposits and small patches and cavity fillings of clay in the zinc carbonate ore bodies.

One specimen found on the New Discovery dump contains calamine veinlets, locally expanded into drusy vugs, so distributed as to suggest that the calamine was formed in shrinkage cracks from material extracted from the clay.

Under the microscope the clay from the Yankee Doodle appears as an interlocking aggregate of minute fibers, of pale-brown color, nonpleochroic, with rather strong birefringence and positive elongation. Its mean index of refraction is a little above 1.58. The general appearance of the fibers is very similar to that of sericite fibers. Clay of similar megascopic appearance, from a pronounced fissure in the Maid of Erin mine, has optical properties more like those of kaolin, being traversed by a network of sericite-like fibers of higher birefringence and containing a few small calamine crystals. These features, together with the relatively low specific gravity of the material, suggest that it is kaolin containing a small percentage of zinc, mostly in the form of the sericite-like mineral.

The brown variety is more widely distributed but is nearly all limited to small deposits, such as the light-brown seams along bedding and joint planes and a few cavity fillings. Those along bedding and joint planes are of bright waxy luster and of uniform dense texture (pl. 51, *B*); those filling vugs are of more or less waxy luster and may have a pronounced finely banded structure (pl. 51, *E*), strongly resembling that of a sedimentary clay. Both varieties slake rapidly in water but lack the high degree of plasticity so characteristic of ordinary clays. The bright waxy material slakes into small chips or splinters but does not become plastic; material somewhat softened and dulled by weathering has a tendency to become plastic but lacks the stickiness of ordinary clay, as well as the characteristic odor.

An exceptional occurrence of the brown variety, sufficiently large to be called a small ore body, was seen in the Belgian mine (Fenton's lease in 1913), replacing limestone along fissures just beneath a sheet of Gray porphyry. It was identical in appearance with low-grade zinc carbonate ore but yielded no effervescence when immersed in hydrochloric acid. In thin section it was found to consist of aggregates of the minutely fibrous sericite-like mineral, more or less stained and obscured by iron and manganese oxides. Microscopic vugs contained growths of the same mineral with radial arrangement around the borders. The larger of these vugs, or local enlargements of veinlets, contain calamine and the sericite-like mineral so intimately mixed as to indicate that the two must have grown at the same time, though the sericite-like mineral evidently began first, giving rise to the radial borders. It was traversed by many short veinlets of calamine with black borders of manganese oxide. Other manganese spots and streaks were also present.

A partial analysis by R. C. Wells shows the presence of 17.8 per cent of insoluble matter and 18.7 per cent

[34] Ford, W. E., Mineralogical notes: Am. Jour. Sci., 4th ser., vol. 38, p. 502, 1914.
[35] Emmons, S. F., Geology and mining industry of Leadville, Colo.; U. S. Geol. Survey Mon. 12, p. 560, 1886. Hillebrand, W. F., idem, p. 605.

of zinc oxide (or 15 per cent of zinc). The remainder, as shown by qualitative tests, contained a large amount of iron oxide and small amounts of magnesia and lime. The insoluble matter doubtless indicates the amount of silica in the sericite-like mineral, or zinciferous clay. The zinc oxide represents a little calamine as well as the sericite-like mineral. The material evidently consists essentially of zinciferous clay, iron oxide, a little calamine, and a little manganese oxide.

The black variety was noted in conspicuous amount only at one place, where the white clay in the Yankee Doodle mine was locally stained by manganese oxide.

The chemical composition of the zinciferous clays is shown by the following analyses.

Analyses of zinciferous clays

	1	2	3	4	5
SiO_2	37.54	35.97	35.33	35.57	36.49
Al_2O_3	24.76	8.81	10.38	10.80	7.06
Fe_2O_3	.64			.40	2.48
FeO				Undet.	Undet.
MgO	.71	.80	.71	.82	.97
CaO	.63	1.87	1.62	.48	1.44
ZnO	18.43	35.40	33.05	31.49	33.46
PbO				None.	Undet.
Na_2O	.36			Undet.	Undet.
K_2O	.66			Undet.	Undet.
H_2O+	[a] 11.07	[a] 7.20	[a] 7.42	6.32	7.06
H_2O-	5.03	10.26	11.64	Undet.	Undet.
CO_2				None.	Undet.
P_2O_5				Undet.	Undet.
	100.10	100.31	100.15	[b] 86.88	88.99
Zn				25.30	26.88

[a] Hillebrand's analysis as tabulated gave only total water, but the amount of hygroscopic water in each analysis is stated in the text (op. cit., p. 605).
[b] By comparison with analyses 1, 2, and 3, the deficiency appears to be chiefly hygroscopic water.

1, 2, 3. "Alteration product of porphyry," Lower Waterloo mine. W. F. Hillebrand, analyst. U. S. Geol. Survey Mon. 12, p. 603, 1886.

4. White zinciferous clay, Yankee Doodle mine. George Steiger, analyst.

5. Brown zinciferous clay, New Discovery mine. George Steiger, analyst.

The first three analyses represent material obtained directly under porphyry; the fourth represents the Yankee Doodle deposit, beneath a silicified shaly bed; the fifth represents the brown, finely banded type. In spite of variations in the mode of occurrence and appearance, the five analyses are very similar to one another in many respects, but attempts to calculate the mineral composition of the ore yield varying and only inconclusive results. The Yankee Doodle material (No. 4), after kaolin and calamine are calculated, has still an excess of silica and zinc, the molecular proportion of the former being a little more than double that of the latter. In the brown banded variety (No. 5) the alumina and all the zinc can be assigned to kaolin and calamine, respectively, leaving an excess of silica and combined water in the approximate ratio of 11 to 2. Attempts to find some definite relations between certain constituents by plotting their percentages on a diagram (fig. 49) do not give very definite evidence, except that the percentage of zinc oxide (ZnO) varies inversely as that of alumina (Al_2O_3). The birefringence of the clays shows that crystalline matter is present, and it may be suggested that they contain kaolin or some closely related aluminum silicate, its optical properties changed by dissolved impurities,

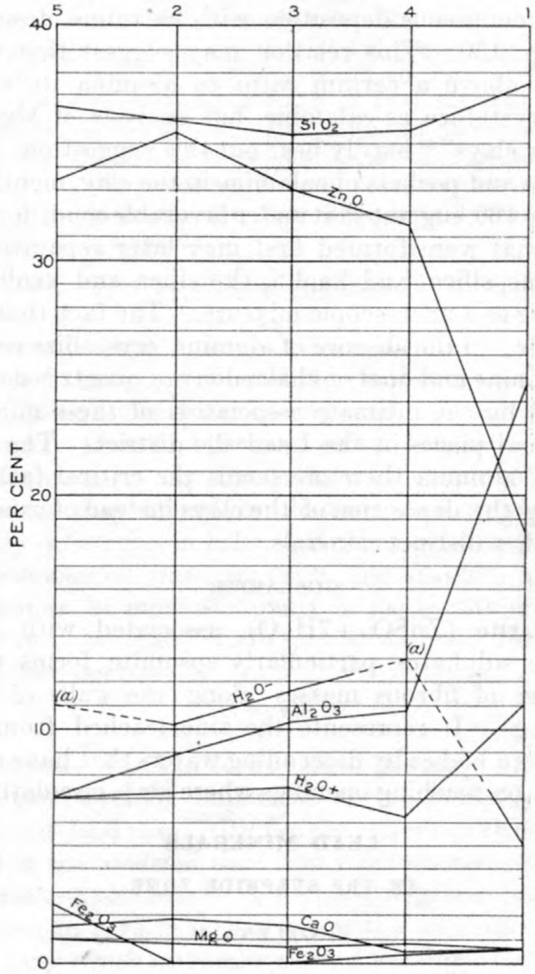


FIGURE 49.—Percentages of constituents in zinciferous clays, arranged in order of increasing alumina. See table on this page

but if it were suggested that such an aluminum silicate held the other constituents in solid solution, it would be necessary to assume that one molecule of it could hold in solution several molecules of each of the other substances—a questionable property. The low-grade clays, furthermore, show in thin section that the more highly birefringent mineral forms a network impregnating a mass whose optical properties are like those of chalcedonic silica and kaolin. If the highly birefringent portion could be analyzed separately it would probably show as high a ratio of zinc oxide to alumina as the high-grade clays. The fact that the percentage of zinc oxide varies inversely as the percentage of alumina suggests replacement by zinc of aluminum. The low-grade deposits indicate that such replacement has occurred in clays previously deposited, but at least some of the high-grade clays indicate that zinc has taken the place of aluminum in solution and that the zinciferous clay has resulted from direct chemical precipitation.

Whatever its true nature, the zinciferous clay has certain relations to definite minerals, as is shown by its contemporaneous deposition with calamine, described on page 160. This relation may suggest that when zinc is above a certain ratio to alumina its excess may crystallize as calamine, but analyses of Missouri "tallow clays"[36] hardly bear out this suggestion. The veinlets and pockets of calamine in the clay, mentioned on page 160, suggest that under favorable conditions the clays that were formed first may later separate into calamine, silica, and kaolin, the silica and kaolin remaining as a microscopic mixture. The fact that zinc and silica, in the absence of alumina, crystallize readily as calamine and opal or chalcedony or quartz is demonstrated by the intimate association of these minerals in several places in the Leadville district. The presence of alumina therefore seems the critical factor in causing the deposition of the clays instead of calamine and other distinct minerals.

GOSLARITE

Goslarite ($ZnSO_4+7H_2O$), associated with other soluble sulphates, particularly epsomite, forms white coatings of fibrous masses along the walls of mine workings. It represents the zinc leached from sulphide ore bodies by descending waters that have evaporated on reaching openings where air is circulating.

LEAD MINERALS

IN THE SULPHIDE ZONE

GALENA

Galena (PbS) occurs in large amount in the unoxidized portions of the blanket ore bodies, although it is not so widespread as pyrite or sphalerite. Like both pyrite and sphalerite, it forms some masses in which other sulphides are very scarce or absent, but more commonly it is mingled with pyrite and sphalerite (pl. 31, *A*) in varying amount. It occurs in greatest abundance in the western portion of the district. In the lodes galena is abundant at some places and entirely lacking at others, but on the whole it is a minor constituent of the ores shipped.

Galena occurs mostly in granular masses, and to a minor extent as well-developed crystals lining cavities. The massive galena consists of irregular grains without crystal boundaries, and the sizes of the component grains vary greatly. Where the galena is pure the largest crystals attain an inch in diameter. More commonly, however, they are one-eighth inch or less. In the finer-grained varieties of mixed ores galena occurs scattered through the mass in minute grains, but pure fine-grained masses, known as steel galena, have not been observed by the writers in the Leadville district, nor have any occurrences been noted in which twinning structure has been developed in the galena by pressure.

Large fractures lined with galena crystals were observed in the Moyer, Tucson, A. Y. and Minnie, Wolftone, and many other mines. Where the incrusting galena crystals are large—that is, from three-fourths inch to 2 inches in diameter—their surfaces are usually dull and show the results of etching by ground waters. Thin crusts of mixed carbonates cover the faces of many of the crystals. These crystals are usually cubes modified by the octahedron. Twin crystals are frequently seen.

Another variety of galena in peculiar crystal form occurs in considerable quantity in nearly all the mines, and is especially abundant in the mines of Iron and Carbonate hills and Graham Park. These crystals are brilliant and in places occur in great profusion as linings in the cavities of the ores (pls. 47, *B*, and 48, *E*). Many of the cubes are twinned, and some of their faces are built up by peculiar rounded irregular and incomplete accretions. Many of these accretions consist of smaller and smaller superposed layers (A, pl. 48, *E*). These layers are similar in origin to those giving the "Gothic window" effect to pyrite crystals (p. 151). Some portions of the crystals, usually on the under sides next to the wall on which they are attached, are rounded and irregular, resembling semifused material. This appearance is not due to fusion, however, but may be interpreted as a variation of the accretionary growth just described, in which the decreasing size of the successive layers is so gradual that no lines of division can be seen between them.

An unusual occurrence of drusy and stalactitic galena was noted on the sixth level of the Tucson mine. This galena had grown upon zinc blende crystals in vugs in sulphide ore along the hanging wall of the Tucson fault. The stalactites were as much as half an inch in length and were distinctly later than the blende or the few crystals of chalcopyrite that accompanied it. The galena was coated with a dusty film that may have been argentite, as the ore at this place assayed 80 ounces to the ton in silver. This occurrence of galena suggests secondary origin, but it is impossible to distinguish sharply between primary (hypogene) and secondary (supergene) galena, for the other forms of galena, as well as the stalactites, have crystallized on the whole later than the blende and other sulphides. The mode

[36] Seamon, W. H., The zinciferous clays of southwest Missouri and a theory as to the growth of calamine of that section: Am. Jour. Sci., 3d ser., vol. 39, pp. 38-42, 1890.

of occurrence of the stalactites, however, accords with other observed occurrences and experiments that have been discussed by W. H. Emmons,[37] in showing that secondary galena may be deposited on blende or pyrite, whereas secondary silver sulphide may be deposited on galena, blende, or pyrite.

Analyses of the ores appear to indicate that nearly all the galena in Leadville contains antimony. It is probable that some bismuth is also present in this mineral.

Although frequently found intersecting other sulphides, the galena is believed to be, with the rare exception just noted, a primary mineral. Nodules of it are scattered through the oxidized ore, where it has been the last mineral to yield to complete oxidation. Such nodules usually carry a higher proportion of silver than the galena found in the distinctively primary zone. All the galena in the Leadville district carried silver, and although the ratio of silver to lead is far from constant, the proportion of silver is usually greater in the galena than in pyrite and sphalerite.

The studies made by Laney indicate that the silver is present in argentite inclosed in or intergrown with galena. No outward characteristics distinguish the galena high in silver from that which is low in silver. A fuller discussion of the silver content of galena will be found on pages 167, 170, and 198.

IN THE OXIDIZED ZONE

MINIUM

Minium (Pb_3O_4), the sesquioxide of lead, occurs in many of the oxidized ores of the district, especially in those which have resulted from the oxidation of sulphides that contained large proportions of galena. It occurs intermingled with cerusite and iron oxides and in places incloses small residual particles of galena. It has been found in a number of mines, notably in the Rock, Dome, and Bessie Wilgus mines, on Rock Hill, and it is probably common elsewhere, though no published reports on it are available. A specimen from the Rock mine was described in 1890 by J. D. Hawkins,[38] of the Globe Smelting & Refining Co., as follows:

The mineral was found between two ledges of outcropping rock, one of porphyry and the other of limestone, the ore of the mine being carbonate of lead, with occasional occurrences of galenite. The minium does not occur as a solid mass but is interspersed with cerusite, and close examination also showed small particles of galenite occurring with the cerusite. The galenite found in the analysis, however, is not this. The sample taken for analysis was a very carefully picked one, a lump of the mineral being broken up, and the red particles of minium alone being taken. This sample was again carefully picked over in order to insure the absence of anything else than the pure mineral. The analysis gave the following results:

Insoluble in HCl	7. 51
Pb calculated as Pb_3O_4	91. 39
Fe_2O_3	. 80
V_2O_5	. 52
	100. 22

Insoluble:	
SiO_2	2. 00
Al_2O_3. Fe_2O_3	. 41
CaO	. 28
Pb 4.42, PbS	5. 08
	7. 77

From the cubical fracture of the minium, resembling that of galenite, and the occurrence of galenite in the red minium, it would appear that the minium here is a pseudomorph after galenite. The vanadic oxide which was found in the mineral no doubt existed as vanadinite, which has been frequently found in Leadville.

The occurrence of sulphide of lead in the pure mineral is rather remarkable and also suggestive. Externally the particles of minium showed no evidence of the presence of any other mineral; it was not until the powdered mineral had been treated with hydrochloric acid and all PbO dissolved that the galenite could be observed. This seems to be conclusive evidence that the minium in this case was a direct alteration from galenite. A like deduction is forced as regards the plattnerite lately found in the Coeur d'Alene Mountains, Idaho, where all the lead ore is sulphide.

LITHARGE (MASSICOT)

Litharge (PbO) occurs here and there in the more ocherous varieties of oxidized lead ores in the form of a light-yellowish earthy material. It has not been definitely identified by the writer but is mentioned by Emmons in the Leadville monograph, page 376. Litharge may be readily distinguished from minium by its difference in color. Neither of these oxides is of commercial importance in the district, although they may be more abundant in the earthy ores than it would be possible to prove without the aid of complete analyses.

CERUSITE

Cerusite ($PbCO_3$) forms one of the most widespread and commercially important of the minerals of the oxidized lead ores. By far the largest portion of the lead in the oxidized zone is in this mineral. It occurs in greatest abundance in blanket deposits but is also present in greater or less quantities in those parts of the lodes which originally carried considerable galena. It is a prominent minor constituent of mixed sulphide from which zinc blende has been leached and in which pyrite has been tarnished or coated with chalcocite. In ore of this kind the cerusite fills cracks and interstices and has clearly been deposited from descending solutions, in contrast to the great bulk of cerusite, which has formed by the oxidation of galena without noticeable migration.

There are few mines in the Leadville district which do not contain at least a small portion of this mineral in their oxidized ores, especially the iron and manganese oxides, in which the crystals may be visible or may be detected only by chemical analysis. Cerusite occurs in three well-recognized forms—as large crystals; as aggregates of small crystals, generally loosely

[37] Emmons, W. H., The enrichment of sulphide ores: U. S. Geol. Survey Bull. 529, pp. 84-86, 1913; The enrichment of ore deposits: U. S. Geol. Survey Bull. 625, pp. 137-140, 1917.

[38] Hawkins, J. D., Minium from Leadville: Am. Jour. Sci., 3d ser., vol. 39, pp. 42-43, 1890.

bound together and known as sand carbonate; and irregularly disseminated in masses of dense silica, which are usually termed hard carbonate. The large crystals of cerusite are found either embedded in manganese and iron oxides or in clay, and occur at many places as radiating clusters or as drusy linings in cavities in the harder ores. Some crystals are white and glassy; others are discolored by minute inclusions of darker minerals, some of which have been proved to be the silver sulphide argentite. Occasionally minute crystalline specks of silver chloride are found coating the crystals of cerusite. It has been shown by many assays and analyses of the Leadville cerusite that this mineral always carries a little silver, which is generally believed to be present either in the form of minute argentite inclusions or minute scattered specks of chloride or bromide.

Large crystals of cerusite were found frequently in the ores worked in the early development of the district. As the work done by the writers was confined largely to the sulphide deposits and to those portions of the oxidized ores which were of lower grade in both lead and silver, the only specimens which they observed were those preserved in the many private collections in Leadville. There are numerous cavities in the galena which are lined with large transparent crystals of cerusite having the form of long prisms capped by the pyramid.

"Sand carbonates" and "hard carbonate" are described under "Oxidized lead ores" (pp. 227-230).

ANGLESITE

In the irregular nodules of galena found in the oxidized ores the galena is usually surrounded by a thin crust made up mostly of anglesite ($PbSO_4$). From this occurrence it is inferred by Emmons that the alteration of the galena passed first through sulphate and then into carbonate. This inference is in accord with observations by Weed and others in regard to the manner in which galena is altered by oxidizing waters.

LANARKITE

Masses of dull blackish "bismuthiferous lanarkite, or sulphato-carbonate of lead and bismuth," are reported by Guyard [39] to have been found in the Florence mine, presumably as an oxidation product of "schapbachite," but no occurrences of this sort have been seen by the writers, and no other record of the occurrence of this mineral has been found in the literature. According to Dana's "System of mineralogy" lanarkite is a basic sulphate of lead (Pb_2SO_5 or $PbSO_4.PbO$).

CALEDONITE

The bluish-green mineral caledonite [$(PbCu)_2(OH)_2SO_4$] is reported from the Lilian mine, on Printer Boy Hill, by Dana,[40] but no full description of it has been found in the literature.

WULFENITE

Molybdenum has been detected by analysis in several of the sulphide ores of the Leadville district, and it is natural that the oxidation product wulfenite ($PbMoO_4$) should be found occasionally in the oxidized ores. It has not been seen by the writers, although in the Leadville monograph Emmons mentions its occurrence, and it is reported by Guyard to have been found in the Little Chief mine. The mineral is evidently rare and of no commercial importance in this district.

DESCLOIZITE OR DECHENITE

A vanadate of lead and zinc occurs in small quantities as a deep brick-red coating on siliceous gangue in the oxidized ores. Ricketts [41] mentions surfaces 6 inches or more across which are completely covered by it. It is of no commercial importance. Dechenite ($Pb(Zn)O.V_2O_5$), the anhydrous vanadate, has been reported, but Dana [42] suggests that the mineral so called is probably descloizite ($4Pb(Zn)O.V_2O_5.H_2O$), the hydrous vanadate.

VANADINITE

Vanadinite [$(PbCl)Pb_4V_3O_{12}$] has not been observed in the Leadville district by the writers, but it was reported by J. D. Hawkins, of the Globe Smelting & Refining Co.,[43] to have been frequently found at Leadville. It was believed by him likewise to be present in the minium which was found in the Rock mine. Vanadium is frequently found in the oxidized ores of the Leadville district, and its presence would probably have been likewise detected in the sulphide ores had tests ever been made for it. It is possible that some of the greenish hexagonal crystals that have been reported as pyromorphite may have actually been vanadinite. The similarity between the two minerals renders their distinction without careful tests somewhat difficult.

PYROMORPHITE

Pyromorphite [$(PbCl)\ Pb_4P_3O_{12}$] occurs in considerable quantities in nearly all the oxidized lead ores of the district. In some places it is easily observed in the hand specimen; in others its presence can be detected only by analysis, as it is thoroughly mingled with the lead carbonate and iron and manganese oxides. Many analyses of oxidized ore show considerable quantities of phosphorus pentoxide and of chlorine, a large part of which, as calculation shows, must be present in the form of pyromorphite. The

[39] U. S. Geol. Survey Mon. 12, p. 616, 1886.

[40] Dana, J. D. and E. S., System of mineralogy, 6th ed., p. 1090, 1909.

[41] Op. cit., p. 29.

[42] Dana, J. D. and E. S., System of mineralogy, 6th ed., p. 790, 1909.

[43] Am. Jour. Sci., 3d ser., vol. 39, p. 43, 1890.

analysis quoted on page 155 and that given below [44] illustrate this fact.

Analysis of carbonate ore from the Waterloo mine

PbO	77.98	Pyromorphite	38.5
P_2O_5	6.48	Cerusite	53.9
CO_2	10.18	Cotunnite	1.1
Cl	.84	Cerargyrite	.1
Ag	.047	CO_2 in gangue	1.3
	95.527		94.9

The cotunnite ($PbCl_2$) represents a small excess of chlorine over the quantity necessary for pyromorphite and cerargyrite. No chloride of lead has been recognized among the ore minerals, and any present is evidently in minute grains.

Slender, tapering, yellowish-green crystals of pyromorphite, as much as an inch long, are frequently found, single and as radiating clusters, in the linings of cavities in the oxidized ores of both blanket ore bodies and lodes (pl. 48, *B*). Many beautiful specimens of this mineral have been obtained from Leadville.

Pyromorphite was also observed in the Evening Star mine, together with cerusite, galena, and a little calcite, cementing a breccia of sulphide and porphyry.[45]

SILICATE OF LEAD

Small reddish crystals from the oxidized ores of certain of the Carbonate Hill mines were determined by Guyard[46] to be a silicate of lead. As he gave no analysis of this material the mineral species can not be definitely stated. No silicate of lead occurring in reddish crystals is listed in Dana's "System of mineralogy."

PLUMBOJAROSITE

Plumbojarosite ($PbO.3Fe_2O_3.4SO_2.6H_2O$), a hydrous basic sulphate of lead and ferric iron, was found in 1913 in the Yankee Doodle mine in the bottom of an old lead stope, just above a small oxidized zinc stope. It had been called "contact matter" but was known to contain considerable lead. The mineral occurs as a yellowish-brown, soft, earthy mass, with a rather shiny luster and a smoother feel than is characteristic of iron oxide or iron-stained lead carbonate. Under the microscope the material is seen to be essentially homogeneous and to consist of minute grains, some of which show a partial to complete six-sided outline under very high magnification. It is much finer grained than the material from Beaver County, Utah, figured by Butler.[47]

Material of the same kind was found under Gray porphyry in the Lower Waterloo mine by Ricketts and by Emmons during the first survey of the district, and analyses of it are quoted on page 230. It was, however, not recognized as a distinct mineral species, owing doubtless to its earthy appearance and close resemblance to other materials of varying though similar qualitative composition, but was regarded as consisting chiefly of a mixture of sulphates. Plumbojarosite was not recognized as a distinct species until 1902.[48]

In 1919 similar material was found with cerusite and remnants of galena in a stope 90 feet above the eighth level of the Penrose mine.

COPPER MINERALS

HYPOGENE MINERALS

CHALCOPYRITE

Chalcopyrite ($CuFeS_2$) is present in comparatively small quantity as a primary constituent of sulphide ores and is associated with both high-temperature and moderate-temperature minerals. In the magnetite ores of Breece Hill it accompanies pyrite, the two minerals forming irregular patches and streaks that ramify through the magnetite. In many of the blanket deposits it can not be detected without a microscope, but Laney's studies of polished sections of the sulphide ores have proved that the zinc blende contains many minute inclusions of chalcopyrite. Recalculation of the chemical analyses of ores given on pages 194 and 197 also indicates that their copper content is due to small particles of chalcopyrite. In the veins it is more conspicuous, though still the most subordinate of the common sulphides, and is associated with pyrite, to a less degree with sphalerite, and here and there with galena. So far as observed the chalcopyrite forms interstitial irregular grains and small masses scattered among the other sulphides. No well-formed crystals have been found.

In some places in the veins, and even in the pyritic blanket ore bodies, chalcopyrite forms irregular streaks through the massive pyrite. These streaks are not fracture fillings and appear to be a feature of the original ore. An unusual occurrence of this kind was found on the third level of the Henriett-Maid mine. In this mine a body of sulphides extended from the Parting quartzite through the White limestone as far down as the Lower or Cambrian quartzite. The upper 30 feet consisted of a mixture of sphalerite and pyrite. The next 10 to 12 feet consisted of pyrite containing about 30 ounces of silver to the ton. The third layer, 20 feet thick, consisted of pyrite containing 15 ounces of silver to the ton. Beneath this was a mass of solid pyrite 80 feet thick containing streaks of chalcopyrite and a higher silver content than either of the two layers above.

Chalcopyrite was present in the high-grade silver ores found in the quartzite in the lowest levels of the Tucson mine, and was there in part intergrown with zinc blende and galena, though for the most part it was later than the blende and earlier than the galena. It

[44] U. S. Geol. Survey Mon. 12, p. 599, 1886.
[45] Idem, p. 602.
[46] Idem, p. 616.
[47] Butler, B. S., Occurrence of complex and little known sulphates and sulpharsenates as ore minerals in Utah: Econ. Geology, vol. 8, p. 313, 1913.

[48] Hillebrand, W. F., and Penfield, S. L., Some additions to the alunite-jarosite group of minerals: Am. Jour. Sci., 4th ser., vol. 14, p. 213, 1902.

is likewise present in much of the ore from the White limestone throughout a large part of the Iron Hill area. In the shoots of mixed sulphide ores between the fourth and eighth levels of the Tucson mine chalcopyrite and its alteration products are localized in those parts of the Tucson reverse fault where siliceous gangue is prominent.

It is difficult to determine conclusively whether the cholcopyrite in these places is all hypogene or in part supergene; but no evidence strongly suggestive of its supergene origin has been found. It is relatively abundant in the lodes where descending waters have been active; but in such places it is so tarnished as to resemble bornite and is commonly coated with chalcocite. Elsewhere in the same lodes where there is no evidence of alteration by descending waters chalcopyrite is irregularly distributed in the interstices among grains of pyrite and zinc blende. It is therefore believed that the lode was more permeable and subject to alteration where chalcopyrite was abundant, rather than that both chalcopyrite and chalcocite were formed by supergene waters.

TETRAHEDRITE

The sulphide ores from the Leadville district, in striking contrast to those from southwestern Colorado and many other of the Colorado districts, contain little tetrahedrite ($Cu_8Sb_2S_7$). The mineral has been observed in one of the veins of the Ibex mine in small tetrahedral crystals, forming drusy linings in vugs in pyrite and chalcopyrite. Light-gray minerals reported as tetrahedrite have been found on Breece Hill in considerable quantity, but careful examination has generally proved that they are bismuth minerals, either kobellite, lillianite, or some undetermined sulphide containing bismuth and antimony. For example, specimens of supposed gray copper found in the Ibex No. 4 shaft proved to contain high percentages of bismuth but no copper. The tetrahedrite that has been identified is usually rich in silver and is presumably the argentiferous variety, freibergite.

SUPERGENE MINERALS

IN THE OXIDIZED ZONE

NATIVE COPPER

Metallic copper is occasionally found in the oxidized ores, usually associated with clay, and appears to have been precipitated from sulphate solutions by the chemical action of the clay. It was found on the fifth level of the Ibex mine in branching, irregular masses, some of considerable size, ramifying through the moist, plastic clay. It has also been found as thin flakes in oxidized ores, notably in Iron Hill.[49] It has never proved of commercial importance.

[49] Blow, A. A., Am. Inst. Min. Eng. Trans., vol. 18, p. 168, 1890.

CHALCANTHITE

The blue hydrous sulphate of copper, chalcanthite ($CuSO_4.5H_2O$), is found in considerable quantity in many of the mines of the district. It is usually found in the uppermost portions of sulphide and partly oxidized ore bodies. The mineral there occurs as scattered fibrous grains mingled with oxides and residual grains of sulphide. It also forms stalactites hanging from the roofs of drifts and stopes driven along veins.

This mineral is now forming in many places, and it is probably deposited in workings from which the water has been largely drained by artificial means. After the water has been pumped out of the mine surface waters passing down through the oxidized zone may become saturated with copper sulphate and, upon reaching an opening where they may partly evaporate, deposit the sulphate. Chalcanthite in commercial quantity was found in the Ibex mine. (See pp. 260, 268.)

MALACHITE

Malachite ($CuCO_3.Cu(OH)_2$) occurs sparingly in the oxidized zone of the Leadville district, being found partly as films and crusts in fractured porphyry and partly mingled with manganese and iron oxides in the upper portions of the oxidized ores. It is perhaps one of the least common of the oxidized minerals in the district, and its rarity is surprising in view of the abundance of limestone and the degree to which this rock has been permeated by oxidizing waters.

AZURITE

The blue basic carbonate of copper, azurite ($2CuCO_3.Cu(OH)_2$), is even more uncommon than malachite. It is occasionally found in small quantity in the uppermost portions of oxidized ores, particularly in the lodes. It occurs very rarely in the blanket ores.

CHRYSOCOLLA

Chrysocolla ($CuSiO_3.2H_2O$), the hydrated silicate of copper, although rare in the Leadville district, is more common in the oxidized ores than the carbonates azurite and malachite. It fills irregular cavities in masses of limonite and manganese oxides, where it generally ranges from bluish green to deep green.

IN THE SULPHIDE ZONE

CHALCOCITE

Chalcocite (CuS) has never been identified in Leadville as a constituent of the unaltered primary ore, but it is one of the most constant constituents of the enriched sulphide ores, where it occurs in two ways—as a thin sooty film coating cracks and fractures in the other sulphides, especially chalcopyrite and pyrite; and as a gray metallic-lustered coating on fragments of chalcopyrite and pyrite or a filling in the fractures of pyritic ore.

The sooty variety of chalcocite is by far the more common. It resembles the black oxide of copper, melaconite or tenorite, but chemical tests verify its identity as chalcocite. It is particularly well developed in the lodes where descending waters have been able to penetrate to the greatest depths reached by the mines and have been confined in their action to a small mass of ore.

It is probable that the larger portion of the copper in the ores of the Breece Hill area and in those along the Tucson-Maid fault is present as chalcocite, although chalcopyrite also is an abundant constituent.

The manner in which the chalcocite occurs in the pyritic or other sulphide ores depends upon the number and distribution of the fractures. In some places the entire mass of ore is slightly shattered and is permeated by chalcocite, which not only fills the fractures but also accumulates as coatings on the walls of vugs or cavities in the original ore. In other places the fractures are few and usually larger. An occurrence of this kind was seen in the third level of the Greenback mine, where a flat blanket body of nearly pure pyrite was intersected by narrow vertical veinlets of chalcocite. The average content of copper in this body was 0.5 per cent. The increase in copper is generally greater where chalcocite is disseminated throughout masses of pyrite.

In the lower levels of the Penn mine chalcocite formed a stringer along the central and more cavernous part of the lode. The lode contained 8 per cent of copper in its richest part and was worked for copper and gold until the chalcocite diminished, in depth, to an insignificant quantity. The gold content decreased with that of copper. A similar occurrence was found in one of the veins on the tenth level of the Ibex mine, where the maximum content of copper was 10 per cent.

SILVER MINERALS

IN THE HYPOGENE AND SUPERGENE SULPHIDE ZONES

Although practically all the sulphide ores that occur in the Leadville district carry greater or less quantities of silver, definite recognizable silver minerals are rare. The argentiferous variety of tetrahedrite—freibergite—and certain of the ruby silver minerals have been found but are so scarce that they may almost be disregarded. The intergrowth of argentite, bismuthinite, and galena, formerly called schapbachite, argentiferous lillianite, and argentiferous kobellite, have formed rich ore in a few places, as in the lowest levels of the Tucson mine; but with these exceptions the silver is concealed in or among the common sulphides, probably in the form of argentite.

ARGENTITE

Argentite (Ag_2S) is rarely if ever visible in the common sulphide ores of the district, although it is doubtless present in close association with galena and with pyrite in the pyritic and siliceous silver ores.[50] It is found in considerable quantity, however, in the rich silver-bismuth ore such as was mined from large cavities in the Cambrian quartzite in the Tucson mine. There it is microscopically intergrown with bismuthinite and galena, in an outer crust an inch or more thick covering an inner crust of coarse-grained galena, which in turn covers a mixture of zinc blende and pyrite. The outer crust and in places the inner crust have a spongy appearance.

Argentite also occurs in the oxidized ores as minute specks in cerusite which produce a dark discoloration and account in some degree for the silver content of lead carbonate ore. Argentite is also reported by Blow as present in the residual nodules of galena that occur in the lowermost portions of the oxidized zone on Iron Hill.

IN THE OXIDIZED ZONE

CHLORIDES, BROMIDES, AND IODIDES

Silver in the form of bromide, chloride, and to a small extent iodide is present in the oxidized ores throughout the district. Locally these minerals are visible, but for the most part they are microscopic and their presence is disclosed by chemical analysis. The material termed "chlorides and bromides" by miners usually consists largely of yellowish basic ferric sulphates and green or blue films of copper carbonate accompanied by enough microscopic silver chlorobromide to yield high assays. The prevailing varieties are the green chlorobromide embolite [Ag(BrCl)] and the colorless chloride cerargyrite ($AgCl$), each of which contains a very small amount of the iodide molecule. Emmons stated that the chloriodide was also present in less quantity and mentioned minute yellow crystals of the iodide, iodyrite (AgI), in the Chrysolite mine. Brilliant yellowish crystals along joints in lead carbonate ore were found in the Weldon mine but not analyzed. As no additional noteworthy data on these minerals were obtained during the second survey, the following paragraphs embody the descriptions of Emmons, Hillebrand, and Guyard in the Leadville monograph[51] and of Ricketts in his study of the ores.[52]

The mineral embolite is invariably light greenish, soft, and sectile and does not change color on exposure to light. It occurs in scales and plates, as single grains or aggregates of such grains, and as rough crystalline coatings on the walls of crevices. The crystalline structure can be seen through a magnifying glass.

[50] Nissen and Hoyt (Econ. Geology, vol. 10, pp. 172-179, 1915) have shown that the silver in argentiferous galena is usually present as microscopic argentite, though it may also occur as tetrahedrite or native metal. See also Finlayson, A. M., Econ. Geology, vol. 5, p. 727, 1910.

[51] U. S. Geol. Survey Mon. 12, pp. 376, 548-549, 600-601, 619-620, 1886.

[52] Ricketts, L. D., The ores of Leadville, pp. 27, 30-38, Princeton, 1883.

It is present in ore of several varieties—hard siliceous matter with numerous intersecting joints and crevices, yellow basic iron sulphates, granular lead carbonate, and locally lumps of decomposing galena. Specimens of carbonate of lead have frequently been found containing 5 to 10 per cent of silver, largely present as chlorobromide. Only a few pounds of such rich ore have been found at any one place, and rarely do many tons from one shoot average more than 100 ounces to the ton.

Lumps of chloride weighing a few ounces have frequently been found, but very few have weighed more than a pound. Emmons mentioned a mass from the Chrysolite mine that weighed more than 100 pounds.

The three analyses given below illustrate the range in chemical composition of typical chloride ores relatively free from other minerals. Nos. 1 and 2, from the Robert E. Lee and Amie mines, respectively, represent the pale-green mineral generally called embolite, and No. 3, from the Big Pittsburgh mine, represents colorless material that is practically pure cerargyrite.

Analyses of typical chloride ores

	1	2	3
Chlorine	13. 78	9. 80	99. 925
Bromine	85. 63	89. 99	None.
Iodine	. 59	. 21	. 075
	100. 00	100. 00	100. 00
Equivalent:			
Silver chloride	21. 59	15. 75	99. 966
Silver bromide	77. 99	84. 09	None.
Silver iodide	. 42	. 16	. 034
	100. 00	100. 00	100. 000

In analysis 1 the proportion of the chloride to the bromide is 4:11; in analysis 2 it is 1:4. In order to determine the relative proportions of chlorine, bromine, and iodine throughout the district, Guyard analyzed a mixture of the lead fumes collected in the dust chambers of eight smelters with the following results:

Silver chloride, 89.10; equivalent to chlorine, 82.45.
Silver bromide, 10.45; equivalent to bromine, 16.83.
Silver iodide, 0.45; equivalent to iodine, 0.72.

NATIVE SILVER

Native silver is found at many places in the oxidized ores of the Leadville district. Although greatly subordinate to the chlorides, it is much more common than was supposed during the first survey. It is present in the blanket ores and less abundantly in the lodes. In a few places it is sufficiently abundant to constitute the principal silver-bearing mineral of the ore.

The native silver occurs both as wire silver and as small plates, scales, or flakes, scattered through the gangue or country rock. It is found in cavities in sulphides, where it has probably been precipitated by reaction between the sulphides and descending waters. The wires are generally small, but some attain lengths of half an inch or more, with striations parallel to their elongation. Some specimens of siliceous ore are formed of bluish cavernous jasperoid in which plates of native silver from 3 to 10 millimeters in diameter are profusely disseminated. To a minor degree the scaly silver is partly coated with thin bluish tarnish, presumably due to the presence of a small portion of sulphide on the outside of the mineral.

NATIVE GOLD

Native gold has been found in varying quantity in many of the Leadville ores. Although most of the ore classed as gold-silver or gold-copper ore, whether primary or altered, contains gold only in microscopic or submicroscopic grains, gold in coarse flakes and wires has been seen in the enriched parts of several of the lodes and closely associated blanket ore bodies in the eastern part of the district, notably in the Ibex, Garbutt, Winnie-Luema, Big Four, Colorado Prince, Great Hope, Printer Boy, and Lilian (Florence) mines.

It has also been found in the original sulphide ore of the London mine and other properties on the east slope of the Mosquito Range and may therefore be expected locally in similar ores within the Leadville district. No native gold has ever been observed in the ores of the Iron Hill or Downtown districts, even in the famous "gold ore shoot"[53] and the rich gold-silver ore on the lower levels of the Tucson mine.

In the placers gold was present as irregular flakes and nuggets. No distinctly crystalline gold has been seen or reported from any of the deposits.

In the Ibex mine gold is reported to have occurred in much of the ore containing considerable zinc blende. A specimen of ore seen in the office of the Ibex Co. contains crystals of sphalerite coated with films of gold. Irving noted several similar occurrences in the Lake City district, Colo. A specimen collected by J. W. Furness[54] from a prospect 10 feet deep about 6 miles northwest of Alma, at an altitude of 13,000 feet, consists of sphalerite, galena, and quartz cutting quartzite, and the sphalerite contains several streaks or flakes of gold. Much of the gold lies in cleavage cracks or suggests an imperfect zonal arrangement parallel to faces of sphalerite crystals.

Wire and leaf gold occurred very abundantly in a seam of sulphide which was found on the sixth level of the Ibex about 200 feet south of the Big Four shaft and which was associated with certain highly siliceous ores interbedded with black "Weber shales." Some of the richest ore found in the Ibex mine was taken from this locality. The oxidized siliceous ore in one of the stopes above the third level of the same

[53] Blow, A. A., op. cit., p. 168.
[54] Presented to U. S. Geol. Survey; No. 79 in collection of polished sections of ores.

mine contained a small but remarkably rich seam of leaf and wire gold mingled with decomposed silicified porphyry. Sixteen sacks mined from this seam carried more than 50 per cent of gold. In a specimen from this locality, seen in the office of the Ibex Mining Co., the gold occurs in a seam of compact jasperoid between limestone and porphyry. The jasperoid is stained deep brown by iron, has a conchoidal fracture, and contains sheets of gold in the joints. Some of these sheets are from 1 to 2 inches across. The gold is pure yellow and 0.860 fine. Another specimen in the company's office, from the sixth level of the Ibex mine, shows a large cluster of zinc blende and pyrite crystals which form a coating half an inch thick on a quartz seam. The quartz, partly stained by oxidation, shows many irregular openings which contain free gold, mostly in long wires but partly in leaf-like plates.

Native gold occurs also in the oxidized zone in some of the lodes that penetrate porphyry. In the No. 7 vein of the Ibex mine it occurs on the tenth level, at the junction of the oxidized and the sulphide ores, as thin leaves on sheeting planes in the porphyry. It formed some rich ore in the Hahnewald stope. Gold has been found abundantly mingled with the oxides and to a greater extent with the partly oxidized sulphides in the southern part of the Winnie-Luema lode. Some of the ore here ran as high as 100 ounces to the ton in gold, and leaf and wire gold occurred in considerable quantity. The blanket ores of the Florence (Lilian) mine carried large quantities of native leaf gold on a narrow contact between the limestone and the overlying White porphyry. The "contact matter" or "vein material" consisted of kaolin or a similar clay in which the native gold was disseminated. Gold also occurred in narrow seams which extended up from the contact for 10 feet or more into the porphyry. Four hundred pounds of ore from one of these seams yielded $10,000. Small quantities of similar rich ore, or "metallics," averaging less than 1 ton a year, have been shipped annually from the Breece Hill area. (See p. 130.)

According to information obtained by Emmons[55] the gold in the Great Hope mine was found in iron-stained "vein material" and Parting quartzite; but the character of the material on the dump as well as the surprisingly small thickness, 60 feet, reported for the Blue limestone led him to suggest that the matrix was jasperoid rather than quartzite. A sample taken from the mine by Tom Gilroy in 1923 consisted of iron-stained jasperoid containing a few visible flakes of gold and a few small vugs lined with pyromorphite. The ore produced in the early days, however, contained some very coarse gold. It is said that between 400 to 500 tons of siliceous gold ore, averaging 1½ ounces of gold and 4 ounces of silver to the ton, was mined at that time, and that one lot of 3,000 pounds yielded 31 ounces of gold to the ton.

The downward concentration of gold in the lodes and related blankets is attributed by W. H. Emmons[56] to the presence of considerable manganese in the ores and wall rocks and of alkaline chlorides in the supergene waters. Reaction between the chlorides and manganese oxide, according to this view, liberated chlorine, which dissolved gold and carried it downward until it was precipitated by contact with sulphides particularly sphalerite, or by ferrous sulphate or some other precipitating agent in the ground water. Where sulphide ore thus enriched in gold has been later subjected to oxidation the coarse gold has resisted re-solution to a considerable extent and remained as residual flakes or wires in the soft, iron-stained siliceous gangue.

This residual gold is the evident source of the placer gold in California Gulch and its tributaries. In spite of the short distance between the placers and their source the fineness of the gold was considerably increased during the transfer. For example, Emmons stated that the placer gold at the mouth of Nugget Gulch was worth from $17 to $19 an ounce, whereas that from the veins in the Printer Boy mine was worth only $15 an ounce.[57] As the placer deposits had been exhausted long before Emmons first visited the district, no further details concerning the physical characteristics of the placer gold could be obtained.

It is significant that California Gulch was not scoured by ice during the last stage of glaciation. Water escaping into it from the side of the Iowa Gulch glacier at the east and west ends of Printer Boy Hill aided in the removal of fine rock débris and in the concentration of gold. The absence of placers in South Evans Gulch, which was glaciated, is in marked contrast. Material eroded from the gold deposits in the northern part of Breece Hill must have been washed into that gulch but was later removed by the glacier.

Native gold has been found in the "lake beds" and in the glacial moraine material far out on the eastern slopes of the Arkansas Valley. Angular native gold was found in a trench in such material in the center of sec. 22, T. 9 N., R. 80 W.

BISMUTH MINERALS

IN THE SULPHIDE ZONE

BISMUTHINITE

Bismuth in small quantities is a rather constant constituent of a large part of the sulphide and oxidized ores of Leadville. Its presence is shown by the analyses of ores on pages 197 and 230 (compare Mon. 12, p. 606) and in analyses of chamber and flue dust, which

[55] U. S. Geol. Survey Mon. 12, pp. 500-501, 1886.

[56] Emmons, W. H., Am. Inst. Min. Eng. Trans., vol. 42, pp. 3-73, 1912.

[57] U. S. Geol. Survey Mon. 12, p. 516, 1886.

contained from 0.01 to 0.05 per cent of metallic bismuth.[58] Bismuthinite (Bi_2S_3) is the only primary bismuth mineral whose identity has been established. Kobellite, lillianite, and schapbachite have also been reported, but most specimens that have been studied have proved to be microscopic intergrowths of bismuthinite and other sulphides. (See pls. 53, *A–C;* 54, *C, D.*) A few have not been satisfactorily identified. It is doubtful if bismuthinite has been found in the ores of Leadville except in these intergrowths, or with argentite, as microscopic inclusions in galena. One of these intergrowths was found coating other sulphides in the rich silver ore that lines cavities in the Cambrian quartzite of the Tucson mine and proved to be very similar to the "lillianite" in the Lilian mine. Both of these occurrences have been studied by Laney and identified as intergrowths of bismuthinite, argentite, and galena.

"Kobellite" from the mines of the Lilian Mining Co., Printer Boy Hill, was described by H. F. and H. A. Keller.[59] It occurs in nodules of various sizes, the largest 7 feet in diameter, which are usually more or less oxidized. The fresh material has a fine-grained structure, steel-gray color, and dark streak. Three analyses were made, with the results given in columns 1 to 3, below.

Analyses of bismuth minerals

	1	2	3	4	5	6
Bismuth	32.62	33.31	33.89	37.11	11.6	33.23
Lead	43.94	44.28	44.03	36.90	20.0	48.21
Silver	5.78	5.49	5.72	8.58	6.06	Undet.
Copper	Trace.	.03	Trace.	.08	1.7	1.74
Zinc				Trace.	.6	
Iron				.18	20.6	Trace.
Sulphur	15.21	15.27	15.19	15.18	28.0	15.73
Antimony						.24
Gangue:						
Lime	.15	.14	.17	.03	1.4	
Insoluble				1.33	6.0	
	97.21	98.52	99.00	99.39		99.15

1–3. "Kobellite" from Lilian mine.
4. "Lillianite" from Ballard mine, R. C. Wells, analyst.
5. "Silver ore" from Cord mine, collected by Mr. Hartwell, manager. Analysis by J. W. Hawthorne, chemist of Empire Zinc Co., 1923.
6. Homogeneous, fibrous radiating lillianite from Gladhammer, Sweden. E. W. Todd, analyst.

The bismuth determinations are regarded by the authors as somewhat low, and in Nos. 2 and 3 there was probably also a loss of lead. The formula derived by the Kellers from their analyses was $3PbS+Bi_2S_3$. They remark that the mineral is interesting, inasmuch as it contains high percentages of silver, whereas antimony is entirely absent. Kobellite, however, according to Dana's "System of mineralogy," contains antimony. In 1889 H. F. Keller[60] described under the name kobellite a mineral for which he deduced the formula $2(Pb,Ag_2,Cu,Fe)(Bi_{2/3}Sb_{1/3})_2S_3$. At the close of this article he suggested that the name lillianite be used for the lead-bismuth-silver mineral which occurs in the Lilian mine and contains no antimony. For this he gave the formula $3(Pb,Ag_2)S.Bi_2S_3$. It thus appears that the so-called kobellite from the Leadville district is in reality "lillianite." An analysis of the "lillianite" from the Ballard mine by R. C. Wells is given in column 4 of the table and may be compared with the three original analyses of the ore from this mine in columns 1 to 3. A very similar analysis is that of fibrous radiating lillianite ($3PbS.Bi_2S_3$) from Gladhammer, Sweden, given in column 6. This material was examined microscopically by Walker and Thomson and found to be homogeneous. It thus appears that a compound of this composition may exist, but the "lillianite" from the type locality in the Leadville district is a mixture of three minerals.

The "schapbachite" of Leadville, which also consists of sulphides of lead, silver, and bismuth and was reported by Guyard[61] to be present in the Florence (Lilian) mine, is evidently, like "lillianite," a mixture of sulphides. The original specimen from Schapbach, Bavaria, was so considered by Sandberger,[62] and a specimen examined by Murdoch[63] proved to be a mixture of two undetermined minerals.

Similar material has been produced from the Cord mine and is represented by analysis 5. The specimen analyzed was presented by Mr. Hartwell, manager of the York tunnel and related properties, to J. A. Ettlinger, who examined it microscopically and reported no visible intergrowth. Its megascopic minerals included siderite, pyrite, and chalcopyrite scattered through a dark-gray fine-grained metallic material, which is a mixture of lead, silver, and bismuth sulphides. It contained 1,783 ounces of silver and 0.40 ounce of gold to the ton.

IN THE OXIDIZED ZONE

Bismutite ($Bi_2O_3.CO_2.H_2O$; exact composition doubtful) was found by Irving in the high-grade bismuth ores in the Ballard mine, and tests of oxidized ores prove the presence of bismuth, probably as bismutite, in several mines. In the Ballard mine bismutite occurs in irregular pockets and lenses or lenticular masses 6 inches to a foot or more in thickness, which are mingled with a yellowish, ocherous gold ore. The bismuth carbonate is here a light-grayish earthy massive material with a greenish cast. It is extremely heavy and is reported by the managers to have yielded 80 per cent of bismuth. In the laboratory it yielded strong tests for bismuth and carbon dioxide but contained no lead nor other metals. The oxidized ore from the Florence mine also contained large quantities of bismuth, probably in the form of bismutite. Small

[58] Guyard, Antony, U. S. Geol. Survey Mon. 12, pp. 712-716, 1886.
[59] Am. Chem. Soc. Jour., vol. 7, p. 7.
[60] Zeitschr. Krist. Min., vol. 17, p. 67, 1889.
[61] U. S. Geol. Survey Mon. 12, p. 616, 1886.
[62] Sandberger, F., Neues Jahrb., p. 221, 1864.
[63] Murdoch, J., Microscopical determination of opaque minerals, p. 38, New York, 1916.

unaltered kernels of "lillianite" are frequently found in the bismutite masses. The chemical tests show that the bismutite contains little or no silver.

Lanarkite is described on page 164 under oxidized lead minerals.

ARSENIC MINERALS

Arsenopyrite is described on page 151 under iron minerals. Native arsenic is mentioned by Dana as having been found in the ore deposits of the Leadville region, but this statement evidently refers to a mineral reported by Clarence Hersey to have been found in a silver-gold mine "5 or 6 miles west of Leadville." The arsenic occurred in nodular concretionary forms and was very brittle.[64]

TUNGSTEN MINERALS

Wolframite and scheelite have been found in small scattered amounts in the siliceous pyritic gold ore of the South Ibex stockwork in Breece Hill.[65]

Wolframite tends to occur in dull brownish-black masses which terminate abruptly in the vein against pyrite and quartz, or against scheelite. These masses contain many small cavities, where some faces and angles of wolframite crystals have developed, but these are generally so corroded that no adequate idea of the crystal form can be gained. In one specimen, however, there is an isolated crystal over half an inch long, projecting into a small vug. The crystal is of flat rhombic or wedge-shaped outline. The broad faces are those of the clinopinacoid *b* {010} as they are parallel to the perfect clevage. The narrow faces are the orthopinacoid *a* {100} and probably the steep dome *t* {102}. No other faces are represented on this crystal. Some faces that are not corroded are rather strongly striated, the striations probably lying parallel to the prism zone. The hardness is apparently as low as 3, as even glistening surfaces are scratched by calcite. This low value may be due in part to the corrosion of the mineral but may also be characteristic of the manganese tungstate hübnerite in contrast to the iron tungstate ferberite, whose hardness is given by Dana[65a] as 5 to 5.5. The luster, though dull for the masses as a whole, is submetallic on cleavage surfaces and uncorroded crystal faces. The color, though prevailingly brownish black, is dark reddish on thin, translucent cleavage flakes. Thin flakes under the microscope are red to yellow. The streak is chocolate-brown to reddish brown. No quantitative analysis of the mineral has been made, but qualitative tests prove it to contain considerable amounts of manganese and tungsten. These results agree with the low hardness (3) and partial transparency in indicating that the mineral belongs to the hübnerite or manganese tungstate part of the wolframite series, as contrasted with ferberite, the iron tungstate, which is harder (5) and opaque.[65b]

The wolframite masses contain numerous small grains of pyrite, some of which are intimately intergrown with wolframite. The intergrowths consist of bladed or tabular individuals of wolframite in diverging groups and separated one from another by thin layers of pyrite. Wolframite comprises two-thirds to three-fourths of the intergrowth. Wolframite is also intergrown on a small scale with scheelite in the central parts of certain scheelite crystals.

The scheelite occurs in localized aggregates, some closely associated with masses of wolframite, others with pyrite and quartz. In some places massive scheelite is surrounded by massive pyrite; in others scheelite crystals, growing on quartz or pyrite crystals, line vugs. The crystals are imperfect doubly terminated pyramids of the tetragonal system, truncated by narrow pyramid faces of the second order. Pyramidal cleavage surfaces are distinct though not prominent. The hardness lies between 4 and 5, the luster is resinous to adamantine, and the color is rather light brown in the larger crystals to pale yellowish in small translucent grains. The crystal surfaces show no conspicuous effects of corrosion. They are free from intergrowths other than those with wolframite already mentioned and grow upon all the other minerals in the veins.

The relations, already described, of the vein minerals to one another indicate that while there were overlaps in the periods of growth, the general order of deposition was as follows: (1) Sericite, quartz, and pyrite in parallel growth, the sericite forming only at the beginning of the stage; (2) pyrite and wolframite, the latter predominating; (3) very little pyrite, a little wolframite, and abundant scheelite, the scheelite continuing to form after the other two minerals had ceased. According to Hess[65c] this seems to be the usual paragenetic relation of scheelite to wolframite, or ferberite, in tungsten veins.

GANGUE MINERALS

QUARTZ

Quartz (SiO_2) occurs in greater or less amount in nearly all the sulphide and oxide ores of the district. It is present in lodes, blanket deposits, and contact-metamorphic ores, and is developed with sericite on a microscopic scale as an alteration mineral in the igneous rocks. It varies greatly in amount, as may be seen from the silica percentages in the table of ore analyses given on pages 193–200.

The percentage of quartz in the sulphide ores ranges from very high to almost zero. It is generally least

[64] Am. Jour. Sci., 3d ser., vol. 39, p. 161, 1890.

[65] Fitch, R. S., and Loughlin, G. F., Wolframite and scheelite at Leadville Colo.: Econ. Geology, vol. 2, pp. 30-36, 1916.

[65a] Dana, E. S., System of mineralogy, 6th ed., p. 983.

[65b] The chemical properties of hübnerite and scheelite described in this paper have been verified by Frank L. Hess, and the physical properties by W. T. Schaller, both of the U. S. Geological Survey.

[65c] Hess, F. L., and Schaller, W. T., Colorado ferberite and the wolframite series: U. S. Geol Survey Bull. 583, p.12, 1914.

in the magnetite-pyrite ores and highest in certain pyritic sulphide bodies. Throughout the eastern part of the district the ores are much more quartzose than in the western part, but exceptions occur in both parts of the district.

In some of the ores, both sulphide and oxide, the quartz occurs as linings of cavities, and in places shows minute clear, glassy, prismatic crystals which are generally free from inclusions. Definite crystals of quartz are less common in the massive sulphide ore. Some of the oxidized ores of the Ibex mine consist of a loose sandy aggregate of small quartz crystals mingled with oxides of iron and ocherous minerals. Very fine colorless crystals of quartz have been found coating calamine crystals in low-grade oxidized zinc ore from the old Mikado dump. Microscopic quartz has been found in parallel growths with brown iron oxide and in agatelike growths lining vugs in the iron oxide. These quartz crystals, together with the chalcedony and opal, were among the latest minerals to be deposited in the oxidized zone.

There is no difficulty in distinguishing the quartz accompanying sulphide ores from the original quartz of the country rocks. The quartz of the sulphide ores is seen under the microscope to consist of distinct crystals and irregular grains, comparatively clear and free from strain effects, whereas the original quartz of the country rocks shows marked strain and characteristic rows of minute inclusions. Much of the quartz of the ore bodies contains inclusions in relatively small quantity, which in some crystals are arranged parallel to the crystal boundaries. A few of these inclusions appear to be fluid, but most of them are indeterminate.

In both blanket deposits and lodes the quartz is more usually present as irregular anhedral grains, which make up a dense aggregate, in part sufficiently coarse to resemble quartzite and in part so extremely fine grained as to have received the name of flint or jasperoid. This flinty variety is one of the commonest products of siliceous replacement in the Leadville district. It occurs in nearly all the mines in greater or less amount. In many places where fissure veins pass through limestone the limestone adjacent to the fissures has been altered to jasperoid. In the Fryer Hill and Downtown areas there are extensive layers of the jasperoid or flint which carry practically no valuable metals and extend far beyond the limits of profitable mining. Here and there the quartz in the jasperoid masses has a coarser texture and is filled with minute cavities lined with quartz crystals. This quartz has a grayish appearance and may be rich both in gold and silver.

In texture the jasperoid usually shows clearly its development by replacement from the limestone, for it exhibits all gradations from anhedral grains to perfectly developed prismatic quartz crystals. These crystals are usually arranged in interlocking aggregates so that triangular cavities are observed between them. Where a rock has been completely altered to jasperoid, as in some varieties of siliceous ore from the Resurrection mine (see pl. 55, *A*, also analysis on p. 321), the anhedral grains lie among the completely developed crystals. Frequently a perfect crystal of quartz will be seen embedded in an anhedral grain. This structure shows that the development of perfect quartz crystals is the first step in the process of silicification. As the process continues the limestone around the earlier-formed crystals is itself replaced, and the result is an interlocking aggregate of perfectly bounded quartz crystals embedded in a groundmass composed of anhedral grains representing the later stages in the replacement of the original limestone.

CHALCEDONY AND OPAL

Clearly recognizable chalcedonic silver is extremely rare or absent in the primary ores of Leadville. Its absence is significant, as chalcedony is one of the characteristic forms of silica found in the relatively low-temperature (epithermal) vein zone, whereas the Leadville ores were formed at higher (mesothermal and hypothermal) temperatures.

Opal ($SiO_2.nH_2O$) and chalcedony occur in considerable quantities as alteration products in porphyry and in ore bodies of the Leadville district. They are believed to have been derived from the decomposition of silicates either in country rocks or in sericite masses within ore bodies in the zone of oxidation. In some places they form beautiful opalescent layers a quarter of an inch thick and 6 or 8 square inches in area.

Chalcedony and opal have been found, usually in small amounts, associated with aurichalcite and calamine, in oxidized zinc ores in the Ibex (Little Jonny) and Belgian mines. They form the matrix of cavity or fracture fillings, and the two zinc minerals are embedded in them (pl. 52).

WOLLASTONITE

Wollastonite ($CaSiO_3$), a silicate of calcium, is confined to the contact-metamorphic deposits of magnetite. It has so far been recognized in only one deposit of this ore—that cut in the My Day drill hole at a depth of 350 feet below the surface. It appears here as small whitish irregular masses, ranging from 0.5 to 10 millimeters in diameter, of extremely irregular form and distribution. Its character can not be determined in the hand specimen. Under the microscope it appears as divergent or fibrous aggregates and can be readily identified.

SERICITE (MUSCOVITE AND PARAGONITE)

The name sericite is here used to include fine-grained silky-lustered varieties of muscovite ($HK_2Al_3(SiO_4)_3$)

and paragonite ($H_2NaAl_3(SiO_4)_3$), which appear identical even in thin section. The muscovite is one of the minerals that have been developed most abundantly in the igneous rocks of the Leadville region by the mineralizing waters that have produced the ore deposits. It has been formed by the reaction of these solutions with the feldspars of the igneous rocks, the "Weber grits," the "Weber shales," and certain quartzite beds and is commonly accompanied by calcite and minor quantities of chlorite and epidote.

The distinctly secondary sericite occurs in small microscopic irregular flakes, usually in aggregates, in the igneous rocks; also in soft claylike masses that accompany nearly all the ores. The sericite flakes in the igneous rocks range from an exceedingly minute size up to 1 millimeter or more in length. Where alteration has proceeded very far the porphyries have been changed almost entirely to aggregates of these sericite flakes, with the original quartz for the most part unaffected. (See pl. 55, *C*.) Outlines of feldspar phenocrysts are observable in these thoroughly altered porphyries, but the mineral is entirely changed to a feltlike mass of sericite with probably some minute grains of secondary quartz. In even the less decomposed varieties of porphyry (see pls. 46, *A*; 55, *B*) sericite is abundantly present, as may be seen from their calculated mineral composition on pages 46–51.

In many places sericite, or a very similar mineral, is present in white dense masses that appear identical with kaolin; but the indices of refraction are equal to or slightly lower than those of typical sericite. Some of these masses are plastic when wet and with kaolin and alunite are included under the local term "Chinese talc." (See p. 174, analysis 1.)

In nearly all the veins of the Leadville district a large amount of soft, claylike gouge is mingled with the ore, either as layers of selvage between the ore and the walls or as platelike partings in the interior of the ore mass. Where the fissures are filled with broken rock material this claylike matter is distributed throughout the mass, but with no regularity in its position. When examined microscopically the clayey material proved to consist mostly of finely divided sericite, with little or no kaolin. Its plasticity, however, suggests the presence of some mineral like leverrierite or montmorillonite.

The only indication of paragonite in the Leadville district is in the recalculation of the chemical analysis (p. 154) representing manganosiderite cut by veinlets of quartz, sulphides, and a mineral that appeared identical microscopically with the typical sericite of the altered rocks and lodes but was evidently composed mainly of the soda mica with very little of the potash mica molecule. This occurrence raises a question as to the relative quantities of the two micas in the sericite of the district. The two minerals are so similar optically that the question can be answered only by a great many chemical tests. So far as the chemical analyses of altered igneous rocks indicate (pp. 46–51), the potash variety is by far the more abundant.

CHLORITE

Chlorite ($H_8(Mg,Fe)_5Al_2Si_3O_{18}$) is the most common alteration product of the dark silicates of the intrusive porphyries and pre-Cambrian granite. It is characteristic of the altered rock at some distance from the larger lodes along which the immediate wall rock has been replaced by quartz and sericite. The chlorite in the Cambrian and Parting quartzites may be in part correlated with that in the altered porphyries but for the most part is regarded as a primary constituent of the quartzite.

EPIDOTE

Epidote ($HCa_2(Al,Fe)_3Si_3O_{13}$) is another alteration product in the igneous rocks and is closely related to chlorite and sericite in origin. In some places it is pseudomorphic after the feldspar and may be easily recognized by its yellowish-green color. Occasionally well-formed prismatic crystals have been found in small cavities. Although epidote is regarded as a common mineral in contact-metamorphic deposits, it is inconspicuous in the deposits of this class in the Leadville district.

RHODONITE

Rhodonite ($MnSiO_3$) is present in the lodes of the Ella Beeler group, in Iowa Gulch, in narrow parallel bands alternating with other minerals. No other occurrence of rhodonite in the Leadville district has been found.

SERPENTINE

Serpentine ($H_4Mg_3Si_2O_9$ or $3MgO.2SiO_2.2H_2O$) occurs exclusively as a gangue mineral of the magnetite-pyrite ores in the Penn, Comstock, and Ibex mines. In these ores it is probably the result of the decomposition of a pyroxene (diopside) or an olivine (forsterite). It is most abundantly present in the highly oxidized and hydrated ores from the old surface workings and upper levels of the old Breece iron mine, or, as it is now termed, the Penn mine. It forms a microgranular aggregate through which the magnetite is profusely scattered as minute grains with partial crystalline form. It also occurs in an exceedingly irregular distribution throughout the magnetite, giving a contorted appearance to the rock, as shown in Figure 50.

The serpentine is in part smooth and massive, in part very finely granular. Its usual color varies from whitish to light green, and many of the specimens from the Penn mine are colored red by iron oxide. In some places the massive serpentine is penetrated by thin seams of a very clear white variety of serpentine. No fibrous serpentine has been noted at Leadville.

FIGURE 50.—Serpentine irregularly distributed through magnetite ore, giving a distorted appearance. Part of the serpentine is stained red by iron oxide

CLAYLIKE MATERIAL

At several places in the oxidized and sulphide enrichment zones there are large masses of white claylike material, commonly referred to as "talc" or "Chinese talc" but containing no true talc. This material is mostly associated with ore bodies; it is probably most abundant along the base of the main sheet of White porphyry and is present along certain other porphyry sheets. It is also prominent in the shaly White limestone close by enriched sulphide ore bodies, as in the Golden Eagle and adjacent mines in Breece Hill, and spots and considerable masses of it have been found within enriched or partly leached sulphide ores, as in the gold-copper ore of the Golden Eagle and the loose-textured ore in the Mikado mine near the Mikado fault. These occurrences within limestone and ore are found on close study to be largely due to the replacement of carbonates, either the original dolomite and calcite of the rock or the manganosiderite disseminated through the sulphides. The masses along porphyry contacts are doubtless due, in part at least, to replacement of the Blue or White limestone, although this relationship was evidently not considered when the contacts in the oxidized zone were most available for study. Other masses form rims around blocks of porphyry and have obviously been derived from them.

Masses of clay, in part heavily stained by iron and manganese oxides, are present between deposits of lead carbonate above and zinc carbonate below. In a few places these masses were stained green by absorbed copper. White, brown, and black clays containing considerable zinc have been described on page 160. The gouge along and within fault zones, some of it white and some colored bluish gray by minute inclusions of pyrite and other opaque matter, may also be considered with this claylike material.

Analyses of white claylike material

	1	2	3	4	5
SiO_2	48.72	43.36	4.55	24.47	27.89
Al_2O_3	34.01	37.78	35.60	38.05	33.79
Fe_2O_3	.56	----	2.26	.93	----
FeO	.66	----	----	.77	----
CaO	----	.22	Trace.	.23	.53
MgO	1.11	.30	Trace.	.30	1.14
K_2O	9.88	Trace.	2.73	2.72	2.83
Na_2O	.67	----	5.28	1.30	1.56
H_2O	4.22	17.95	15.05	16.67	[a] 16.51
SO_3	----	Trace.	34.55	15.48	15.75
	100.03	99.91	100.00	[b] 101.15	100.00

[a] By difference.
[b] Includes 0.23 P_2O_5.

1. Amie mine, in ore body. Ore collection No. 55b.
2. New Discovery mine. Ore collection No. 55a.
3. Big Pittsburgh mine, contact of Gray porphyry. Ore collection No. 56c.
4. Morning Star mine. Ore collection No. 56.
5. Swamp Angel tunnel, contact of White porphyry. Ore collection No. 56b.

This material, according to available analyses, consists of hydrated aluminum silicates and alunite in varying proportions. Of the material represented by the above analyses, No. 1, from the Amie mine, consists mainly of very finely divided sericite. Its calculated mineral composition is sericite 89 per cent (including 5 per cent of the paragonite molecule), chlorite (pennine) 4 per cent, silica 6 per cent, and hydrous iron oxide 0.7 per cent. Hillebrand[66] describes it as grayish white with pearly luster, compact, and very soft, rubbing off on the fingers. It was evidently derived directly from porphyry, as it contained remnants of feldspar crystals, which were removed by washing before analysis. This material was less claylike than the other four samples. Similar material, which under the microscope proved to consist almost entirely of sericite, has been noted in other parts of the district, some of it in unaltered ore, and there are doubtless gradations in composition from such material to material represented by the other analyses.

Material from the New Discovery mine, represented by analysis No. 2, was pure white, veined with manganese oxide, compact, and soft (hardness=2), rubbing off on the fingers when dry. When fresh and moist it had a greenish opaline appearance and was translucent on thin edges but became opaque on exposure. The sample analyzed contained no manganese oxide. After two or three years' exposure to air it still retained 3.36 per cent of hygroscopic water. No further loss of water took place below 160°–170° C., although the

[66] U. S. Geol. Survey Mon. 12, pp. 603–604, 1886.

sample became black owing to the carbonization of organic matter. The analysis shows 0.8 per cent too much alumina and 4.9 per cent too much water to agree with the formula for kaolin but corresponds closely to published analyses of halloysite, an amorphous mixture of alumina, silica, and water. No microscopic description is available to show whether it consists of amorphous or crystalline material or a mixture of both. Similar material was found in the Morning Star and adjacent claims and analyzed by Ricketts.[67]

The material represented by analysis No. 3, from a Gray porphyry contact in the Big Pittsburgh mine, was pure white and resembled the sericite of No. 1. Calculation from the analysis gives soda alunite 67.7 per cent, potash alunite 19, sericite 4.8, kaolinite 1.8, goethite 2.5, free silica 1.6, and excess water 2.66. The minor constituents are arbitrarily chosen in the absence of microscopic data. As the material did not have the hygroscopic properties shown by Nos. 2, 4, and 5, the excess water is presumably distributed in the different minerals.

No. 4, from the Morning Star mine, and No. 5, from the White porphyry contact in the Swamp Angel tunnel, were also white streaked with iron and manganese oxides. The calculated mineral composition of No. 4 is soda alunite 16.7 per cent, potash alunite 23.2, sericite 0.8, kaolinite 51.9, excess alumina 1.9, and excess water 4.0. The excess alumina may be present as diaspore or hydrargillite, as in certain high-alumina clays, or may with the calculated kaolinite be present in an amorphous mixture. The excess water is again strikingly abundant. Hillebrand found only 1.23 per cent of hygroscopic water, and the greater part of the excess is evidently distributed among the different minerals. No. 5, by the same method of calculation, contains 19.9 per cent each of soda and potash alunite, 4.8 per cent of sericite, and 42.8 per cent of kaolin. Instead of excess alumina, it contains 5.8 per cent of excess silica. Excess water amounts to 5.0 per cent, whereas Hillebrand found 4.58 per cent of hygroscopic water. The amount of calculated excess water that can not be definitely accounted for as hygroscopic is greatest in Nos. 2 and 4, where hydrous aluminum silicate is present and alumina is in excess of the kaolin ratio. No. 4, with the greatest excess of alumina, also has the greatest excess of nonhygroscopic water. Hillebrand suggests that lime and magnesia in Nos. 4 and 5 might be present with alumina in indefinite hydrated silicates, but as residual grains and small lumps of residual carbonates have been found in similar white clays in the district, the lime and magnesia may quite as well represent unreplaced particles of the Blue limestone.

[67] Ricketts, L. D., The ores of Leadville, pp. 28–29, Princeton, 1883.

CALCITE

Calcite ($CaCO_3$) is rare as a primary gangue mineral accompanying the sulphide ores but is abundant in much of the oxidized ore. It occurs most commonly in small crystals, lining cavities in ore and gangue, but large and handsome rhombohedrons on cerusite ore from the Evening Star were noted by Ricketts.[68] Many of the oxidized zinc ores and associated iron and manganese ores contain cavities lined with colorless to white flat, disklike rhombohedrons of calcite. These crystals lie with their edges normal to the cavity walls and represent the latest mineral growth in these ore bodies. Crystals of calcite have also been found lining caves in the oxidized zones of many of the mines, and veinlets are present in the oxidized zone.

ARAGONITE AND NICHOLSONITE

Aragonite ($CaCO_3$), the orthorhombic form of calcium carbonate, is confined even more strictly than calcite to the oxidized zone and the walls of drifts and stopes. It is occasionally found in close association with the oxidized zinc ores but has not been noted in direct contact with zinc ore minerals. It forms diverging to spherical radiating columnar aggregates, or groups of such aggregates (pl. 51, *C*), usually if not invariably white. The one occurrence found by the writer formed pockets in brown siliceous iron oxide. So far as its general appearance and mode of occurrence are concerned, aragonite may be mistaken at first glance for calamine; but it lacks the characteristic bladed form of calamine and can further be distinguished by its brisk effervescence in very dilute hydrochloric acid.

The aragonite studied by the writer proved to contain little or no zinc, but a variety containing as much as 10 per cent of zinc ($Ca(Zn)CO_3$) was studied by G.M. Butler, who gave it the name nicholsonite. According to Butler,[69] nicholsonite is identical with aragonite in all but three particulars. The specimens with high percentages of zinc have a higher specific gravity than aragonite, show a decided adamantine rather than a vitreous luster, and have a better cleavage (good pinacoidal and poor prismatic) than pure aragonite. The nicholsonite was found in the oxidized iron-manganese ore in the Blue limestone and was named after S. D. Nicholson, of the Western Mining Co., who brought it to Butler's attention.

DOLOMITE

Dolomite ($CaMg(CO_3)_2$) is present in the leaner ores as unreplaced rock; also as white rhombohedrons

[68] Op. cit., p. 29.

[69] Butler, G. M., Some recent developments at Leadville, second paper, The oxidized zinc ores: Econ. Geology, vol. 8, pp. 8–9, 1913.

lining vugs in sulphides and as small granular masses inclosing sulphide grains. In these occurrences it may be confused with manganosiderite, which is far more abundant. Gradations between the two minerals are common, and they can not be distinguished without chemical analysis or determination of index of refraction.

Dolomite also occurs characteristically as white striped patches in the Blue limestone near ore horizons. These patches consist of roughly parallel streaks of white dolomite alternating with streaks of the Blue limestone. Some of them contain vugs lined with unit rhombohedrons of dolomite. Qualitative tests show the white dolomite to contain little if any more iron than the blue dolomite of the country rock, and the patches are attributed to recrystallization of the rock material and the elimination of its carbonaceous matter. Similar striped patches accompany the ore bodies in the Red Cliff district, to the north, and are aptly termed "zebra rock."

ANKERITE

Ankerite [$(Ca,Mg,Fe)CO_3$] was found by Philip Argall in the Mikado mine in 1919. It filled or lined small cavities in granular zinc blende and was similar to drusy siderite and dolomite in its paragenetic relations. It may be far more abundant than the lack of other known occurrences would indicate, for it so closely resembles both siderite and dolomite in appearance and mode of occurrence that it is easily overlooked. The relation of ankerite to the other carbonates has obviously not been determined.

RHODOCHROSITE

Although the rhodochrosite molecule ($MnCO_3$) is present in practically all the carbonates that form constituents of the primary ores of Leadville, it is very rare as a distinct mineral. It is said to have been found in veinlets in the sulphide ore in the A. Y. and Minnie mine, and it is reported to have been present in considerable abundance in the ores from the Mammoth mine, in Evans Gulch. These occurrences have not been seen and are not supported by chemical analyses; the possibility that the reported rhodochrosite is manganosiderite is therefore not excluded. Authentic rhodochrosite has been reported in considerable quantity in certain of the lodes of the Ella Beeler group and occurs abundantly in the Dinero vein, in the Sugar Loaf district.

BARITE

Barite, or heavy spar ($BaSO_4$), occurs rather sparingly in most of the Leadville district, except in the outlying area around the head of Iowa Gulch and in the Downtown and Fryer Hill areas. In the Iowa Gulch area it is characteristic gangue mineral accompanying quartz, galena, and blende in sulphide ores and quartz and cerusite in the corresponding oxidized ores. In the Downtown and Fryer Hill areas it is frequently found in local irregular masses composed of tabular crystals in divergent aggregates. Single crystals range from half an inch to 2 inches in diameter. These masses have been found mainly in or close by oxidized ore bodies, but their relations to the ores and wall rocks indicate that they were deposited with the original sulphide ore. No well-developed crystals have been found in these masses, but a few small yellow tabular crystals bounded by prism and basal faces were found in vugs in brown siliceous iron oxide from East Fryer Hill. These were clearly of later origin than the iron oxide and must have been deposited during a late stage of the period of oxidation. Some white crystals in vugs in sulphide ore said to come from the Yak tunnel were also seen but gave no indication of secondary origin. These crystals had been mistaken by lessees for cerusite, which they resembled rather closely.

ALUNITE

Although no alunite [$(KNa)Al_3S_2O_{11}.3H_2O$] has been identified by microscopic study, its presence in claylike material is indicated by analyses 3, 4, and 5 on page 174. Owing to the inaccessibility of most of the workings in the oxidized zone during the resurvey, it has not been feasible to gain a quantitative idea of the presence of alunite, or a very definite idea of its mode of occurrence and relations to other supergene minerals.

EPSOMITE

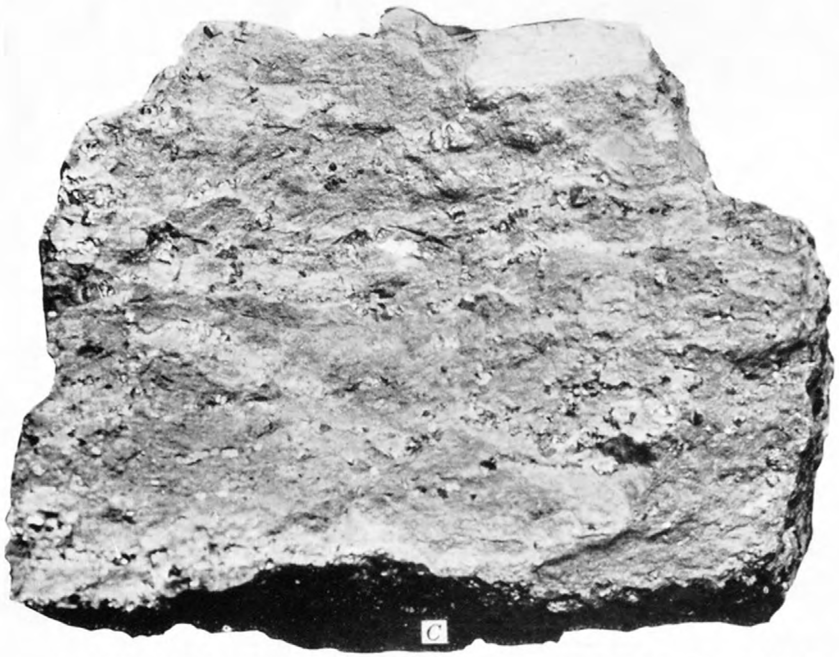
Epsomite ($MgSO_4+7H_2O$) has been found at a number of localities as linings of fibrous material or capillary crystals, along the walls of drifts, both in the oxidized zone and in the sulphides that lie not far below the lower limit of oxidation. The fine, needle-like fibers are in places arranged with their longer axes perpendicular or at a high angle to the wall from which they project, so that they bear a strong resemblance to a coating of frost covering a surface of rock. These crusts, though not rare, are not so common as the other sulphates, goslarite, chalcanthite, and melanterite, all of which have been deposited by the evaporation of descending mine waters.

SULPHUR

Native sulphur is frequently found in the oxidized ores mingled with cerusite and other oxidized minerals. Emmons states that a mass of sulphur 2 feet in diameter associated with a little cerusite was found in a drift extending northward from the north incline in Iron Hill. It was free from iron and had evidently "resulted from the reduction of galena, the lead having been removed in the state of carbonate." [70]

[70] U. S. Geol. Survey Mon. 12, p. 397, 1886

A. THIN SECTION OF TYPICAL SERICITIZED WHITE PORPHYRY IN EARLIEST STAGES OF THE PROCESS
B. CRYSTALS OF SPECULARITE REPLACING DOLOMITE
C. CRYSTALS OF SPECULARITE REPLACED IN PART BY PYRITE OF A LATER PHASE OF MINERALIZATION

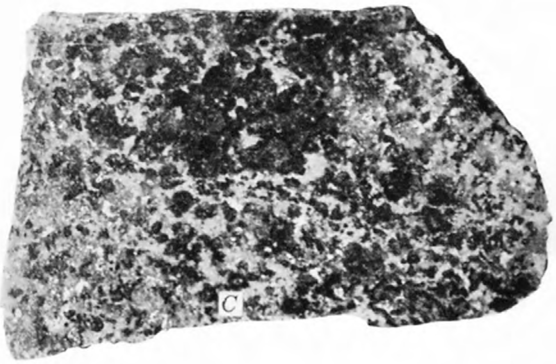


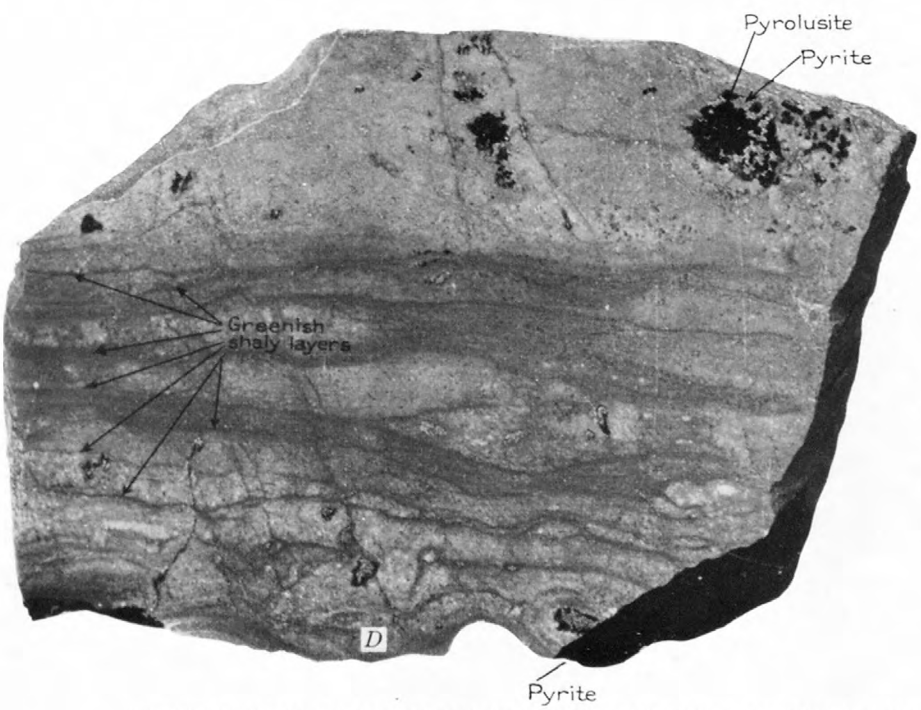
A. MASSIVE MANGANOSIDERITE CUT BY DARK VEINLETS OF SULPHIDES AND QUARTZ WITH A LITTLE SIDERITE

B. FRESH GALENA CRYSTALS TYPICAL OF VUG LININGS IN LEAD SULPHIDE ORES OF CARBONATE HILL AND GRAHAM PARK

C. ALTERED SHALY LIMESTONE IMPREGNATED WITH DARK GRAINS OF MAGNETITE AND LIGHT GRAINS OF PYRITE

D. MANGANESE-BEARING SIDERITE IN LARGE CRYSTALS LINING CAVITY IN LEAD-ZINC ORE FROM BLANKET BODY IN THE EAGLE (IRON MASK) MINE AT REDCLIFF





A. FINE-GRAINED MANGANOSIDERITE CUT BY VEINLETS OF GALENA, PYRITE, AND SPHALERITE

Vugs lined with manganosiderite crystals

B. PYROMORPHITE CRYSTALS FROM OXIDIZED ORE IN IBEX MINE NEAR NO. 2 SHAFT

C. PHOTOMICROGRAPH OF MANGANOSIDERITE ALMOST COMPLETELY REPLACED BY SULPHIDES

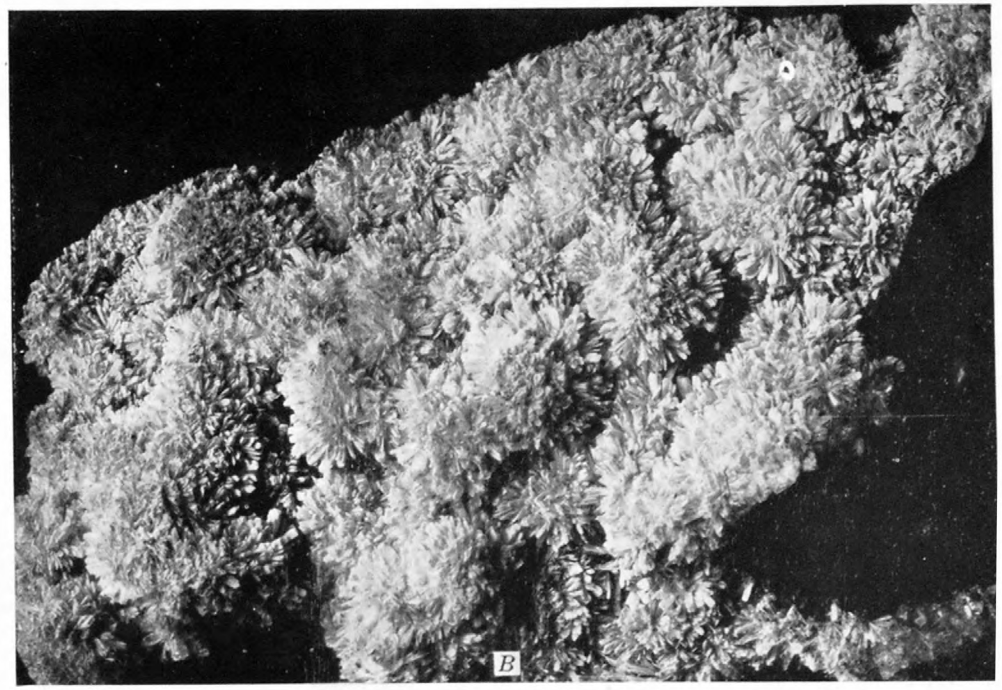
Light-gray areas are manganosiderite; white areas are cavities filled with white kaolin; dark areas are pyrite, galena, and sphalerite; black areas are an unidentified mineral

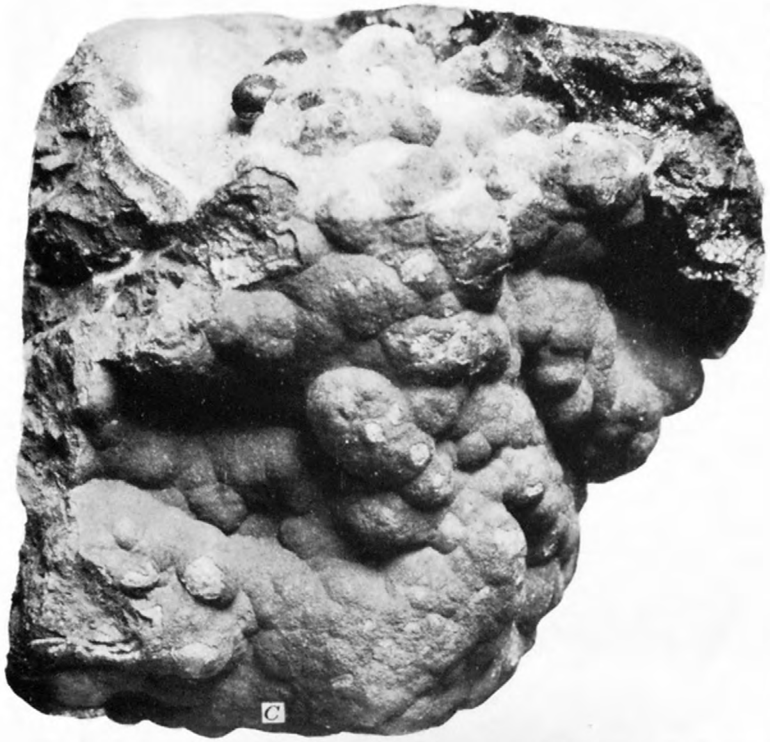
D. MASSIVE MANGANOSIDERITE WITH SHALY LAYERS THAT PRESERVE BEDDING OF ORIGINAL WHITE LIMESTONE

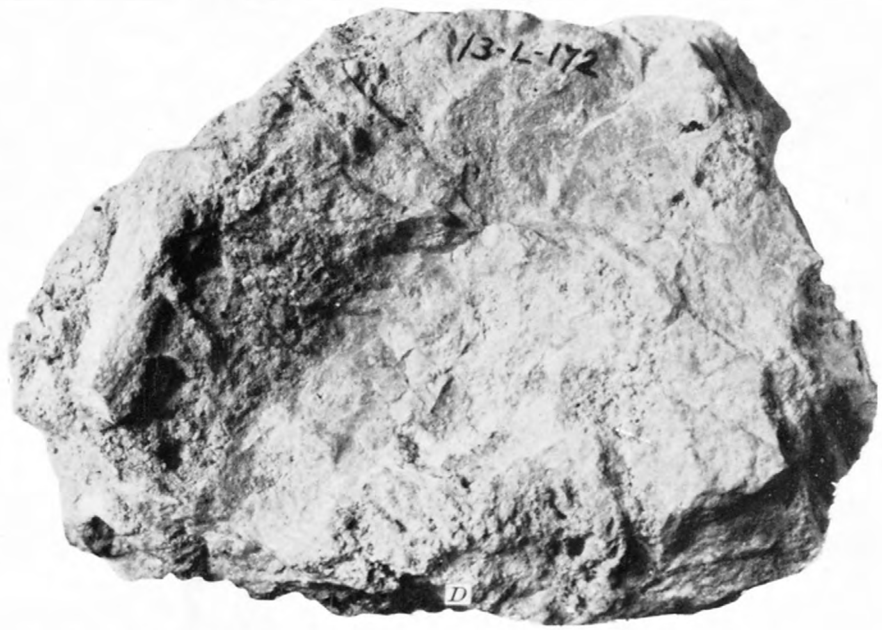
Contains a few impregnations of pyrite and pyrolusite, the latter marking the beginning of oxidation

E. CORRODED GALENA CRYSTALS WITH INCOMPLETELY DEVELOPED SURFACES

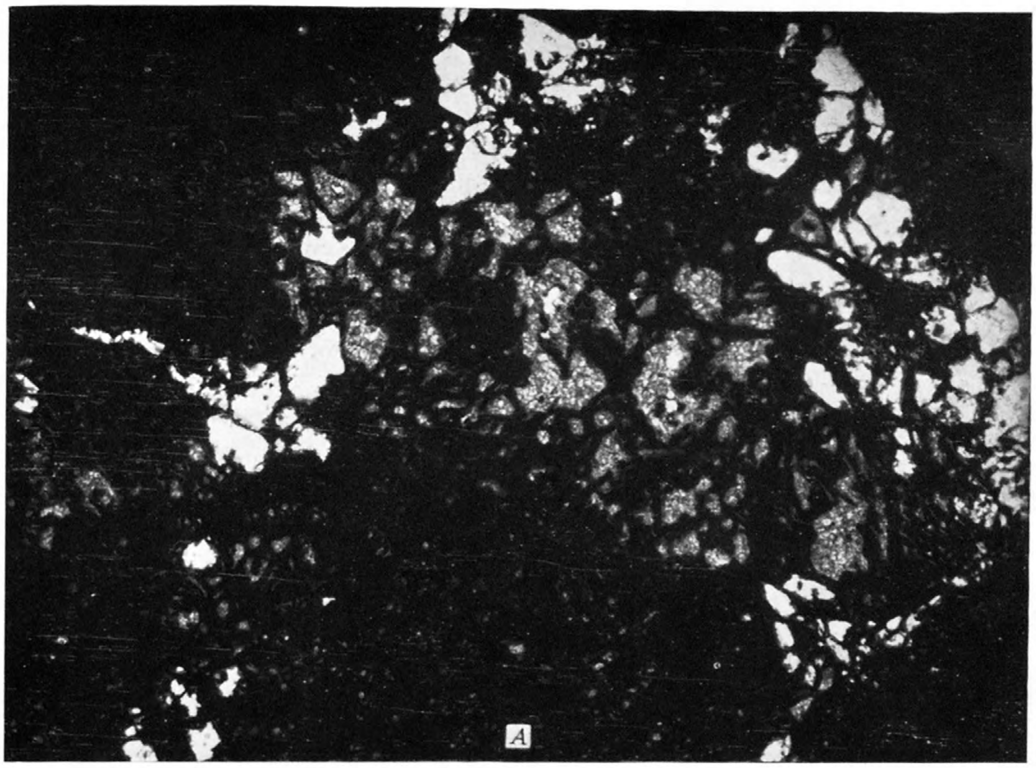
Common in vugs in lead sulphide ores of Carbonate Hill and Graham Park

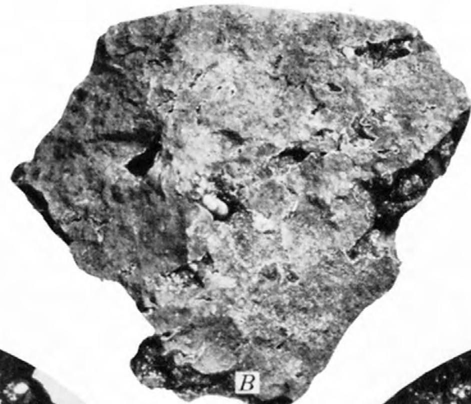


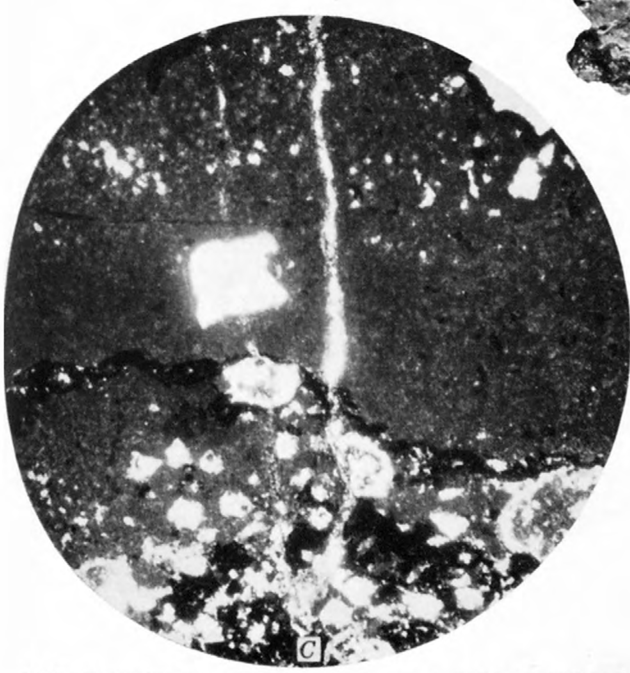


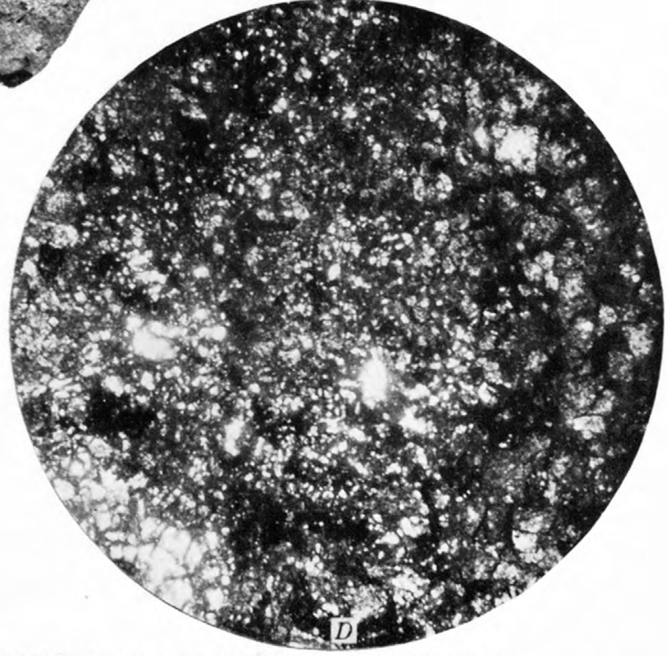


A. BROWN ZINC CARBONATE ORE WITH WHITE DRUSES OF CALAMINE, WOLFTONE MINE
B. CALAMINE DRUSE COATING BROWN ZINC CARBONATE ORE, NEW DISCOVERY MINE
C. CHALCOPHANITE (BLACK) COATING BROWN ZINC CARBONATE ORE AND COVERED IN PART BY CALAMINE, NEW DISCOVERY MINE
D. GRAY FINE-GRAINED ZINC CARBONATE ORE, POROUS IN PLACES FROM THE LEACHING OUT OF UNREPLACED MANGANOSIDERITE, WOLFTONE MINE









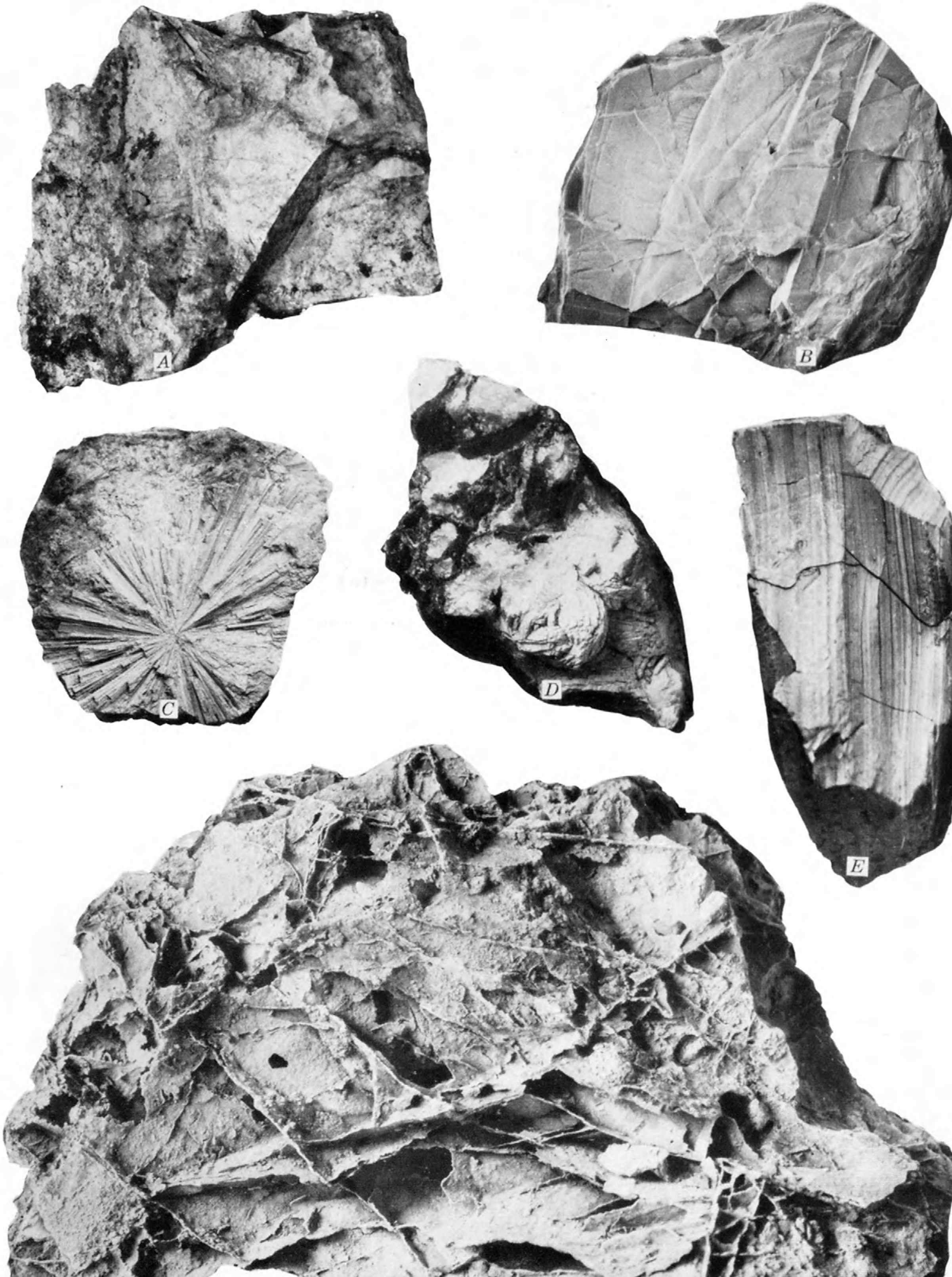
A. PHOTOMICROGRAPH OF BROWN ZINC CARBONATE ORE WITH FINE DRUSES OF SMITHSONITE, DOME MINE

B. SPECIMEN SHOWN IN *A*

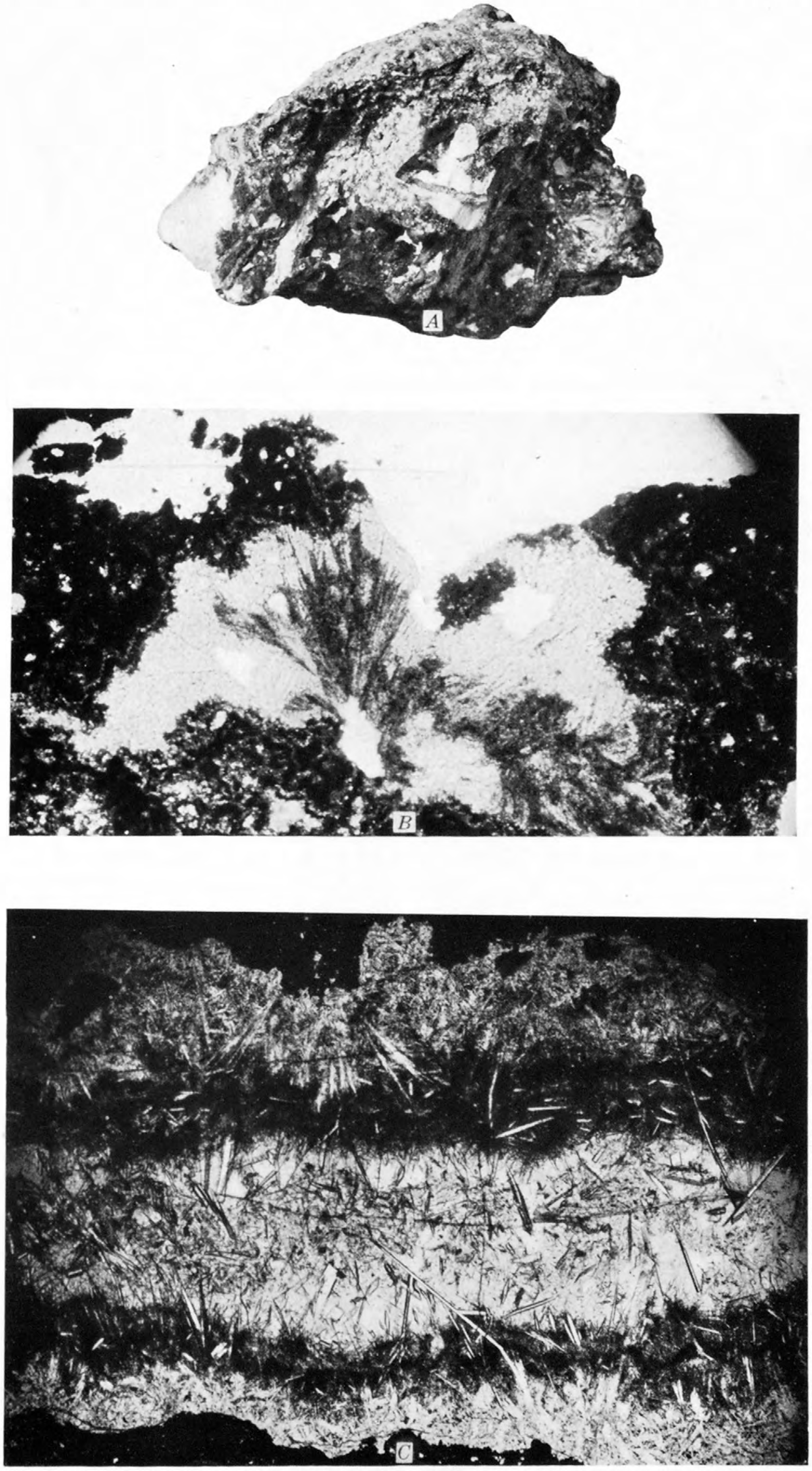
C. PHOTOMICROGRAPH OF GRAY ZINC CARBONATE ORE INCLOSING REMNANTS OF SULPHIDE ORE, WOLFTONE MINE

D. PHOTOMICROGRAPH OF FINE-GRAINED ZINC CARBONATE REPLACING COARSE-GRAINED MANGANOSIDERITE, WOLFTONE MINE

The white spots are holes made during the grinding of the section



A. WHITE ZINCIFEROUS CLAY, YANKEE DOODLE MINE
B. BROWN DENSE ZINCIFEROUS CLAY, NEW DISCOVERY MINE
C, *D*. ARAGONITE FILLING CAVITIES IN BROWN IRON OXIDE
E. BROWN BANDED ZINCIFEROUS CLAY, NEW DISCOVERY MINE
F. CELLULAR SMITHSONITE FROM SECOND LEVEL OF MOYER MINE

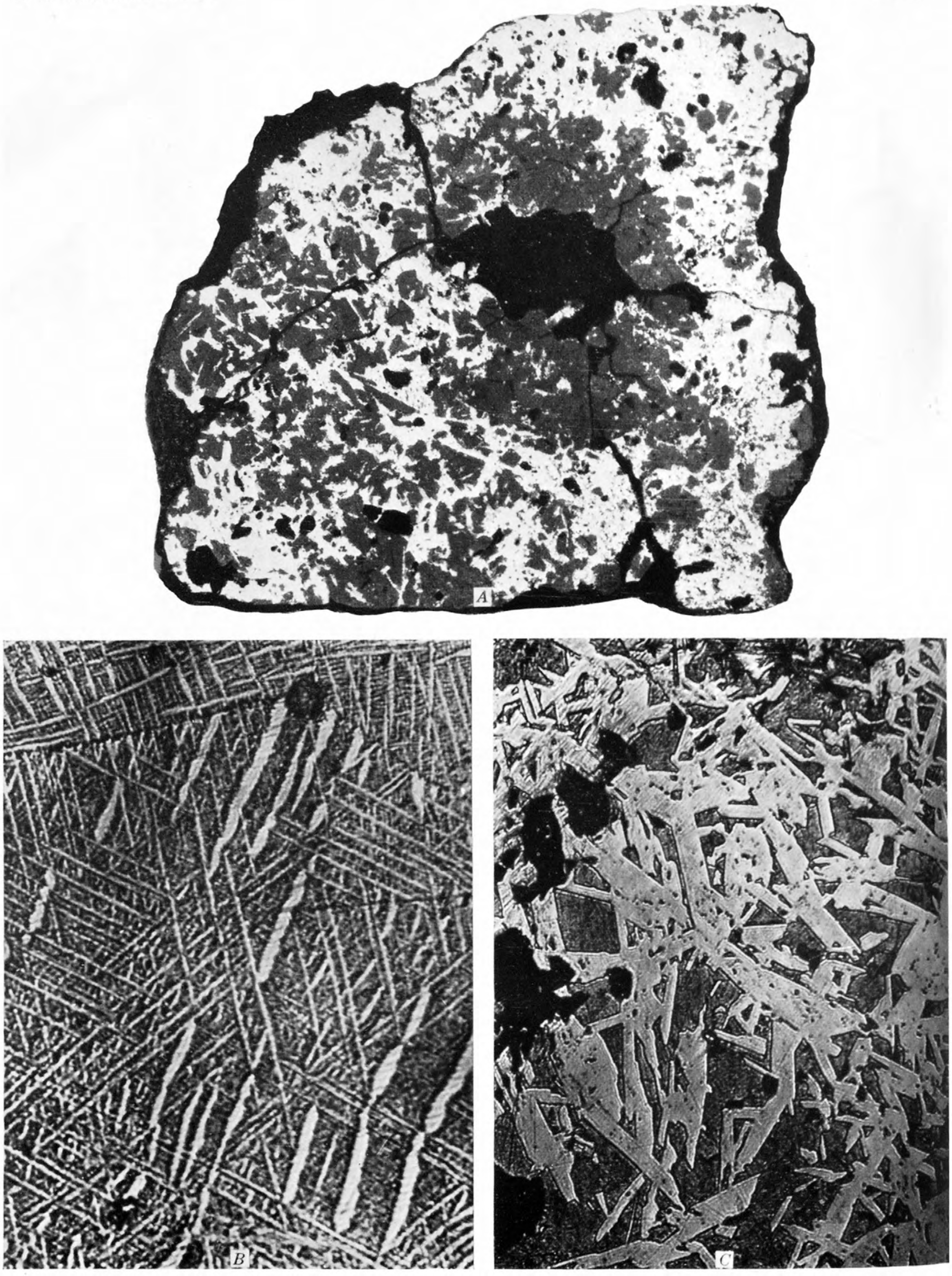


A. BROWN ZINC CARBONATE ORE WITH DRUSES OF AURICHALCITE, LITTLE JONNY MINE

The aurichalcite is white in the picture but pale bluish green in nature

B. PHOTOMICROGRAPH SHOWING DARK RADIATING NEEDLES OF AURICHALCITE AND WHITE RADIATING AND CRISSCROSSING BLADES OF CALAMINE FILLING CAVITY IN BROWN ZINC CARBONATE ORE, LITTLE JONNY MINE

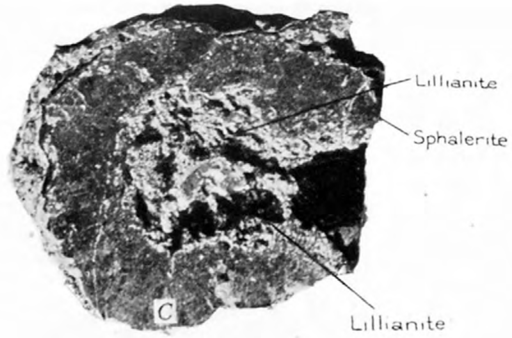
C. PHOTOMICROGRAPH OF VEINLET CONSISTING OF PRISMS OF CALAMINE AND LONG NEEDLELIKE CRYSTALS OF AURICHALCITE IN A MATRIX OF OPALINE SILICA, WITH WALLS OF LOW-GRADE BROWN ZINC ORE, BELGIAN MINE

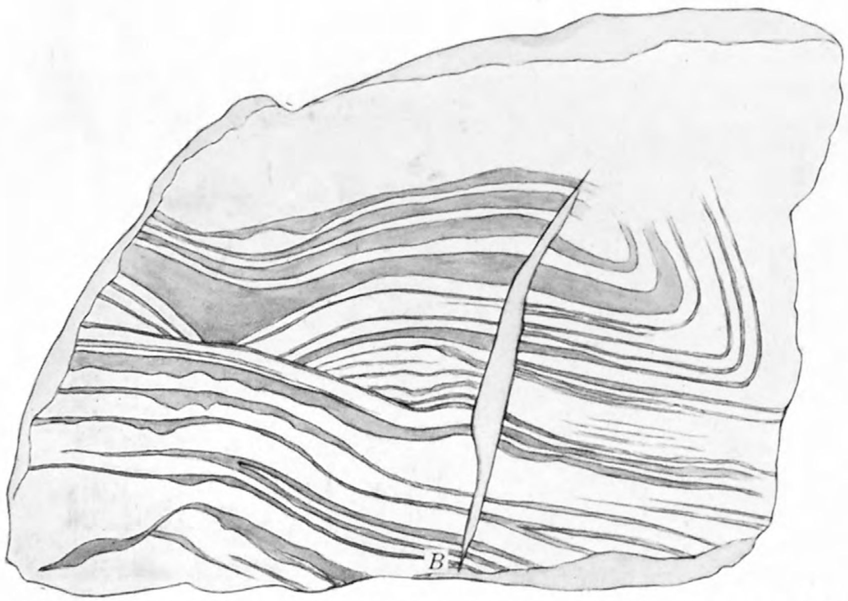


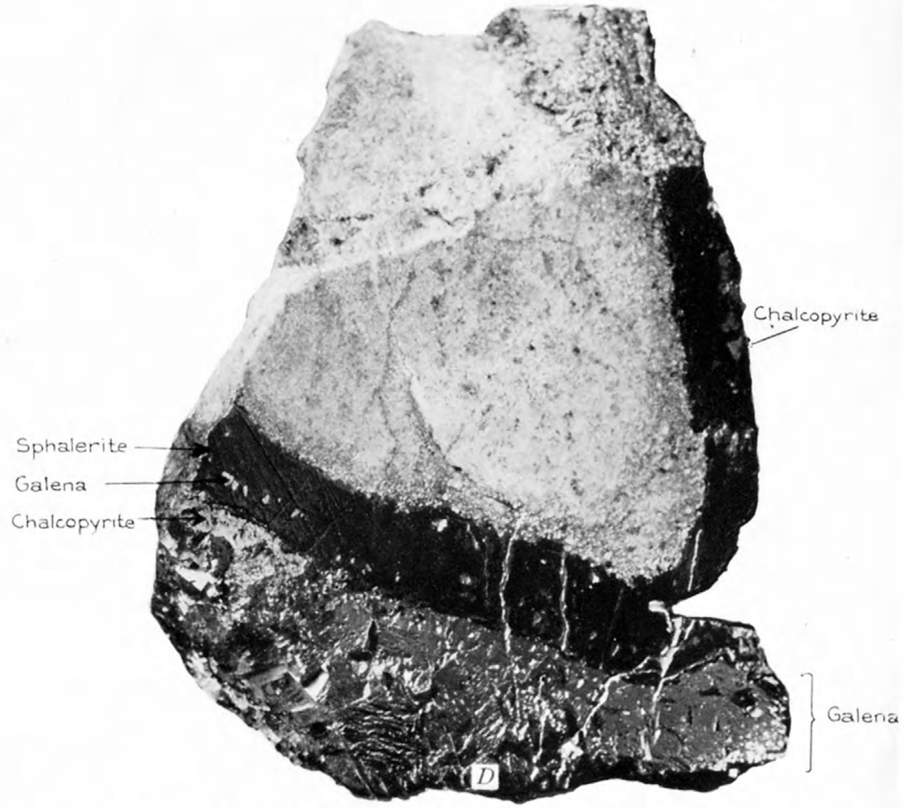
A. INTERGROWTH OF PYRITE AND SUPPOSED LILLIANITE OR SCHAPBACHITE

B. PHOTOMICROGRAPH OF LILLIANITE, AN INTERGROWTH OF BISMUTHINITE AND ARGENTITE, BALLARD MINE

C. PHOTOMICROGRAPH OF LILLIANITE, AN INTERGROWTH OF BISMUTHINITE AND ARGENTITE, TUCSON MINE



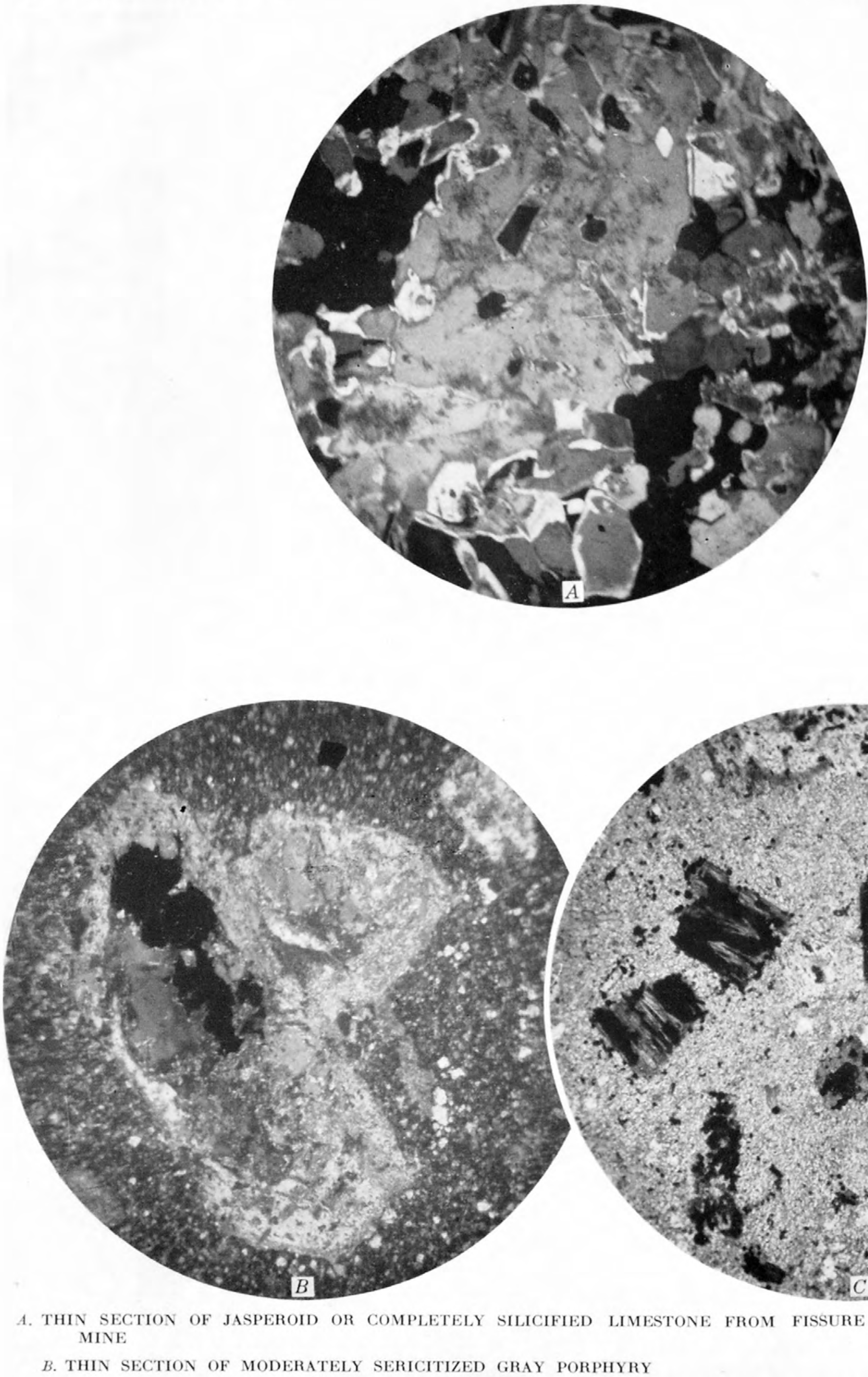




A. ALTERNATEDISTORTED BANDING OF PYRITE AND SPHALERITE AND PYRITE-SPHALERITE MIXTURES, SHOWING FOLDING OF ONE SET OF LAYERS TRUNCATED BY A SECOND SET

B. DIAGRAM SHOWING MORE CLEARLY THE UNCONFORMITY OF BANDING ILLUSTRATED IN *A*

C, D. PHOTOMICROGRAPHS OF ORE CONTAINING LILLIANITE, TUCSON MINE



A. THIN SECTION OF JASPEROID OR COMPLETELY SILICIFIED LIMESTONE FROM FISSURE VEIN IN RESURRECTION MINE

B. THIN SECTION OF MODERATELY SERICITIZED GRAY PORPHYRY

C. THIN SECTION OF GRAY PORPHYRY SHOWING MEDIUM TO ADVANCED STAGE OF PROPYLITIC ALTERATION

CHAPTER 9. PRIMARY (HYPOGENE) ORES AND ORE BODIES

In the chapter on mineralogy (pp. 145–176) some idea is given of the material constituting the ores. In the present chapter the distribution of the ore bodies and the chemical and physical features of the different kinds of primary or hypogene ore are described.

HYPOTHERMAL OR "CONTACT-METAMORPHIC" ORES

The term "contact-metamorphic" applied to ore signifies a replacement deposit composed of minerals formed at high temperature close to the contact of an intrusive igneous mass with which the ore is in close genetic relation. The ores included in this class at Leadville conform to this meaning as regards mineral composition and distribution around an intrusive stock, but their genetic relation, as shown on page 209, is not so close to the exposed porphyry as to some later unexposed intrusion within the stock.

These ores are commercially the least important. Iron ore of this class altered by oxidation has been shipped since the early days from the Breece iron or Penn mine, but other shipments have been limited to ore that has been cut and enriched by later pyritic gold ore.

DISTRIBUTION

These ores, in which magnetite and specularite are the principal metallic minerals, are found in quantity only in the Breece Hill area. These two minerals, however, are minor constituents of ores elsewhere in the district—for example, along the Tucson and Maid faults in the Iron and Carbonate Hill areas—and contact-metamorphic ores can not be sharply separated from the more abundant sulphide ores in distribution, form, or mineral composition.

The largest magnetite ore bodies have been found in the Penn, Nettie Morgan, Comstock, and Robert Burns mines and on the sixth, seventh, and eighth levels of the Ibex mine. Another body 7 feet thick was cut between two Gray porphyry sheets in the My Day drill hole at a depth of 350 feet. They are all irregular replacement deposits in limestone and in this respect may be termed "blanket" ore bodies. In some places the limestone is entirely replaced and the ore is bounded by walls of intrusive porphyry. Where unreplaced masses of limestone remain, their boundaries with the ore are in part gradational and in part sharp. The limestone bordering the ore in the Robert Burns and Comstock mines is readily identified as Blue limestone both by its lithologic character and by its stratigraphic position above the Parting quartzite. The limestone wall rocks in the Penn and Ibex mines are also believed to be Blue limestone, but the structure in both mines is so complicated that this is not certain.

CHARACTER

The hypothermal ore consists of a mixture of magnetite, specularite, and in places dark-red hematite and pyrite, with minor quantities of chalcopyrite and a little zinc blende and galena. Red massive siliceous hematite has been found only in the old open cut of the Breece iron or Penn mine, where the ore has been long subjected to oxidation. The gangue consists of the silicates serpentine, wollastonite, epidote, and sericite, the carbonate siderite, which contains varying quantities of magnesium and manganese, and a little quartz. Magnesite may be associated with the serpentine but has not been identified. The serpentine is an alteration product of a pyroxene or olivine. Serpentine and siderite are the most abundant gangue minerals. Wollastonite has been found only in the My Day drill hole but has doubtless been destroyed or obscured elsewhere by alteration processes. Epidote occurs very sparingly, and other silicates characteristic of contact-metamorphic ores are absent.

The central parts of the ore bodies consist of magnetite with varying amounts of specularite, which together constitute 80 per cent or more of the whole. A chemical test of this ore by W. F. Hillebrand in the laboratory of the United States Geological Survey proved it to be entirely free from titanium, chromium, magnesium, phosphorus, and zinc. Near the edges serpentine and carbonates increase in quantity, and in some places magnetite is disseminated through adjoining shaly limestone. Even in the purest masses of magnetite, small irregular interstitial grains and patches of siderite are present (fig. 163). This mixture of magnetite and siderite is the most common variety of the ore.

Serpentine is most abundant in the open cut of the Breece (Penn) iron mine, though it is present to some extent in all the magnetite ores. An analysis of the serpentine-magnetite ore from the Breece iron mine is given on page 178.

Pyrite occurs in part as irregular, rather coarsely crystalline patches, from which irregular branches extend into the massive magnetite. It also fills distinct fractures in the magnetite. It is accompanied in both modes of occurrence by quartz, which varies directly in quantity with the pyrite. As these minerals increase in quantity they mark a gradation into siliceous pyritic ore. This ore was for the most part, however, deposited distinctly later than the magnetite. Quartz is inconspicuous or absent in the purer magnetite masses.

Around the edges of the contact-metamorphic ore bodies magnetite impregnates the strata for considerable distances (pl. 47, *C*). The magnetite forms bluish streaks and is accompanied by sericite and pyrite. Under the microscope parts of the linear groups or streaks of magnetite are seen to be inclosed in relatively large pyrite cubes which have replaced the adjacent rock material. Here as well as within the main mass of ore the pyrite was formed subsequently to the magnetite.

Analysis of contact-metamorphio ore from Breece (Penn) iron mine

[R. C. Wells, analyst]

SiO_2	19.01	H_2O+	5.88
Al_2O_3	[a] 20.32	TiO_2	.18
Fe_2O_3	13.71	ZrO_2	None.
FeO	9.90	CO_2	1.85
MgO	24.35	P_2O_5	.14
CaO	.03	MnO	.02
Na_2O	.42	FeS_2	4.17
K_2O	.09		
H_2O	.43		100.50

[a] The high alumina is unaccounted for in Irving's description. It may be present as spinel and chlorite and may have been supplied by shaly beds just above the Parting quartzite.

Very little of the magnetite-pyrite ore is entirely free from oxidation. In some places where oxidation is rather pronounced a good deal of vivianite is present, which indicates the presence of considerable phosphorus, in contrast with the test by Hillebrand cited on page 177 but in accordance with the analysis above.

The ores containing magnetite are characteristically low in gold and silver except where pyrite and quartz are conspicuous. They rarely contain more than half an ounce of gold and a few ounces in silver to the ton.

MESOTHERMAL ORES

VEINS AND STOCKWORKS

EARLY HISTORY

Veins including single veins and vein zones, have been known and worked in the Leadville district for more than 60 years, but throughout a great part of this time their commercial importance and geologic significance have received comparatively little attention. The Printer Boy vein was discovered in 1868 and is reported to have produced between $600,000 and $800,000 in the first two years of its history. Other deposits that were producers of some importance in the late seventies and early eighties are the Ontario, Tiger, Green Mountain, Ready Cash, 5–20, and Colorado Prince veins and the Antioch stockwork.

The discovery of carbonates in 1874 and the almost immediate rise of the blanket ore bodies to a preeminent position in the production of the district lessened interest in the veins until 1891, when the development of productive veins in the Ibex mine began to attract general attention. Since then discoveries of rich ore shoots from time to time have maintained a fluctuating interest in the veins. That certain recent developments in these veins were proclaimed by some writers[1] as discoveries of a kind of ore deposit whose existence was hitherto unsuspected in the district was not surprising, as there had been little publicity regarding the most steadily productive veins.

The danger of serious legal complications regarding apex rights that might have arisen if the existence of veins were too widely advertised may readily explain the apparent neglect of a significant geologic fact, even if the vast production of the blanket bodies had not for so long overshadowed all other forms of deposit. But the increasing number of veins that have become productive in the district, the mining of rich ore from several of them, and the discovery of connections between veins and blanket ore bodies have gradually gained for the lodes or veins general recognition.

CLASSIFICATION

The veins are classified for purposes of description as major and minor. These terms are used here primarily to indicate relative economic importance, but as all the longer and more continuous veins so far discovered have fortunately been profitable or have offered hopeful indications at some points along their courses, the grouping would hardly be altered if it were based on size alone. Each of the veins classed as major either has in fact been extensively explored or appears to justify considerable development work. The veins classed as minor include some which are fairly wide; these have as a rule been explored only for very short distances but have commonly been shown by exploration of adjacent ground to be short or discontinuous. Some of the minor veins that have been found remain undeveloped because of their small size or the low grade of their ore.

NUMBER OF DEVELOPED VEINS

Irving obtained information more or less complete on 53 major veins, from nearly all of which ore has been produced, and 76 minor veins. Others doubtless remain to be discovered as development work is extended.

Only four stockworks have been mined. These are the Antioch and South Ibex, in Breece Hill, and two

[1] Ralston, O. C., Leadville fissure veins: Mines and Minerals, vol. 32, p. 549, 1912. Butler, G. M., A Leadville fissure vein: Econ. Geology, vol. 7, pp. 315-323, 1912; Colorado School of Mines Quart., vol. 8, pp. 1-8, 1913.

in the Cord mine, in Iron Hill. The Antioch is in porphyry in the vicinity of several minor veins; the South Ibex, mostly in "Weber grits," is contiguous with the Ibex No. 4 vein where it passes close to the Garbutt vein; the Cord stockworks, in Cambrian quartzite and Gray porphyry, are enlargements of the Cord vein at its intersection with the Tucson-Maid fault.

DISTRIBUTION AND GROUPING

The veins are chiefly confined to the portion of the Leadville district lying east of the 106° 15′ meridian, and nearly all of those within this area lie east of the Weston fault. Of those that lie to the west of the Weston fault only six are known to have been productive—one each in the Penn, Tucson, Cord-White Cap, Wolftone, and Greenback mines and one of very minor importance in the Penrose mine. A number of veins too small for development have been discovered in the Yak and Agwalt tunnels west of the Weston fault and in the Antioch workings.

It is quite possible that a few more veins may yet be found in the western portion of the district wherever the lower strata have not been extensively explored; but exploration as a whole has already been extensive in this part of the area, and the small number of the lodes discovered is evidence of their relative scarcity.

The distribution of the veins in the eastern part of the districts is shown on Plate 56. On this plate the spacing of the veins does not show them in exactly their true relations, as they have been found at many different depths, and only a few have been traced to the surface. Owing to the slight vertical range of most of them it is impracticable to represent them on a single horizontal plane.

The veins in the area east of the Weston fault are either isolated, as the Winnie-Luema, Sunday, and Silent Friend, or lie closely spaced in well-defined groups. The four principal groups, named in the order of their economic importance, are the Ibex, Big Four, Resurrection, and Ella Beeler. To these may be added the Iron Hill group and the Carbonate Hill group. Each of these groups is included within a very small area and is separated from its neighbors by correspondingly broad areas that are practically barren or undeveloped. Thus the Ibex group contains no less than 70 veins, all included beneath a surface area 1,400 by 2,000 feet; the Big Four group, nine veins in an area 1,500 by 1,200 feet; the Resurrection group, nine veins within an area 1,600 by 800 feet; and the Ella Beeler group (south of the Leadville district), seven veins in an area 1,200 by 3,000 feet. The Iron Hill group includes the Cord vein and one or more veins parallel to it in the Cord mine. The Carbonate Hill group includes a developed vein on the eighth level of the Wolftone mine and one on the seventh level of the Greenback mine, besides a few veins too small to work. Further exploration may add other veins to these two groups.

The spacing of the veins within the several known groups is so close that it does not seem likely that the wide intervening areas are wholly devoid of veins. As the veins present few outcrops and therefore must be discovered mainly in underground workings, it appears possible that the failure to find veins in some area may be due to lack of underground exploration. This possibility is strengthened by the fact that the Sunday, Luema, Penn, Silent Friend, and Printer Boy veins were found in comparatively isolated positions well out in the largely barren areas intervening between the groups.

DISTRIBUTION OF VEINS IN COUNTRY ROCK AND RELATION TO STRUCTURAL FEATURES

The veins intersect all the bedrock formations in the Leadville district, except the rhyolitic agglomerate. Only the smaller and less continuous veins occur within a single kind of rock, and this rock is usually one of the intrusive porphyries. All the veins that are productive or that have been traced for more than a hundred feet pass from one formation to another; the walls of some veins, indeed, present a bewildering succession of formations. This is particularly true of the Ibex group of veins on Breece Hill, where the sedimentary formations are cut by an unusually large number of porphyry sheets, some of which are very irregular.

The veins have been little disturbed by deformation since their deposition. They are broken here and there by recent faults, most of which are too small and too widely spaced to affect mining seriously.

All the larger and continuous veins have been found in those rock masses which consist of alternating sedimentary beds and porphyry sheets. Within the large mass of Gray porphyry that forms the western slope of Breece Hill many fissures are present, but they are all small and discontinuous and have so far proved disappointing. There seems to be some probability that the more massive and tougher body of Gray porphyry has offered a greater resistance to extensive fracturing than the complex made up of different varieties of rock. The shale strata are also unfavorable, especially along the faults of considerable size; veins that are productive elsewhere are likely to pinch where one or both walls consist of shale.

Most of the larger veins are in faults of considerable size. The Ella Beeler vein, in the Iowa Gulch area, according to information supplied by Charles J. Moore, lies in the Weston fault, which shows more displacement than any other mineralized fault. South of the Iowa fault the vein is in the reverse part of the Weston fault, between an eastern hanging wall of pre-Cambrian granite and a footwall of White porphyry, Blue limestone, and lower formations; north of the Iowa fault it continues between an east wall of "Weber grits" and a west wall of White limestone and lower formations. There are several parallel slips in the fault zone, and several veins in the Ella Beeler group; and more exploration is necessary before the structural relations are thoroughly understood. Other veins that clearly occupy faults of considerable size are the Silent Friend, Nevada, Winnie-Luema, Modoc, Garbutt, and Ibex No. 4. The Sunday vein has also been reported to occupy a fault, but the amount of displacement has not been recorded.

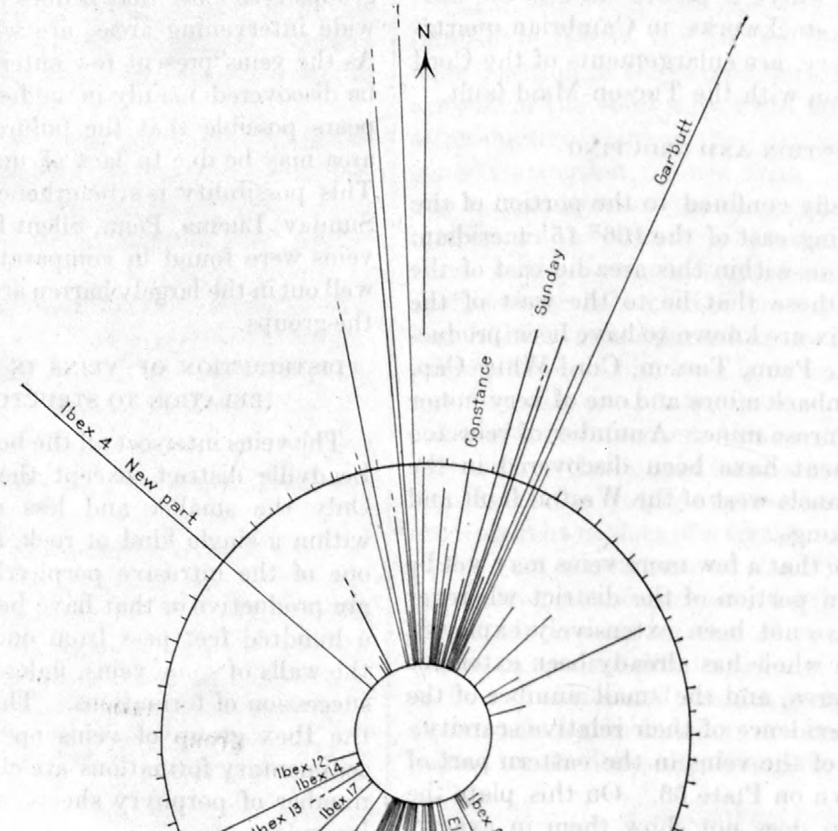
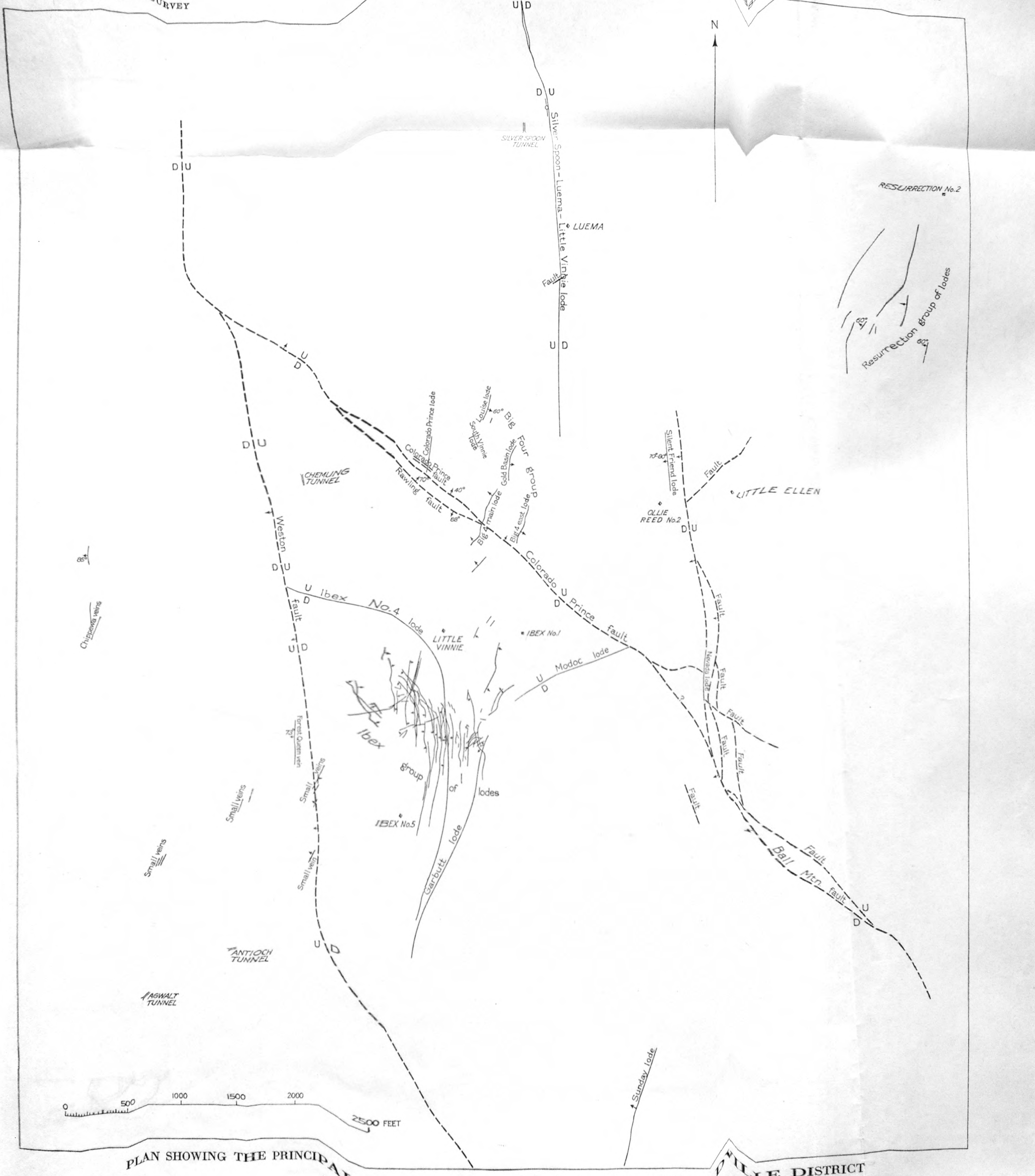


FIGURE 51.—Strike and relative explored length of most of the major veins of the Leadville district

RELATION OF VEINS TO EROSION

With the exception of the Garbutt, Sunday, and possibly the Printer Boy veins, whose early history is little known, the important veins of the Leadville



PLAN SHOWING THE PRINCIPAL VEINS AND FAULTS IN THE EASTERN PART OF THE LEADVILLE DISTRICT

MAP SHOWING VEIN AND BLANKET ORE BODIES IN IBEX AND ADJOINING MINES

district have been discovered by underground workings. The scarcity of outcrops is due to three distinct causes: (1) The fissure fillings are much less resistant to erosion than the inclosing wall rocks; (2) a heavy mantle of "wash," glacial débris, and "lake beds" almost wholly covers the district, and in the areas from which it is absent fissures are notably scarce or entirely absent; (3) the great majority of veins so far mined do not extend upward to the bedrock surface. They either terminate upward in the flat blanket ore bodies, as in the Resurrection mine, or simply die out and disappear before reaching the surface, as in parts of the Ibex mine.

Of those few veins which have been actually traced to the bedrock surface, two, the Garbutt and Sunday, crop out in "Weber grits." The rest are found in the deeply eroded portions of the district—for example, north of the Colorado Prince fault, where several veins have been traced up to the bedrock surface, notably the Luema-Winnie, Louise, Big Four, St. Louis, and South Winnie.

The prevalence of veins in the more deeply eroded areas suggests that shale beds, particularly the "Weber shales," acted as barriers against which the veins terminated upward in blanket deposits; but intense mineralization at Breece Hill and on the western slope of Ball Mountain reached into the "Weber grits." Well-defined outcrops in this mineralized area are scarce, owing to the abundance of disintegrated rock or "wash," but the great amount of leached silicified grits and porphyry proves that mineralization has been extensive and suggests that additional veins await discovery in this area. Further deep exploration beneath the large blanket deposits in the western part of the district may disclose veins similar to those in the Cord, Greenback, and Wolftone mines.

STRIKE, DIP, AND COORDINATION

PREVAILING ATTITUDE

The veins for the most part strike north to north-northeast. Exceptions are the crescent-shaped fault fissures containing the Ibex No. 4 and No. 5 veins, the northern parts of which strike northwest, and the Modoc vein, which strikes east-northeast. The prevailing direction of strike is represented in Figures 51 and 52, in which the average directions are plotted about a common central point and the approximate length of the veins is represented by the length of the respective radiating lines. Most of the major veins trend within an arc of 42°, N. 12° W. to N. 27° E., but a few strike between N. 30° E. and N. 75° E., and the northwestern part of the Ibex No. 4 vein strikes N. 50° W. The greatest production has come from the group of more northerly trend, and this doubtless accounts for the rather general impression that all veins of the district have north-south trends.[2] The strikes of the minor veins in the Ibex mine (fig. 52) range through a greater arc, but most of them are within the same arc as those of the major veins.

Most of the veins dip at high angles, usually between 70° and 90°. A few dip at considerably lower angles. Thus the Constance vein, on the south side of Iowa Gulch, dips as low as 38° in places, and other veins dip between 50° and 60°; but these are outnumbered by veins of nearly or quite vertical dip. An average of 34 observations is 74°, which may serve as an approximate general average.

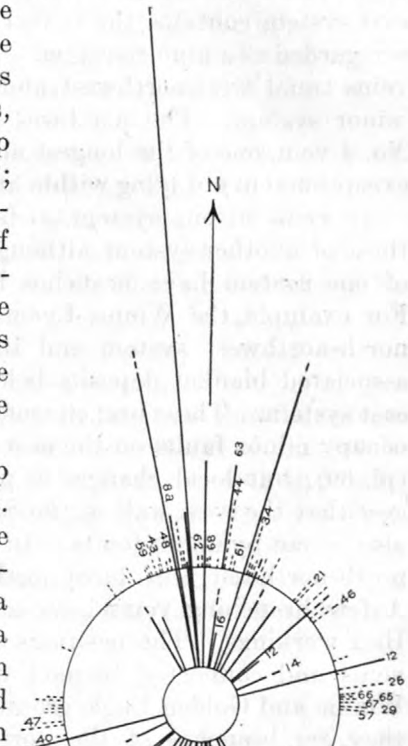


FIGURE 52.—Strike and length of major and minor veins in the Ibex mine. The lines indicating minor lodes are not continued through the circle, and their length is shown by the portions outside the circle

Variations of dip occur on all the veins. The attitude of some approximately vertical veins ranges from a vertical position to a very steep dip, which is here to the west and there to the east. In the main or west vein of the Big Four group the dip in the upper levels was vertical, but as the vein was followed downward it assumed a west dip at gradually smaller angles. In general the dips change little along the strike, but they change very markedly in a few veins; the No. 15 vein of the Ibex, for example, has a dip of 75° W. at one end and a dip of 75° E. at the opposite end.

Although Figures 51 and 52 give little indication of more than one rather poorly defined system, Plate 56 indicates three fairly well defined systems of veins—north-northwest, north-northeast, and east-northeast. The north-northeast system is the most prominent and contains the largest number of productive veins,

[2] Boehmer, Max, Am. Inst. Min. Eng. Trans., vol. 41, pp. 162–163?, 1911.

including the southern parts of the crescentic veins. The north-northwest system also includes some of the most continuous and productive veins in the district, including the Winnie-Luema, Silent Friend, Nevada, Penn, and a few of the Ibex group. The east-northeast system contains the fewest productive veins and is regarded as a minor system. A few scattered minor veins trend west-northwest and may be considered a minor system. The northwestern part of the Ibex No. 4 vein, one of the longest and most productive, is exceptional in not lying within any of these systems.

No veins in one system, so far as known, intersect those of another system, although certain major veins of one system have branches belonging to another. For example, the Winnie-Luema vein belongs to the north-northwest system and its branches and their associated blanket deposits belong to the east-northeast system. These branch veins, so far as discovered, occupy minor faults on the east side of the main vein (pl. 69), but local changes in position of strata suggest that the west wall in the Silver Spoon mine may also be cut by minor faults. In the Resurrection mine north-northeast veins have north-northwest branches. A few branching veins have also been found in the Ibex workings. The positions of the north-northeast veins and connected blanket deposits in the Little Winnie and Golden Eagle ground (pl. 57) suggest that they are branches of the northwestern part of the Ibex No. 4 vein, which strikes about N. 50° W., but no connections had been established up to 1925. It therefore appears that the veins occupy conjugate groups of faults and accessory fissures that were mineralized at one time.

IRREGULARITIES

Most of the strikes represented in Figures 51 and 52 are averages of curving or undulatory veins. The veins in many mining districts are characterized by angular bends (fig. 53) where the vein filling alternates

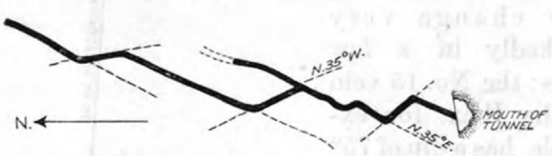


FIGURE 53.—Vein with angular bends, common in many mining districts. (After J. D. Irving, U. S. Geol. Survey Bull. 478, p. 42, 1911)

from one set of fissures to another. Some veins in the Leadville district approach this character, but their changes in direction are rarely sharp, and many are so gradual that they appear due to curvature of single fissures rather than to intersections of different fissures. Where faulting has taken place along intersecting fissures, however, the development of auxiliary breaks around the intersections, as suggested in Figure 28, and the shearing away of the sharp angles may develop a pronounced curvature. To what extent the curves of the veins at Leadville are original features of single fissures or fissure zones and to what extent they are effects of faulting along intersecting fissures is not known.

A very few of the veins are approximately straight in their developed parts. The others may be divided into crescentic lodes and lodes of irregular curvature.

Crescentic veins.—Crescentic veins are those with dominant curvatures in one direction only. The radii of curvature differ for different veins but are fairly constant for individual veins. The thickening of some veins, as the Ibex Nos. 4 and 5, in the middle parts of their courses accentuates their crescentic appearance. Ten crescentic veins have been recognized. Their regularity is somewhat disturbed by minor flexures, but their great size makes them conspicuous when mapped. (See pls. 56 and 57.) The 10 crescentic veins so far developed and their radius of curvature (in plan) are listed below.

	Radius (feet)		Radius (feet)
Ibex No. 4	950	Resurrection No. 1	1,700
Ibex No. 5	950	Resurrection No. 7	1,700
Ibex No. 3	200	Resurrection No. 6	1,500
Ibex No. 15	140	Gold Basin	420
Ibex No. 16	130	Winnie-Luema	6,400

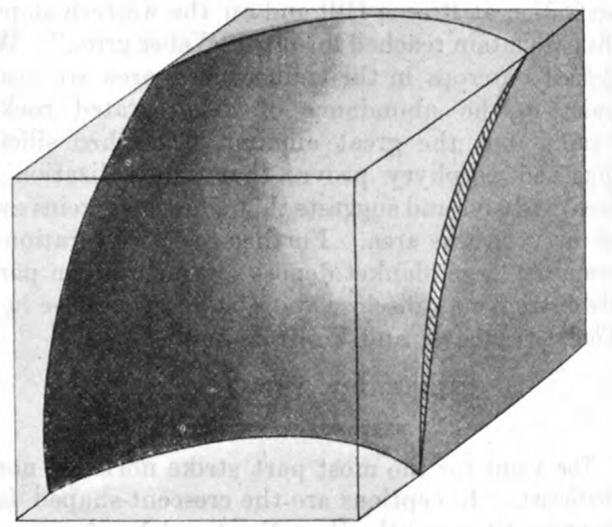


FIGURE 54.—Diagrammatic projection of part of Ibex No. 4 vein, showing curvature along strike and dip

The crescentic form is more pronounced in some veins than in others, and where the radius is large, as in the Winnie-Luema, the curvature is so gradual that but for the extensive development of the vein it could scarcely be detected. The Ibex No. 4 and No. 5 veins are strongly curved in their middle parts but become practically straight for considerable distances in both directions (pl. 57).

The dip of all these veins except one is toward the inner side of the crescent but is subject to minor deviations. In some of the veins the angle of dip is least at the top and increases rapidly downward, so that the side which is concave in horizontal section is convex in vertical section. (See fig. 54.) The Ibex No. 4 and No. 5 veins are nearly parallel veins of this character only 180 feet apart. Neither is perfectly continuous on all levels; each in places breaks up into slightly overlapping parts. Some of the minor veins between them have similar curvature. The other crescentic veins are less thoroughly known.

Veins of irregular curvature.—The most conspicuous veins of irregular curvature are the Ibex Nos. 1, 2, 8, and 9, the Garbutt, and the Big Four. The Ella Beeler, Constance, Clear Grit, Helena, and Fortune veins, in the Iowa Gulch area, are also of this class. Some of these veins are roughly crescentic as a whole, and others deviate about equally on either side of a straight course. Some undulate principally in their middle parts and become practically straight near one or both ends. The local trends tend to shift from one major system of strike to another, but the transitions, as already noted, are along smooth curves. Local changes in trend rarely exceed 40°.

Other irregularities.—Besides variations in strike and dip, other features, such as minor parallel veins, pinches and swells, "horses," and branchings, are noteworthy. Minor parallel veins are of common occurrence, and several of them have proved large enough or rich enough to be worked, notably in the Ibex mine and along the Winnie-Luema veins. It is a somewhat common characteristic of the veins at Leadville, as elsewhere, that where ore has been deposited in a sheeted zone the main vein occupies only a minor portion of the zone, and parallel minor veins are irregularly distributed along each side of it. In some places where the main vein thins out a parallel vein thickens, and the workable part of the vein consists of a steplike series of closely related veins. Most of the minor parallel veins in the district have been discovered thus far accidentally. Systematic crosscutting to prospect for such veins as well as for parallel major veins has been much neglected and is one of the first things to be considered in the efforts to increase the productivity of veins under development and to discover new veins.

Swells and pinches are present in nearly all the veins. Most of the swells are due to a thickening of the brecciated material that originally filled the fissure, which was especially subject to replacement by ore. Veins that enter readily replaceable limestone may either widen into lenticular bodies or send out flat blanket masses along certain beds. Many such occurrences are known. Other veins cross limestone beds without appreciable increase in width, and examination of the few accessible occurrences of this kind has shown that the limestone was protected from replacement by clay gouge along the walls of the fissure. Even a thin gouge may be an effective protection against replacement.

The pinches seen are due to the strong development of gouge or to the presence of considerable shale on one or both walls of the vein. The pay shoots of the Garbutt vein are found, in part at least, where the walls are coarse-grained "Weber grits," quartzite, or Gray porphyry, whereas the intervening spaces are marked by pinches between shale walls or by a mingling of vein minerals and unreplaceable shale fragments within the vein. The shale in the upper levels belongs to the Weber (?) formation and that in the lower levels to the "transition shales" at the top of the Cambrian quartzite.

Horses of included rock are few, but some of them are large—for example, the Big Four lode contains a large granite "horse" which occurs well above the nearest point at which the vein lies between granite walls. In other veins smaller horses are occasionally found. They are rarely, however, in their original positions but have been considerably affected by differential movement of the two walls.

Most of the veins are very free from small irregular branches extending into the outer walls of the fissure zone. The outer walls are generally smooth and uninterrupted, and the intervening ground consists of shattered rock separated by veins and stringers of ore. Small branches have been noted in the Garbutt vein, however, particularly where one or both walls are shale.

TERMINATIONS

Most of the veins become too thin or too low in grade for mining before their terminations are reached. Where the terminations have been reached or closely approached the veins pinch to a knife-edge, split into a maze of small veinlets, or terminate abruptly against shale or against rhyolite agglomerate of postmineral age. Most of the veins in the Ibex mine thin to very narrow seams both along the strike and upward and downward along the dip. Many veins appear in the ower levels of the Ibex of which no trace can be found above, and likewise many of those in the upper levels thin out downward along the dip. Some veins pinch out in both directions along the strike and both upward and downward along the dip, so that the entire vein is completely included within the explored portion of a rock mass. The Winnie-Luema vein narrows down at the south end to a small, unprofitable vein, and in its northernmost part it is a wide network of small veins, separated by silicified rock, which have been found to be of too low grade for profitable mining.

Owing to the prevailing low angle of dip of the country rocks, changes in wall rock are less numerous along the strike than along the dip of veins, and terminations of veins are mostly independent of wall rock. The upward terminations of several veins, however, as stated on page 181, are controlled by some particular stratum, commonly the "Weber shales." Some of the stronger vein fissures cut through the thinner shaly beds at lower horizons but fail to penetrate the "Weber shales." Where their walls were sufficiently sealed by gouge changes in the kind of wall rock have had no influence on the mineralogy or thickness of the vein, but along many veins where the walls were imperfectly sealed the limestone between layers of shale or sheets of porphyry has been replaced by blanket ore shoots. Some small veins terminate in blanket bodies beneath such an impervious cap, and some of these blanket bodies connect with other small local veins that extend upward through the shale or porphyry to limestone at a higher horizon, where they connect with another blanket body. (See fig. 55.) These relations were clearly shown in White limestone in the Golden Eagle workings of the Ibex mine in 1922, but the blanket bodies at the top of the Blue limestone, worked in the early days, have long been inaccessible. Their trends are generally parallel to those of the veins, however, and descriptions by those who have worked in them suggest that they are the upward terminations of veins (pl. 57).

The downward terminations of minor veins may be found connected by blanket bodies or mineralized streaks along bedding planes with lower minor or major veins. The downward limits of the major veins, however, have not been reached and are not likely to be, as the ores are likely to become of too low grade for mining after the downward limits of sulphide enrichment have been reached.

DIMENSIONS

The average length of the veins at Leadville, 700 to 800 feet, is short in comparison with the average length of veins in many mining districts. The lengths at Leadville mostly range from 200 to 1,000 feet. Exceptionally long veins include the Fortuna-Helena, in the Iowa Gulch area, reported to be 2,100 feet long; the Ibex No. 4, 2,700 feet (pl. 57) and the Winnie-Luema, nearly 4,000 feet (pl. 56). The widths range from a mere knife-edge at the terminations to more than 100 feet in the greatest swells. These unusually large swells, however, extend only for short distances, and a general average thickness of ore is not more than 3 feet. The workability of such narrow veins has been due largely to enrichment but in part to the easy removal of shattered waste material between the sides of the ore streak and the solid walls of the fissure zone. There is no definite basis for estimating the total depths of the major veins.

ORES OF THE VEINS

The veins are the result for the most part of replacement along shear zones and to a minor extent of cavity filling. Their principal original metallic mineral is pyrite, which is accompanied by minor quantities of chalcopyrite, zinc blende, galena, argentite, and bismuthinite, and rarely by tetrahedrite and pyrargyrite. These primary sulphides are supplemented in the zone of sulphide enrichment by chalcocite, bornite, and locally visible gold and silver, one or more of which are generally essential to raise the ore to a profitable grade. The original gangue minerals are quartz and sericite, with minor quantities of siderite or manganosiderite, and locally barite. Rhodonite has been reported from veins in Iowa Gulch. In the zone of sulphide enrichment white claylike material is abundant. In the oxidized zone the veins are changed to mixtures of brown and red iron oxide, black manganese oxide, cerusite, chrysocolla, horn silver, native gold, and claylike material. Representative analyses of siliceous ores from veins or connected blankets are given on page 200 and accompany the descriptions of certain mines in chapter 13 (pp. 226–318).

The ores of the veins may be divided on the basis of dominant mineral composition into three classes—

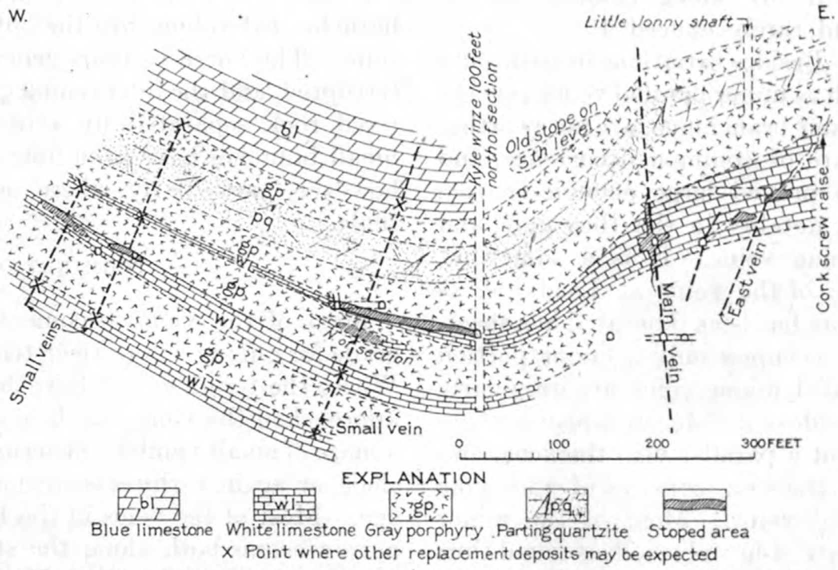


FIGURE 55.—East-west section 20 feet north of Little Jonny shaft, showing relation of veins to blanket ore bodies in the Golden Eagle workings, Breece Hill

(1) pyrite-chalcopyrite ore, with subordinate zinc blende, well developed in the Ibex, Big Four, and St. Louis groups; (2) highly siliceous ore, represented by the Resurrection group; (3) mixed siliceous sulphide ore, locally with prominent galena, represented by the Winnie-Luema vein. Although typical ores of these three classes are quite distinct from one another, gradations are common, and more than one class may be represented within a single vein. This is particularly true of the Winnie-Luema vein. According to commercial classification (p. 318) these veins include ore of all classes, but very little mixed sulphide ore containing zinc in paying quantities has been shipped from them. Practically all the siliceous gold-silver, lead, and copper ores has come from them or from small blanket ore bodies connected with them.

PYRITE-CHALCOPYRITE ORE

The pyrite-chalcopyrite ore, which is the most common variety, consists mainly of the two minerals from which it is named, with minor or inconspicuous quantities of quartz and altered wall rock. In places the two sulphides form solid masses filling the entire thickness of the vein. The chalcopyrite occurs in irregular interstitial grains among the larger and more abundant grains of pyrite and may be easily overlooked unless present in unusually great quantity. Vugs lined with the two minerals and rarely containing tetrahedrite are present here and there. The unaltered ore is hard unless softened by local films or streaks of highly sericitized rock. The ore most sought, however, has been altered to some degree and may appear as crumbly granular pyrite more or less tarnished or blackened by chalcocite. Where chalcocite is most conspicuous close inspection shows it to be mainly the product of a replacement of chalcopyrite. The chalcopyrite first becomes tarnished or coated by bornite, which in turn is replaced by chalcocite. Ore rich in chalcocite is likely to be rich also in silver or gold or both, but records of assays and smelter returns do not show any definite ratio between copper and gold or silver. Although quartz is a minor constituent, the ore shipped is distinctly more siliceous than the pyritic ore of the large blanket deposits in the western part of the district. It also contains more copper and gold.

A prominent subvariety of this ore, which constitutes the largest shoots in the veins of the Ibex and Garbutt mines, consists mainly of pyrite cubes half an inch or more in diameter embedded in gray, fine-grained quartz or jasperoid. The texture and structural relations of the ore point to deposition by replacement. Oxidized portions of these ore shoots consist of honeycombed jasperoid with cubic cavities that are either empty (pl. 58, *D*) or partly filled with iron oxide, basic iron sulphate, or jarosite. The pyrite cubes have also been found partly or completely separated by practically pure sericite, and, in the sulphide enrichment zone, by masses of white claylike material which has replaced sericite, shaly limestone, "Weber grits," or carbonate gangue.

The jasperoid matrix just described grades in many places into a cavernous variety that has resulted from the removal in solution of incompletely replaced rock or carbonate gangue. These caverns are lined with loosely compacted pyrite and quartz crystals. The pyrite and any chalcopyrite present are coated or considerably replaced by black, sooty chalcocite, which is accompanied by a little iron sulphate. The loose ore can be shoveled like gravel and has contributed greatly to the output of the Ibex mine.

HIGHLY SILICEOUS ORE

The highly siliceous ore in the Resurrection mine consists of dense quartz or jasperoid which has replaced sheeted zones in limestones and in which sulphides are usually scarce or absent. Galena and pyrite, however, are locally present in considerable quantity, and their oxidation results in siliceous lead carbonate ore.

MIXED SILICEOUS SULPHIDE ORE

The mixed siliceous sulphide ore consists of pyrite, chalcopyrite, zinc blende, and galena irregularly distributed through a gangue of quartz and silicified and sericitized wall rock. Small portions of ore in the Ella Beeler and Clear Grit group have a banded or crustified structure but are exceptional. The sulphides commonly form granular masses occupying the entire width of the vein or lenticular shoots within masses of gangue. Vugs lined with crystals of one or more sulphides are present here and there in the sulphide shoots. The general order of deposition of the sulphides was first pyrite, second zinc blende, and third chalcopyrite and galena. Quartz was deposited throughout the process but mainly before and with the pyrite and blende. Zinc blende and galena are prominent in some shoots and practically absent in others. Where they are abundant the ore is similar to the mixed zinc-iron-lead sulphide ore of the large blanket deposits in the western part of the district but is more siliceous and contains more copper and gold and locally more silver. The zinc blende, like chalcopyrite and pyrite, is in places coated with black films, probably of copper sulphide.

These ores, like the other vein ores, have been considerably enriched with chalcocite and precious metals. The generally vertical or steeply dipping positions of the veins and the easy passage of water downward along them between their impervious walls of gouge have favored this kind of enrichment to relatively great depths, whereas conditions have not favored similar enrichment of the blanket ore bodies except in parts adjacent to and connected with mineralized fissures.

RELATION OF ORE BODIES TO CHARACTER OF WALL ROCK

As most of the major veins traverse rocks of several kinds, the influence of the physical and chemical properties of the different rocks on ore deposition is noteworthy. Mineralization in granite and porphyry has consisted chiefly of the replacement of broken material or sheeted rock within the fissure zone. The vein matter usually terminates abruptly on each side, against a selvage of gouge (finely ground sericitized rock); but the immediate wall rock is highly silicified for a few inches, beyond which for a considerable distance it is altered to a mixture of quartz, sericite, and thinly disseminated pyrite. As distance from the vein increases chlorite representing the original black minerals of the rock appears, and is accompanied by a minor amount of epidote. The alkali feldspar is only slightly altered, but plagioclase is considerably or completely altered to a mixture of sericite, epidote, and calcite. This partly altered rock grades into fresh rock. The zones of alteration are narrow in the granite but are so extensive in the porphyry that it is doubtful if specimens quite free from mineralization can be found within the Leadville district.

Pyritic zones are also extensive in the Cambrian and Parting quartzites and "Weber grits" near the veins or related blankets. The pyrite fills interstices among the original quartz grains and is accompanied by microscopic sericite and inconspicuous secondary quartz. Sericite is abundantly developed at several places, however, near both veins and blankets, and evidently represents alteration of shaly beds.

The vein matter itself locally spreads from the fissure along bedding planes of the quartzite and "Weber grits," and rarely it replaces calcareous beds. No replacement bodies of workable size connected with veins have been noted within the quartzites at Leadville, but in the Red Cliff or Gilman district, north of Leadville, an ore replacing a calcareous bed in Cambrian quartzite has been stoped as a local enlargement of the Bleak House vein. This vein was described in 1913 by Means,[3] who favored the view that the vein was later than and crosscut the replacement deposit, but the evidence presented was not convincing. When the locality was visited by Loughlin in 1922 the vein itself, which had contained pyritic ore enriched in silver, had been worked out, and similar ore from adjacent parts of the replacement deposit had also been exhausted. The ore that remained in the walls of the stope was rather fine grained zinc or zinc-lead sulphide averaging 15 ounces to the ton in silver. There was no opportunity to study its relation to the pyritic silver ore.

Similar deposits due to the replacement of beds in the "Weber grits" have been noted along the Garbutt vein and some of the Ibex veins.

[3] Means, A. H., Geology and ore deposits of Red Cliff, Colo.: Econ. Geology, vol. 10, pp. 1-27, 1915.

The stockworks have been developed where veins connect with shattered quartzite, "Weber grits," or porphyry at the intersections of fissures. They consist of networks of veinlets which cement and to a minor degree replace the fragments of rock. The Antioch stockwork, worked by an open cut in the eighties, is entirely in porphyry and has a roughly chimneylike shape. At the surface its north-south diameter is 215 feet and its east-west diameter 150 feet. It tapers downward, and the ratio of ore to rock fragments increases from top to bottom. The ore is entirely oxidized. The South Ibex stockwork is in "Weber grits" and a few intercalated sills of Gray porphyry. It has a roughly elliptical plan, with its longer axis parallel to the Ibex No. 4 vein. On the Ibex 500-foot level it measures 130 by 120 feet; on the 900-foot level, 150 by 40 feet. These limits are determined by the contents of the ore rather than by any marked decrease in the ratio of ore to rock fragments. The two stockworks examined in the Cord mine are at the intersection of the Cord vein with the Tucson fault zone and have been productive on the northwest or hanging-wall side of the Cord vein. The lower stockwork is in Cambrian quartzite at the ninth level, and the upper in a Gray porphyry sill cutting White limestone at the sixth level. Ore of the same character has been reported in the intervening White limestone or transition shale, where shattering evidently permitted free circulation across the shale beds; but the ore mined in the limestone along the Cord vein has been taken mostly from blanket replacement deposits.

The extent to which the character of the ore may be influenced by that of the wall rocks is strikingly illustrated by the No. 63 Ibex vein and its connected blankets. Where the walls are of porphyry, pyrite is the dominant mineral and forms relatively fine, even-grained masses, but where the ore body passes into "Weber grits" the amount of quartz gangue increases markedly and the pyrite consists of very coarse-grained aggregates and isolated crystals, mostly of cubic shape, which reach more than an inch and rarely 4 inches in diameter.

In the limestones, particularly in the beds that alternate with shaly beds, nearly all the veins spread out into blanket ore bodies. Where the veins approach their upward terminations, as in the Nos. 3, 16, and 26 veins of the Ibex group, the blankets are unusually large and the fissures themselves terminate entirely; but where the veins are strongly developed the blankets extend out as branches at irregular intervals and the veins continue with undiminished intensity. The blankets in general have their longest dimensions parallel to the strike of the veins with which they are connected; but in the Winnie-Luema vein the northeastward trends of the blankets are determined by branch faults or fissures that seem to have guided the solutions and localized their action.

Very few of the veins pass through either shaly strata or limestones without the development of lateral shoots of ore; indeed, it would be a matter of great difficulty to find among the Ibex veins one without such auxiliary shoots attached to it at some portion of its course. These blanket bodies are much more abundant than can be appreciated from an examination of the mine maps or sections, because many of them, not having been sufficiently profitable to pay for exploration, were left unexplored and are not recorded on the maps and sections.

BLANKET ORE BODIES

GEOGRAPHIC DISTRIBUTION

By far the greatest part of the total tonnage of ore from the Leadville district has come from the large bodies formed by the replacement of limestone, commonly termed blanket deposits. Besides these a few similar though much smaller deposits replacing quartzite and "Weber grits" have also been mined. These blanket ore bodies are widely distributed throughout the district, as shown in Plate 45, and have been worked in a few places to the east and south of the area there represented; but the largest are in the western half of the district. They commonly occur in groups, some merging into one another and others isolated.

In much of the intervening and surrounding areas the limestones have been either eroded, displaced by intrusive stocks of porphyry, or so deeply buried beneath glacial deposits or the Weber (?) formation that thorough prospecting has not been attempted. Elsewhere they have been found to be barren or of too low grade to pay for mining. The barren and unprospected areas are considered in chapter 14 (pp. 323–326).

As the larger mining companies have kept excellent progress maps the positions and outlines of the larger blanket ore bodies are adequately represented in Plate 45; but maps of several of the smaller properties could not be obtained, and it has therefore been impossible to represent all the ore bodies. This statement applies particularly to the old properties in and between Stray Horse and Little Stray Horse gulches, and in less degree to the properties on Yankee Hill. This deficiency, however, does not seriously impair the value of Plate 45 as a basis for a general study of the distribution of the ore bodies. The most striking feature of their distribution is the roughly radial arrangement of the groups around the intrusive center of Gray porphyry at Breece Hill. Many of the single ore bodies also have a radial arrangement around this center. There are exceptions, however, to both rules, as is to be expected from the fact, discussed elsewhere, that the location and grouping are controlled largely by other structural features, notably the reverse faults and normal faults and fissures formed subsequent to the intrusion of the porphyry sills.

RELATION TO COUNTRY ROCKS

The replacement ore bodies or blankets have been found in each of the sedimentary formations, but most of them are inclosed in the Blue or the White limestone. The Cambrian "transition shales" or "red cast beds," which contain many thin beds of limestone, also contain several ore bodies of considerable size in areas of intense mineralization, and in these areas the quartzites also contain a few small ones. Blanket replacement deposits are also present here and there along veins in the Weber (?) formation. The principal function of the shales, however, and particularly of the porphyry sills, has been to serve as an impervious cover beneath which the ore-forming solutions spread and replaced limestone.

Limestone.—The Blue limestone has contained the greatest number and the largest of the ore bodies so far mined, partly because the ore bodies in this formation were more easily discovered and worked and were more accessible to enrichment than those in lower strata. Many of the ore bodies in the White limestone and the underlying "red cast beds" lie beneath those in the Blue limestone and are therefore obscured in the mapping on Plate 45, but even with due allowance for this fact the difference in number and size is striking. In total production during the entire life of the district no other formation has excelled the Blue limestone in any considerable area, but the White limestone has been the most productive for several years in the Iron Hill areas and probably in the Carbonate Hill areas, and production from the Yak tunnel workings has largely come from ore bodies in the White limestone since 1913 or earlier. There are also fair chances of finding new ore bodies in certain undeveloped parts of the White limestone beneath ore bodies in Blue limestone. Drilling in the White limestone in the East Fryer Hill area in 1919 was disappointing. Mining in the White limestone in the Downtown area was also discontinued in 1923 but largely because of the high cost of operation and the rather depressed state of the metal market. Diamond drilling in other places has located ore of too low grade to encourage further development. These disappointments are offset by the large production from the deposits in White limestone in the Cord and Tucson mines in Iron Hill and the Wolftone and neighboring mines in Carbonate Hill, where ore deposition was intense along the Tucson-Maid fault zone. The White limestone and underlying "red cast beds" elsewhere along this zone, especially beneath ore shoots in Blue limestone, are well worthy of thorough prospecting. The White limestone, however, is less pure than the Blue limestone and is not covered by so thick and impervious a cover to dam back the ore-forming solutions, and therefore it should not be expected to contain as extensive ore bodies as the Blue limestone away from centers of intense ore deposition. Solutions reaching the Blue limestone were obliged to travel along it slowly for long distances, whereas those which began to migrate along the White limestone were likely to escape upward and deposit their ore in the Blue limestone.

Quartzite.—The Parting quartzite and the Cambrian quartzite beneath the "red cast beds" contain a few ore bodies. Ores in the Parting quartzite are known in the Maid, Greenback, and Wolftone mines and in the workings from the White Cap and Cord winzes in Iron Hill. They are usually small and pyritic and either form connections between ore bodies in the limestones above and below or adjoin mineralized fissures. They are made up of stringers of ore along closely spaced intersecting fractures, with disseminated particles of sulphide between them, and do not usually form continuous masses of solid ore.

The Cambrian quartzite beneath the "red cast beds" rarely contains blanket ore bodies; the few that have been found are either thin beds replaced by pyrite, rarely more than 1 foot thick and usually connected with vertical fissures, or downward extensions of ore bodies in the "red cast beds" or "transition shales." An unusual ore body occurs in the Tucson mine about 60 feet below the top of the quartzite. It partly fills small caves dissolved along certain shattered beds and partly replaces the wall. It is connected with vertical mineralized fissures carrying the same minerals. The ore was unusually rich in silver, gold, and bismuth and contained considerable galena and zinc blende, with minor quantities of chalcopyrite, whereas ore in the quartzite usually consists almost entirely of pyrite.

Thin, flat beds of sulphides in the Cambrian quartzite have also been found in the Shenango and Maid mines. A large body of oxidized ore which was found in the Hibschle mine of the Downtown district lay mainly in the transition shales immediately beneath the White limestone, but extended downward into the Cambrian quartzite. Thin layers of sulphide are frequently penetrated by the diamond drill well within the Cambrian quartzite, but they are usually of too low grade to justify mining.

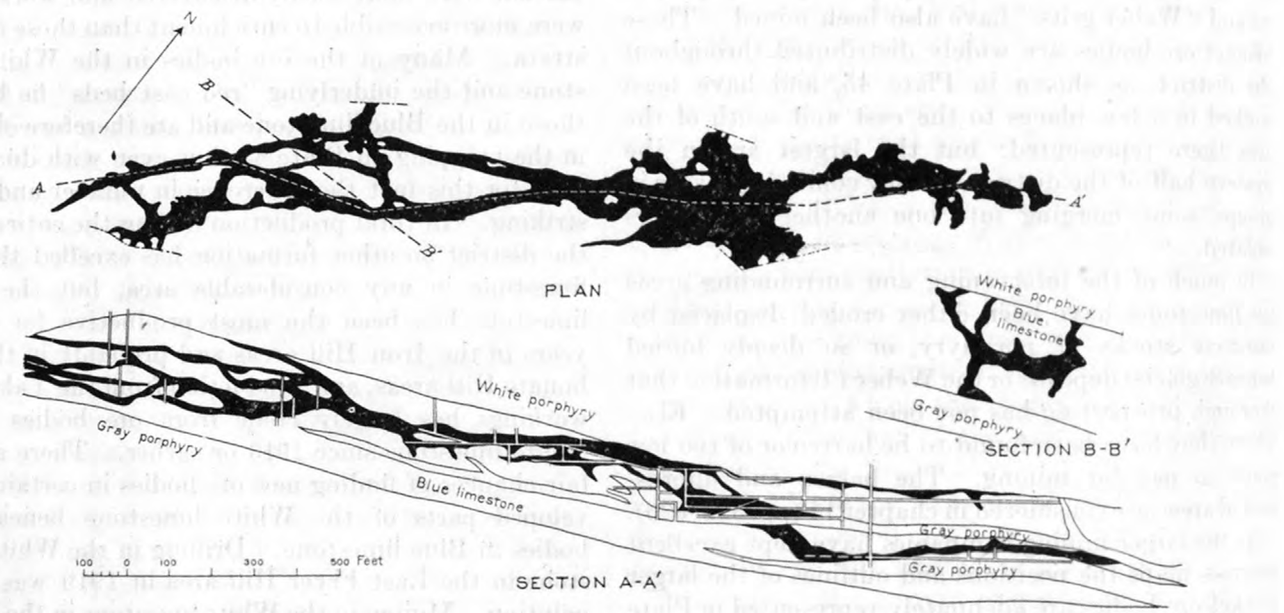


FIGURE 56.—Plan and sections of the Gold ore shoot, Iron Hill. (After A. A. Blow)

Weber (?) formation.—No blanket ores have ever been found within the black shales (the so-called "Weber shales") which lie at the base of the Weber (?) formation. A very few blanket replacement deposits of notable size have been found in the overlying "Weber grits"—for example, along the Garbutt vein (fig. 29 and pl. 57). A few lentils of limestone occur in the formation, and ore bodies have occasionally been found in them. Their exact statigraphic position can not be definitely determined, but they appear to be well above the black shale member. Some ore has been found in one of them on Prospect Mountain, north of the Leadville district, at a geologic horizon that must be many hundreds of feet above the base of the formation. Lentils of impure limestone have also been encountered in the "Weber grits" on Breece Hill in the vicinity of the Ibex property, but they are not known to be ore bearing. It is possible that some of the upper blanket ore bodies of the Ibex mine may replace lentils in the Weber (?) formation, but the excessively broken character of the intrusive bodies in this area makes the geologic horizon difficult to determine. It is not likely that ore bodies of size or consequence will be found in the Weber formation in the Leadville district, although in the Tenmile district, to the north, these limestone lentils are among the main ore-bearing beds.

ORE HORIZONS OR "CONTACTS"

The blanket ore bodies in the Leadville district, as is to be expected of deposits formed by solutions, nearly all lie at horizons where a readily replaceable rock is overlain by a relatively unreplaceable and impermeable rock. The replaceable rock is everywhere or nearly everywhere calcareous; the overlying rock may be shale, quartzite, or other sediment, but that above most of the important blankets is a sheet of porphyry, and the number of horizons favorable for ore varies principally with the number of porphyry sheets. The rocks at favorable horizons are, of course, not everywhere mineralized; suitable structure, and especially the presence of fissures through which the ore-bearing solutions may reach these horizons, are essential to the formation of large bed deposits. The horizons at which the blankets commonly occur are locally known as "contacts," and at any given place they are numbered in descending order, regardless of their stratigraphic position. At most places, however, the "first contact" is the horizon at which the main sheet of White porphyry overlies the Blue limestone. Although the limestone-porphyry contacts are on the whole the most productive, the localizing effects of sedimentary layers may conveniently be presented first.

The ores in the Blue limestone attain their greatest extent in its upper portion, immediately below either the overlying black shale or a porphyry mass that lies at or a little below the same horizon. From this horizon downward, where the limestone is not interrupted by additional intercalated intrusive porphyries, the ore bodies occur in somewhat diminishing number. Immediately above the Parting quartzite, and from that horizon upward for distances that differ in different localities, but with a possible maximum of 30 feet, the limestone is usually thinner bedded and interrupted by thin beds of shale alternating with quartzite beds.

Some ore bodies that occur within this shaly portion have replaced the thin limestone beds only, and others have replaced the shale and quartzite as well.

In the middle part of the Blue limestone ore bodies are found entirely inclosed in limestone, as in Rock Hill (pl. 59), but ore bodies are less common where intrusive sheets of porphyry are absent than where they are present and form impermeable barriers that favor concentration of the ore.

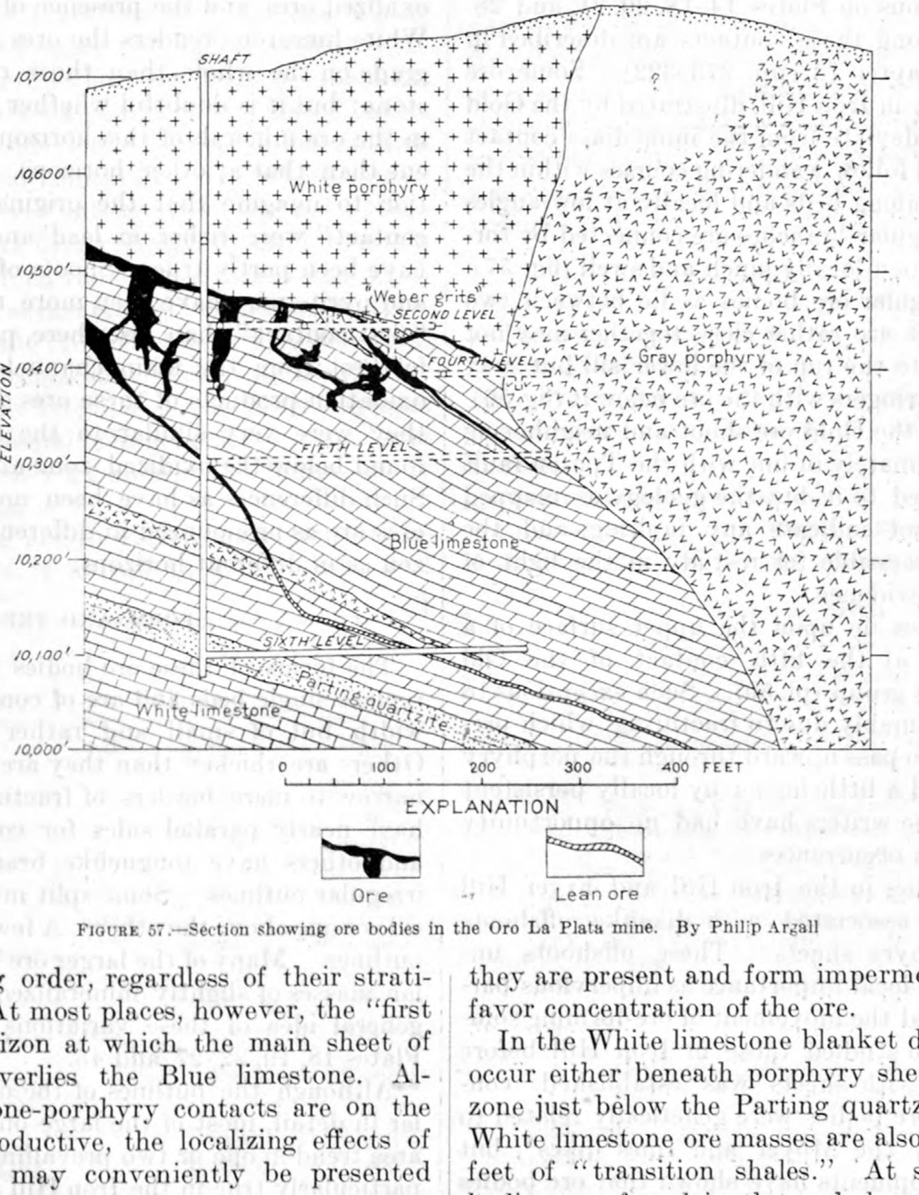


FIGURE 57.—Section showing ore bodies in the Oro La Plata mine. By Philip Argall

In the White limestone blanket deposits commonly occur either beneath porphyry sheets or in the shaly zone just below the Parting quartzite. Beneath the White limestone ore masses are also common in the 40 feet of "transition shales." At several places ore bodies are found in these shales, although they are absent from the purer limestone layers above. Their repeated preference for these shaly beds seems to be due more to the mechanical effect which the thin, impervious, and comparatively resistant shales have had in stopping the upward passage of mineralizing waters and directing their circulation along the intercalated limestone beds than to any chemical cause. They have thus been formed in spite of the less replaceable nature of the shale layers and are likely to contain correspondingly high percentages of siliceous gangue. A few ore bodies appear to be entirely inclosed in White limestone, but it is probable that subordinate shaly layers have determined their position.

Porphyry sheets are numerous in some places and together with the shales already mentioned have produced as many as ten or eleven "contacts." These "contacts" in different parts of the district are shown in Plate 59, which summarizes the pertinent structural data discussed in chapter 5 (pp. 60–106) and represented in the sections on Plates 14–18, 20, 21, and 28. The ore bodies along these contacts are described in some detail in chapter 13 (pp. 273–322). Some ore bodies, particularly in Iron Hill, illustrated by the Gold ore shoot (fig. 56) deviate from the immediate contact with porphyry and follow wandering courses within the limestone, locally along beds and locally at low angles to the beds. Irregular branches are connected by tortuous channels, which locally pinch and swell (fig. 57). Such of these irregular ore bodies as lie between two porphyry sills that are rather close together may not only reach down to the top of the lower sill but may even connect by stringers with the ore below it (fig. 56). The deviations of the Gold ore shoot and neighboring shoots are approximately in line with the Tucson fault and may be related to it, but the geology as mapped by Blow [4] does not indicate any faulting, and the workings are inaccessible for restudy in the light of recent structural evidence.

A few ore bodies lie upon the upper surface of a porphyry sill, as at the fifth contact of the Old Mikado-Shenango group (pl. 59). Such exceptions to the rule are presumably due to fracturing, which permitted solutions to pass upward through the porphyry only to be stopped a little higher by locally persistent shale beds, but the writers have had no opportunity to study any such occurrences.

Certain ore bodies in the Iron Hill and Fryer Hill areas are closely associated with dikelike offshoots from Gray porphyry sheets. These offshoots undoubtedly were of local importance as impervious barriers that restricted the movement of ore-forming solutions. Blow, who studied those in Iron Hill before their connection with sheets was established, concluded that the ore bodies were genetically related to them, particularly the Moyer and Imes dikes [5]; but subsequent developments have shown that ore bodies are quite as numerous and large in places free from dikes. It may also be noted that ore bodies are especially abundant in the vicinity of Gray porphyry intrusions regardless of shape, but this is due to the access afforded to the solutions by fracturing of the strata during the intrusion and does not imply that the Gray porphyry is the immediate source of the solutions.

[4] Blow, A. A., Am. Inst. Min. Eng. Trans., vol. 18, pp. 145-181, 1890

[5] Idem, pp. 154-156.

RELATIVE RICHNESS OF ORES AT DIFFERENT "CONTACTS"

The ores of the uppermost horizon, which throughout most of the district is the contact between White porphyry and Blue limestone, are nearer the surface and therefore more extensively oxidized than those at the contact between Gray porphyry and Blue limestone, and those in the White limestone are nearly everywhere sulphides. Considerable enrichment in silver has undoubtedly taken place in the thoroughly oxidized ores, and the presence of shaly matter in the White limestone renders the ores replacing it of lower grade on the whole than those replacing Blue limestone; but it is doubtful whether the ratio of metals in the ore minerals of this horizon is essentially different than that at other horizons. There is a temptation to imagine that the original ores of the "first contact" were richer in lead and silver. This may have been partly true. Shoots of galena low in zinc and pyrite may have been more numerous along the "first contact" than elsewhere, particularly in places farthest from the main channels of supply; but the oxidation products of these ores show that as a whole they were very similar to the mixed sulphide ores found below the oxidized zone at all the "contacts." Such differences as have been noted in the sulphide ores are as pronounced in different parts of one horizon as in different horizons.

FORM AND TREND

The forms of these ore bodies vary greatly. Some replace single beds and are of considerable length and width but of small and rather uniform thickness. Others are thicker than they are wide, and in places narrow to mere borders of fractures (fig. 57). Some have nearly parallel sides for considerable distances, and others have tonguelike branches and generally irregular outlines. Some split into two parts, side by side or one above the other. A few have nearly circular outlines. Many of the larger ore bodies inclose irregular masses of slightly mineralized or barren rock. A general idea of these variations may be gained from Plates 18, 19, 22, 27, and 45.

Although the outlines of the ore bodies are irregular in detail, most of the large ones in any restricted area trend in one or two prevailing directions. This is particularly true in the Iron Hill area, where the main ore bodies, whether single or composite, are roughly parallel and trend east-northeast. Other groups of roughly parallel ore bodies are in the vicinity of Fryer Hill and Graham Park and to the north of South Evans Gulch. Less marked parallelism may be noted at other places.

BOUNDARIES

As most of these ore bodies are bounded along their upper surfaces by sheets of porphyry or beds of shale or quartzite, their tops conform to the bedding, but their sides and bottoms are commonly irregular. In some places thin beds or slabs of limestone between porphyry or shale have been almost completely replaced. This is strikingly illustrated by the old replacement bodies of the Fairview and Fryer Hill area, which were the first ones examined by Emmons (pl. 67), and by a large ore body inclosed in White porphyry in the Moyer mine. The origin of these ore bodies was recognized only after unreplaced remnants of Blue limestone were exposed in the stopes.

Within the White limestone and the underlying "transition shales" so many partings of difficultly replaceable shale intervene between beds of dolomitic limestone that numerous completely replaced layers of limestone occur, some only a few feet or inches thick but of considerable horizontal extent. Where mineralization has been very intense, even the more resistant shaly layers have been replaced by ore for certain distances, beyond which the ore body ends in a series of prongs or wedges separated by unreplaced rock.

In several places the ore bodies depart entirely from their contact with unreplaceable rocks, and their upper boundaries become as irregular as the lower. Stopes in these ore bodies resemble in general form the caves that have been formed by solution of limestone by underground streams.

The passage from ore to barren rock along these irregular boundaries is abrupt in some places and gradual in others. Abrupt transition is particularly characteristic within the Blue limestone. Where the transition is gradual the rock is much fractured or shattered, and the ore extends along the fractures, which decrease in number away from the main ore body. These shattered border zones are rarely more than 10 feet thick, and the fragments of rock in them are impregnated with ore and gangue minerals.

The relation of the form of ore bodies to the channels through which the ore was introduced is obscured in many places by oxidation, but in some places extensive ore deposits are associated with shattered zones that are terminated or interrupted by layers of shale or porphyry. Where fissures and sheeted zones are open and not interrupted the ore commonly forms narrow linings along them and rarely extends into the walls for any considerable distance. Where the fissures or shattered zones are interrupted the ore-forming solutions continued their progress along bedding planes and minor joints, but they were so impeded that there was opportunity to spread into and react with large volumes of rock.

DIMENSIONS

The intricate shapes of the rèplacement ore bodies render exact measurement of dimensions somewhat difficult, but the accompanying table will give an idea of the maximum dimensions of some of the larger ore bodies.

Many smaller blankets occur, but their tabulation would serve no useful purpose, as the table will show how large some of the ore masses are.

Approximate maximum dimensions, in feet, of some of the larger blanket ore bodies

Name	Length	Width	Thickness	Remarks
North Iron shoot	3, 100	520	60	Length includes a faulted portion west of the Iron fault.
South Iron shoot	1, 500	400	60	
Gold Ore shoot	2, 750	300	120	Faulted off at northeast end.
White Cap South shoot	1, 100	200	50	Shoot originally supposed by Blow to be continuation of White Cap shoot.
Moyer Main shoot	2, 050 NE. 1, 400 N. 5° W.	500	90	Second contact shoot, formed by the junction of two shoots of different trend. The lengths of both are given. Average thickness about 50 feet.
Vivian-Hall-Rickard-Stone shoot.	2, 000	500	110	Shoot thick at north end but much thinner at south end.
Rock shoot	800	300	30	
Reindeer-Bessie Wilgus shoot.	900	500	50	
Crescent-Catalpa-Morning Star-Wolftone-R. A. M. shoot.	3, 550	1, 000	50	Probably a composite of several shoots.
Small Hopes upper shoot	1, 150	220	40	In small upper contact parting.
Mahala "second contact" shoot.	1, 150	200	55	
Greenback "third contact" shoot.	440	300	200	An example of nearly equidimensional shoot. (Determined only by drills.)
Bangkok-Jamie Lee shoot	1, 220	Average 30	Unknown	An example of a long, narrow shoot.
Pennsylvania shoot	900	About 300	Not over 6	An example of a siliceous gold shoot.
Little Ellen-New Years shoot.	1, 460	450	Not over 50	An example of a very broad but thin "first contact" shoot. Average thickness probably 5 feet.

ORIGINAL ORES

CLASSIFICATION

As oxidation has thoroughly changed the character of the ores in many of the blanket ore bodies, particularly in the Blue limestone, the ores must be considered under two general heads—sulphide ores and oxidized ores. The sulphide ores have been altered considerably near the surface of ground water, by leaching, enrichment, or both; but the altered ores are very subordinate in quantity to the original sulphide ores. The character of the original sulphide ores is of especial interest because of its bearing on the origin of the ores and the relations, already discussed at some length, of the blankets to the veins. The oxidized ores and the enriched sulphide ores, however, are more conveniently considered in chapters 11 and 12 (pp. 220–272), which follow that on the genesis of the original ores.

The primary ores of the replacement bodies or blankets are usually of comparatively simple mineral composition. They contain a few common minerals in relatively large amounts, together with small though important quantities of less common species. They are in the main mixtures of pyrite, sphalerite, galena, and, locally, subordinate chalcopyrite, with quartz (generally in the form of jasperoid) and variable though usually small amounts of manganosiderite or a related carbonate. In some localities the sulphides greatly preponderate; in others the quartz or jasperoid. In still other places one portion of an ore mass is more siliceous than another, both varieties occurring together in the same mine. The carbonates are present in many of the ores but entirely absent in others. In some places they occur in great quantity and are rather uniformly distributed through the ore bodies, but more commonly they form nearly pure masses enveloping the sulphide ore and distinguishable with difficulty from the inclosing limestone.

Added to these more abundant minerals are smaller quantities of argentite; of bismuthinite, including "kobellite" and "lillianite," which locally so preponderate as to form a separate class of bismuth-silver ores; and here and there of barite. Mingled with the ore are also residual masses of limestone, shale, and porphyry, which have been usually partly to completely altered by mineralizing solutions.

The component minerals of the sulphide ores are mingled in very different proportions, and all gradations exist between equal mixtures and masses composed principally of one mineral. No entirely satisfactory classification that will include all the possible mineral combinations can be devised, because of the varying proportions, but for purposes of description it is possible to adopt a grouping that will serve to distinguish the more abundant varieties, of which the others are merely to be regarded as mixtures. The larger divisions can be made on the basis of the relative quantities of gangue minerals and sulphides; the minor divisions on the basis of the relative abundance of the different metallic sulphides. In this manner we may arrive at the following grouping:

1. Massive sulphide ores, consisting of preponderating amounts of metallic sulphides:
   - *a.* Pyritic or iron ores.
   - *b.* Galena or lead ores.
   - *c.* Sphalerite or zinc ores.
   - *d.* Chalcopyrite-bearing mixed sulphides or copper ores.
   - *e.* Mixed sulphides.
   - *f.* Argentite-bismuthinite, or silver-bismuth ores.
2. Carbonate sulphide ores, consisting of mixtures of sulphides and large amounts of manganosiderite.
3. Siliceous sulphide ores, consisting of mixtures of sulphides with large amounts of quartz or jasperoid:
   - *a.* Pyritic gold ores.
   - *b.* Chalcopyritic gold ores.

The first two of the above groups are merely variations of a single class, due to a relatively small or large amount of manganosiderite. The third group includes the siliceous ores of blankets directly connected with veins, which have already been considered, and a few similar ores that have not been proved to connect with veins.

MASSIVE SULPHIDE ORES

The basic ores may be subdivided according to the relative preponderance of the different component sulphides, which are mingled together in all proportions. Ores that consist chiefly of one sulphide are best designated by the name of that sulphide, although from the smelter's standpoint pyritic ores with iron in excess may be termed "iron ores," and the others may be designated by the principal base metal present. The rarer varieties that contain the bismuth and silver sulphides in considerable quantity may be termed "silver-bismuth ores." Ores with two or more sulphides present in large amount are called "mixed sulphide ores." Few of the blanket bodies where unenriched contain commercial quantities of copper, so that division *d* is unimportant, though the corresponding division in the group of enriched ores is locally of considerable extent. As the transitions from one division to another are gradual, no definite limits to the divisions may be set unless they are the minimum quantities of different metals present for which the miner is paid.

In order that the character of the ores may be most readily understood each of the five main divisions and the different mixed sulphide ores are separately described.

Pyritic Ores

CHEMICAL AND MINERAL COMPOSITION

The pyritic iron ores when completely fresh and unaffected by enrichment are often extremely pure aggregates of pyrite with relatively small quantities of other sulphides. Some of them contain enough silver to be profitably mined, but many large masses are of value chiefly for their fluxing properties or as potential sources of sulphuric acid. Bodies of nearly pure pyrite are found in the mines of Iron Hill, Carbonate Hill, Graham Park, Breece Hill, and Evans Gulch and are present in greater or less number in nearly all portions of the district where the sulphides have been extensively exploited. In some places the relatively pure pyrite forms the entire sulphide body, as in certain stopes of the Maid, R. A. M., Greenback, Mahala, Tucson, Moyer, Wolftone, Ibex, and other properties. In other places the pyritic mass forms only a portion of the total mass and grades into relatively pure galena or sphalerite, or into mixed sulphides.

The pyritic ores, though in some places notably free from gangue, in others contained larger amounts of quartz than the other sulphides, and some of them are very siliceous. The more siliceous pyritic ores are comparatively high in gold. In some places, as in the El Paso ore body on East Fryer Hill, the ore is an intimate mixture of pyrite and siderite with few, if any other minerals present.

The analysis given below of one of the so-called "white iron" or pyrite bodies of the Henriett-Maid mine furnishes an excellent example of very pure pyritic ore.

Analysis of pyrite from Henriett-Maid mine, Leadville, Colo.

[R. C. Wells, analyst]

Fe	46.26	CaO	0.004
S	53.25	MgO	.065
TiO_2	.11	$FeSO_4$	.33
SiO_2	.068	H_2O	.18
Cu	.078	CO_2	.08
Ag	.017		
Zn	.005		100.454
As	.007		

Specific gravity of specimen, 4.725; of powder, 4.964. Pore space, 4.5 per cent.

The calculated mineral composition is as follows: Pyrite, 99.27 per cent; chalcopyrite, 0.02 per cent; arsenopyrite, 0.02 per cent; sphalerite, 0.01 per cent; argentite, 0.02 per cent (or 5 ounces of silver to the ton). The arsenic indicates the source of the minute quantities of arsenic found in the flue dust of the smelters. The natural gangue, consisting of carbonate, quartz, and rutile (?), amounts to less than 0.5 per cent, and the ferrous sulphate was evidently produced during the grinding of the sample for analysis. Manganese was not determined but may be present and included in magnesia.

Besides large masses of such nearly pure pyrite as is represented by this analysis, there are many ore bodies composed mainly of a mixture of sulphides which contain bands or irregular masses of pure pyrite.

In order that the gradation of extremely pyritic ore into the mixed sulphides may be easily comprehended, a selected group of analyses is presented below, and the approximate mineral composition has been calculated from four of them. They are illustrative of the less pure pyritic ores in which the pyrite is still dominant. These are commercial analyses and not so complete as the analysis just given but are approximately correct for the more abundant sulphides.

No. 1 is the analysis cited above, repeated in part for the sake of comparison. Nos. 2, 3, 4, 5, and 8 are essentially complete as regards metal content, and calculation of enough sulphur to accompany them in the common sulphide minerals of the ore brings the totals close to 100 per cent. The manganese and a little iron, however, may have been present as manganosiderite, which would imply a correspondingly less amount of sulphur and the addition of a little carbon dioxide. The small amount of silica or "insoluble" present represents quartz with more or less sericite. Nos. 6, 7, 9, and 10 presumably contained relatively high proportions of soluble gangue minerals, probably carbonates, and as no determinations of CO_2 or the alkaline earths were made the summation falls considerably short of 100 per cent. The small amount of manganese recorded in analysis 7 indicates that very little manganosiderite was present in the soluble gangue Cadmium was not looked for, but minute quantities are doubtless present in the zinc blende.

Analyses of ores with dominant pyrite

	1	2	3	4	5	6	7	8	9	10
Fe	46.26	44.10	41.20	41.00	40.50	39.90	39.50	35.40	32.6	22.3
Pb			1.00	1.00	.80	1.00	.10	2.21	2.7	11.2
Zn	.005	3.20	5.00	5.50	9.00	4.50	7.15	14.24	8.3	.0
Cu	.078								.1	.2
Ag	.017	.046	.30	.034	.027	.028	.033	.014	.029	.074
SiO_2	.068	[a] 1.70	[a] 1.30	[a] 1.40	[a] 1.75	[a] 2.20	[a] 2.05	[a] 2.7	[a] 7.5	[a] 8.0
S	53.25	[b] 51.24	[b] 49.43	[b] 51.52	[b] 48.75	[b] 47.60	[b] 44.00	44.76	41.1	26.7
Mn			.70	.40	.40		.30			
		100.286	98.66	100.854	101.227	95.228	84.133	99.324	92.329	68.474
Au ounces per ton	Not det.	.16	.14	.10	.08	.09	.07		.05	.04
Ag do	5.00	14.80	9.50	10.90	8.30	9.10	10.35	4.5	9.20	23.7

[a] Insoluble. [b] Calculated.

1. Henriett-Maid mine, Carbonate Hill.
2-7. Iron Hill. Analyses furnished by courtesy of Iron Silver Mining Co.
8. Freeland, F. T., Am. Inst. Min. Eng. Trans., vol. 14, p. 189, 1886. Analysis by William R. Boggs, jr.
9-10. Analyses furnished by Ohio & Colorado Smelting Co.

Calculated mineral composition of certain ores

	1	8	9	10
Pyrite	99. 21	64. 01	66. 87	45. 28
Excess iron in carbonate (?)				. 61
Sphalerite (marmatite):				
ZnS	. 01	21. 19	12. 36	None.
FeS		8. 82	2. 32	
Galena	None.	2. 55	3. 10	12. 92
Argentite	. 01	. 014	. 04	. 074
Chalcopyrite	. 22		. 28	. 57
Silica	. 07	2. 70	7. 50	8. 0
	99. 52	99. 284	92. 47	67. 454

These analyses also bring out in a rather striking manner the relation of the gold and silver to the sulphide minerals. As is shown elsewhere in greater detail, the gold in nonsiliceous sulphide ore rises steadily with the increase in pyrite, and the silver content shows no relation to that of any other mineral in the ores. It has often been supposed that the silver is contained in the galena, but no such relation is apparent in these analyses.

TEXTURE AND STRUCTURE

By texture is meant the form and size of the mineral grains and their relation to one another, and by structure the larger features, such as banding and honeycombed structure, which involve the whole ore mass and are only in part dependent on the form and size of the grains.

The pyritic ores that are pure consist of pyrite grains which vary greatly in size and do not possess definite crystalline boundaries. In some of the coarser-grained varieties they show a slight tendency toward the development of crystal faces, but these are exceptional in the massive portions of the pyritic ore. In the finest-grained variety the crystal faces are so small that they can barely be distinguished with the naked eye and give the mass a peculiar velvety sheen.

The prevailing diameter of grain is perhaps 1 millimeter. The variations in the size of grain occur throughout the pyrite masses with little regularity. Extremely fine-grained masses are interrupted by those of very coarse grain, in some places abruptly and in others by gradual increase in size of grain. Whatever may be the size of grain the pyrite masses are commonly intersected by minute veinlets, ranging from mere threads up to some more than a quarter of an inch in width, which are filled with relatively coarse-grained pyrite, accompanied in places by sphalerite, galena, and chalcopyrite.

The very fine-grained pyrite is usually massive and contains few if any cavities. The slightly coarser-grained material, however, abounds in irregular cavities which give to it a well-marked cellular structure. Where these cavities have been protected from the access of surface waters they are generally empty and lined with well-developed glistening crystals of pyrite. The commoner crystal form is the pyritohedron, although the cube and octahedron are also sparingly developed. The pyrite crystals that project into these cavities are usually solid, but a few have a skeleton form like the galena crystals in Plate 48, *E*.

At the margins of the blanket masses, where pyrite is the principal ore mineral, the change to the surrounding carbonate rock is gradual, and the gradation zone consists of carbonate rock containing isolated crystals of pyrite. (See pl. 58, *C*.) These crystals of pyrite represent the earlier stages of replacement, and in some places in the fine-grained massive ore they can be seen surrounded by aggregates of irregular grains, just as in jasperoid formed by replacement of limestone quartz crystals are often found embedded in an aggregate of fine, irregular quartz grains.

In addition to the features just described many of the pyrite bodies show when viewed in mine workings a well-marked banding, which in some places is continuous with the bedding of replaced limestone but is more commonly of roughly spherical or ellipsoidal form. This banded structure is characterized by differences in size of grain and arrangement of the pyrite crystals, or by narrow cavities between successive layers. Similar banding is present in the mixed sulphide ore, where bands of zinc blende or galena alternate with bands of pyrite.

Zinc Blende Ores

CHEMICAL AND MINERAL COMPOSITION

The zinc blende or sphalerite ores, like the pyrite ores, are in some places almost entirely free from other sulphides; but the most purely sphaleritic ore grades, through varieties in which zinc blende is dominant, into mixed sulphide ore.

The sphalerite, described in detail on page 156, is nearly all of the dark ferruginous variety marmatite, popularly known as "black jack." Lighter-colored varieties, correspondingly low in iron, are present in small quantity in the ores of Iron Hill and South Iron Hill, but no chemical analyses of them are available.

Analyses of zinc sulphide ores with dominant zinc blende

	1	2	3	4	5	6	7	8	9	10
Zn	55.08	[a] 52.80	[a] 47.60	[a] 45.10	41.00	39.65	37.70	25.45	24.30	23.40
Fe	4.00	12.10	14.80	17.80	14.00	17.80	18.70	7.70	19.30	27.60
Pb	6.71				5.00	.70	.50	11.45	5.90	.80
Mn		(b)	(b)	(b)				.10	.10	.20
Ag	.32									
Au	Trace.									
S	32.44	34.7	35.70	36.40						
SiO_2	.92	.20	.40	.20	2.00	1.50	2.00	7.70	17.40	2.40
	99.47	99.80	98.50	99.50						
Gold ounces per ton					.02	.025	.02	.02	.01	.02
Silver do	94.50				7.00	6.50	6.20	9.25	2.60	4.60

[a] Zinc includes 0.1 to 0.35 per cent cadmium.
[b] Included in the iron; ranges from 1.3 to 3.7 per cent.

1. Minnie mine, Iron Hill, Leadville. Analysis by W. R. Boggs, jr.; cited by Freeland, F. T., Am. Inst. Min. Eng. Trans., vol. 14, p. 189, 1885. This analysis is not recalculated.
2. Adams mine, Carbonate Hill, Leadville. Analysis by A. W. Warwick.
3. Colonel Sellars mine, Iron Hill, Leadville. Analysis by A. W. Warwick.
4. Yak tunnel, Iron Hill, Leadville. Analysis by A. W. Warwick.
5. South Iron Hill. Average analysis of zinc ores for 1911. Furnished by courtesy of Empire Zinc Co.
6–8,10. Moyer mine, South Iron Hill. Analyses furnished by George O. Argall.
9. Tucson mine. Analysis furnished by George O. Argall.

Calculated mineral composition of certain zinc sulphide ores

	2	3	4	5	6	7	8	9	10
Sphalerite (marmatite)	[a] 90.6	[a] 83.9	[a] 84.2	73.5	[b] 71.0	[b] 67.5	[b] 45.8	[b] 43.7	[b] 42.4
Pyrite	9.0	14.3	15.0	13.3	22.1	24.6	6.1	31.5	49.6
Galena				5.7	.8	.6	13.2	6.8	.9
Argentite	Not det.	Not det.	Not det.	.0	.0	.0	.0	.0	.0
Insoluble (probably mainly quartz)	.2	.4	0.2	2.0	1.5	2.0	7.7	17.4	2.4
	99.8	98.6	99.4	94.5	95.4	94.7	72.8	99.4	95.3

[a] ZnS.Fe(Mn)S.
[b] Calculated on the assumption of 5ZnS.FeS for marmatite. In analyses 8, 9, and 10 the Mn is included in the marmatite.

These analyses are arranged according to their zinc content and represent ores ranging from practically pure zinc blende (marmatite) to mixed sulphides. Nos. 8 and 9 may be conveniently classified as zinc-lead ore, and Nos. 9 and 10 average about as much in pyrite as in blende. As carbon dioxide was not determined it is not known to what extent iron and manganese are present as carbonates instead of sulphides; but it is inferred that in analyses in which the totals are appreciably below 100 the deficiency is due largely to carbon dioxide and magnesia in manganosiderite or dolomite and to moisture.

The low gold content is in keeping with the rather low percentage of pyrite, but the ratio of gold to pyrite is by no means uniform. The silver content, as in the pyritic ores, is independent of the percentages of the other metals and is calculated as argentite.

TEXTURE AND STRUCTURE

Except where sphalerite occurs as groups of large crystals lining cavities, it forms a granular aggregate in which no crystals have well-developed boundaries. Its texture, like that of the pyritic ore, varies widely; it grades from an exceedingly fine-grained aggregate with a velvety sheen and an almost black color to coarser-grained material in which the individual grains are one-eighth of an inch or more in size. The coarser-grained ore shows a more pronounced brownish tinge, especially where the grains have been slightly shattered or the ore crushed or abraded.

In the finest-grained ore the blende is relatively free from cavities and is dense nonporous material, but with increase in size of grain much of the ore becomes cellular and shows irregularly distributed cavities, similar to those in the pyritic ore, lined with marmatite crystals. In some places cavities are so numerous that the ore is composed of a loosely coherent mass of black blende crystals. As in the pyrite ore, most of the cavities are empty, but some contain coatings of carbonates and, where they are within reach of surface waters, also kaolin and calcite.

The sphalerite ores that are pure do not usually show distinct banding, but if the light is allowed to fall on a freshly broken surface at a small angle a series of parallel shadowy bands representing the original sedimentary banding is commonly visible. These bands can often be detected even in ores that are free from shale and consist entirely of sphalerite. White chert lenses are also of common occurrence and contrast strikingly with the dense black sphalerite.

Where considerable quantities of galena and pyrite are present in the sphaleritic ore, the galena and blende are intimately mixed, though most of the blende finished crystallizing before the galena. The pyrite, even in small quantities, especially in the finer-grained blende, is earlier than the blende and occurs as distinct cubic crystals embedded in the granular zinc blende. These pyrite crystals were evidently developed in the limestone as a first stage of replacement (pl. 58, *C*), and the balance of the rock around them was then replaced by zinc blende. Where the relative amounts of the two minerals approach one another the characteristic banding or an evenly mingled arrangement is commonly present, and the two minerals appear to have formed at the same time (see p. 204); but close inspection shows that in at least part of the banded ores the pyrite bands were introduced first and the zinc blende later filled the linear cavities between the pyrite bands as well as cracks across them.

The distribution of the zinc sulphide ores much resembles that of the pyrite. Some blanket masses are composed almost entirely of zinc blende. Others contain shoots of nearly pure blende that pass gradually or abruptly into mixed sulphides in which pyrite or galena or both are uniformly disseminated with the blende. Again, the zinc-blende ores may form alternating bands in the pyritic ores. Zinc ores can not be said to be characteristic of any one portion of the district to the exclusion of others, for they occur in some quantity throughout the district. They are perhaps more abundant in the Carbonate Hill, Iron Hill, and Graham Park areas than elsewhere. They are distinctly subordinate to the pyritic ores but are believed to exceed the galena ores in total quantity.

Examined under the microscope the denser sphalerite ores are seen to consist chiefly of zinc blende, which is arranged in minute irregular grains of roughly rounded form. Sparsely but uniformly scattered among these grains are small quartz crystals in perfectly developed short, stout prisms, terminated by pyramids at both ends. They are set at all angles in the sphalerite matrix. Where the ore contains more gangue the grains of blende are more nearly rounded, though they have a crystalline outline, and are usually separated from one another by threadlike partings of an aggregate of a light transparent mineral. Where the gangue is still more abundant the blende and this light-colored aggregate form branching masses which penetrate one another in a very intricate mosaic. This light-colored aggregate consists of a mixture of carbonates, presumably of the manganosiderite group, and a small amount of mineral resembling chlorite, which have been derived from the original shaly material of the replaced country rock. Barite is also present in small quantity. Scattered here and there through the blende are cubes or irregular patches of pyrite and varying amounts of galena. In addition to these sulphides there are a few irregular patches of a blackish mineral which may be argentite. They are much less brilliant than the galena when seen in reflected light and in places form thin bands that surround the pyrite crystals or masses and separate them from the inclosing sphalerite. Unusually siliceous zinc sulphide ore consists of extremely jagged patches of blende scattered through a fine-grained clear mosaic of quartz. The quartz grains have irregular boundaries with one another but have crystal boundaries in contact with the sphalerite, which is evidently of later formation.

Galena Ores

MINERAL AND CHEMICAL COMPOSITION

Bodies of ore consisting exclusively of galena or of galena with very small admixtures of other sulphides are present in nearly all portions of the Leadville district but are much less common than either the highly sphaleritic or the highly pyritic ores. They are usually present as portions of bodies of mixed sulphides in which the lead content is locally higher than in the rest of the blanket mass, and they may pass gradually or abruptly into the mixed sulphides.

A natural supposition was current in the earlier days of development that the sulphide ores would prove to consist more largely of galena than of other sulphides, as comparatively pure lead carbonate bodies were of common occurrence in the oxidized zone and were more extensively developed than the iron oxide masses because of the relatively greater profit to be gained from them. It now seems beyond question that the pure carbonate bodies are not the oxidized representatives of pure galena masses of equivalent dimensions but are generally the lead-bearing remnants of a mixed sulphide body from which the zinc and to a less degree the iron have been removed by descending waters in the oxidized zone. Some lead carbonate shoots were undoubtedly originally solid galena masses before oxidation, but most of them probably differed but little from the ordinary mixed ores of the sulphide zone.

No analyses of nearly pure galena are available, as pure galena ores are much more rare than pure pyrite and sphalerite ores. An analysis of a specimen of lead ore from the seventh level of the Tucson mine was made by W. F. Hillebrand in the laboratory of the United States Geological Survey and illustrates the mineral composition of a common variety of lead sulphide ore.

Analysis and calculated mineral composition of lead ore from the seventh level of Tucson mine

[Analyst, W. F. Hillebrand, April 13, 1908]

Insoluble	5.25	Galena	51.27
Pb	44.40	Zinc blende:	
Zn	22.26	ZnS	33.22
Cu	.05	FeS	5.98
Sb	.01	MnS	.09
Sn	.01	Chalcopyrite	.18
Bi	Trace.	Pyrite	.88
Fe	4.78	Carbonates:	
Mn	.13	$FeCO_3$	1.97
FeS_2	.88	$MnCO_3$	.11
CaO	.27	$MgCO_3$	.50
MgO	.24	$CaCO_3$	.50
S (calculated)	[a] 20.63	Insoluble	5.25
	98.91		99.95

Cd, Te, As, Ni, Co, not found.

[a] Sulphur evidently calculated on the assumption that all the iron and manganese were present as sulphide. If the prevailing ratio of 5ZnS : 1FeS in zinc blende is assumed, a small excess of iron remains and may be calculated with MgO and CaO as carbonate. This adjustment and the arbitrary assignment of equal parts of Mn to zinc blende and carbonate gangue brings the calculated sulphur to 20.1 per cent, the calculated CO_2 to 1.28 per cent, and the total analysis to 99.66 per cent.

The microscope shows this ore to contain pyrite, sphalerite, galena, carbonate (probably manganosiderite), quartz, and a little finely divided material of light color, low refractive index, and low double refraction, which could not be definitely identified. Here and there a light-colored mineral (barite ?) in minute radial groups may be observed. If it is barite its percentage in the analysis is included in "insoluble." The copper was determined from 45 grams of the powdered ore. Tests were made on 45 grams for cadmium, tellurium, arsenic, nickel, and cobalt, but no trace of these elements could be detected. The trace of bismuth is probably present as bismuthinite. The lime and magnesia are undoubtedly carbonates, as carbonates are recognizable under the microscope, and the manganese is probably present in part as carbonate and in part as a minor constituent of zinc blende (marmatite). The insoluble matter is almost entirely quartz but may contain a little barite and some of the aluminous material from shaly partings in the original rock. Some of it is probably sericite, but still more is in the light-colored aggregate whose nature could not be definitely determined with the microscope. No positive evidence is available as to the minerals containing antimony and tin.

As a basis of comparison the following analyses are illustrative of the character of the ores with dominant galena from several parts of the Leadville district.

Analyses of ores with dominant galena

	1	2	3	4	5	6	7	8	9	10
Pb	72.65	55.00	50.86	46.90	46.20	44.40	43.50	43.10	42.10	40.30
Zn	5.66	----	12.86	10.50	11.10	22.26	12.80	13.20	12.50	9.80
Fe	1.60	3.85	9.30	12.20	11.90	Fe 4.78; Fe in FeS_2 .41	12.00	10.40	12.60	19.40
Ag	.14	.019	.039	.034	.035	Not det.	.034	.031	.032	.028
Au	Trace.	----	Trace.	.0009	.0006		.0006	.0006	.0006	.0009
S	15.66	[a] 12.97	24.50	[a] 23.49	[a] 25.20	21.77	[a] 25.56	[a] 23.85	[a] 25.91	2.80
Insoluble	4.12	15.00	1.88	2.40	1.90	5.25	2.00	2.50	2.60	
	99.83	86.84	99.439	95.52	96.36	98.73	95.89	93.08	95.74	72.33
Gold ounces per ton	----	Not det.	----	.03	.02	----	.02	.02	.02	.03
Silver do	41.5	5.50	11.50	9.95	10.20	----	9.80	9.05	9.20	8.30

[a] Calculated.

1. Galena ore from Minnie mine, Iron Hill. Analysis by W. R. Boggs, jr. Cited by Freeland, F. T., Am. Inst. Min. Eng. Trans., vol. 14, p. 189, 1886.
2. From Little Chief mine, 1880. See U. S. Geol. Survey Mon. 12, p. 623, 1886.
3. Mixed sulphides with dominant galena from Minnie mine, Iron Hill. Analysis by W. R. Boggs, jr., cited by Freeland, F. T., op. cit.
4-5, 7-10. From Moyer mine, Iron Hill. Average analyses of 50-ton lots. Furnished by George O. Argall.
6. Galena-sphalerite ore from Tucson mine, seventh level. Made in the laboratory of the U. S. Geological Survey by W. F. Hillebrand. Same analysis given in detail at top of this page. Repeated here for comparison.

If these analyses are recalculated on the same basis as the sphalerite and pyritic ores the following results are obtained:

Calculated mineral composition of galena ores

	1	2	3	4	5	6	7	8	9
Galena	83. 94	63. 55	58. 76	54. 18	53. 37	51. 27	50. 27	50. 05	48. 65
Zinc blende (marmatite):									
ZnS	8. 44		19. 16	15. 65	16. 54	33. 22	19. 08	19. 67	18. 63
FeS	. 71		1. 13	2. 82	2. 99	5. 98	3. 45	3. 55	3. 36
MnS						. 09			
Pyrite	2. 47	8. 27	18. 47	22. 36	21. 48	. 88	21. 08	17. 49	22. 48
Argentite	. 16	. 02	. 02	. 02	. 02	Not det.	. 02	. 02	. 02
Chalcopyrite						. 18			
Carbonates:									
$FeCO_3$						1. 97			
$MnCO_3$						. 11			
$MgCO_3$						. 50			
$CaCO_3$						. 50			
Insoluble	4. 12	15. 00	1. 88	2. 40	1. 90	5. 25	2. 00	2. 50	2. 60
	99. 84	86. 84	99. 42	97. 43	96. 30	99. 95	95. 90	93. 28	95. 74

In these recalculations the galena is to be considered as accurate, for the lead is present only as galena and the galena is pure PbS except for very small amounts of antimony which it may contain and which do not materially affect the calculation. Analysis 6, in which pyrite (Fe_2S) was separately determined, shows the composition of the blende to be 5ZnS.FeS. No. 10 has not been recalculated, as the assignment to pyrite of iron in excess of that ratio brings the total to 105 per cent. This iron is presumably present in both pyrite and carbonate. In analyses 1 and 3 a somewhat lower percentage of FeS than that commonly observed is assigned to the sphalerite, but the formulas given are presumably accurate, as sulphur has been determined and the analyses sum up close to 100 per cent. The ores represented by the other analyses presumably contained considerable amounts of soluble carbonates, which were not determined.

SILVER CONTENT INDEPENDENT OF GALENA

The indefinite relation of the silver content to lead, zinc, and iron sulphides shown in the foregoing descriptions of ores may be emphasized because of the common supposition that silver and lead in ores of these classes are closely related.

In addition to the analyses given above, more than 120 assays of Leadville ore containing lead and silver have been collected and are represented diagrammatically in Figure 58 in the order of increasing lead content. As nearly or quite all of the lead in the sulphide ores is present as galena, this diagram also represents the relation of silver to galena. No assays or analyses of nearly pure galena are available, but those represented in the diagram suffice to show the wide variation in the ratio of silver to lead.

The quantity of silver varies widely for any given percentage of lead, some of the highest percentages of silver being accompanied by low percentages of lead, and vice versa. These assays represent ores in which there is little likelihood of enrichment. All the samples were obtained from stopes in which the secondary copper sulphides—the only visible indication of sulphide enrichment—were absent. None of the assays represent certain residual nuclei of galena found in the oxide ores and reported to be invariably enriched in silver.

The absence of correlation between galena and silver is further emphasized by the persistence of silver to the same general extent in pyritic and sphaleritic ores that are entirely free from galena.

TEXTURE AND STRUCTURE

The galena, except where it occurs as linings of cavities, forms medium to coarse-grained masses whose grains have no crystal boundaries but interlock with one another. The diameters of the grains vary greatly, from a minimum of about 1 millimeter to a maximum of nearly 2 inches, even within a single small mass, and the uniformity of grain so commonly observed in both sphalerite and pyrite is lacking. The average diameter of the galena grains (one-fourth to one-eighth inch) is noticeably larger than those of the two other minerals. Galena that fills cavities in sulphide ore or in rock and has resulted from filling and not from replacement is invariably coarser grained, the grains reaching 1 inch or more in diameter. Where it incompletely fills cavities it forms brilliant crystals (pls. 47, *B*, and 48, *E*).

"Steel galena," composed of grains less than 1 millimeter in diameter, is comparatively rare. The grains are finest where mingled with sphalerite.

Where galena and pyrite occur together, galena was the later to crystallize, for the pyrite occurs as cubic crystals, rarely more than three-eighths of an inch in diameter, inclosed among irregular galena grains. A later generation of pyrite, however, occurs here and there, and some cavities in galena ore are lined with pyrite cubes. In the lean ores, quartz crystals are inclosed in galena and were clearly the first to crystallize. Where sphalerite and galena occur together, the grains of both minerals are prevailingly so irregular that it is difficult to prove any difference in age; but close inspection shows that where any difference is suggested galena appears to have crystallized later than the blende. In short, galena is the latest of all the important primary ore and gangue minerals.

Copper Ores

CHEMICAL AND MINERAL COMPOSITION

The copper-bearing sulphide ores are less readily interpreted than the lead, zinc, or iron sulphide ores, as their primary content may not be easily distinguished from that due to downward sulphide enrichment. Even in the deeper levels of the mines in Carbonate, Iron, and Breece hills secondary chalcocite appears as a black powder in the vugs of the ores, and unless analyses and specimens are examined together the relative quantities of the minerals containing the copper can not be estimated even approximately. Many of the ores contain chalcopyrite, and probably all of them would show a small percentage of copper if complete analyses were available. The invariable presence of chalcopyrite even in the purest pyritic masses, which are wholly unaffected by alteration, and as microscopic inclusions in zinc blende establishes its primary origin beyond question. In a few blanket bodies as well as in several veins chalcopyrite is unusually abundant, and as these occurrences are mostly within reach of downward-enriching waters their secondary origin is suggested; but no evidence has been found to prove that they are not local segregations of primary chalcopyrite. Chalcocite, on the other hand, occurs as sooty coatings of vugs, films on pyrite and zinc blende, and fillings of fractures in primary ore. So far as noted it has all been formed by processes of downward enrichment. It may therefore be stated that the primary ores all contain minute thinly disseminated grains of

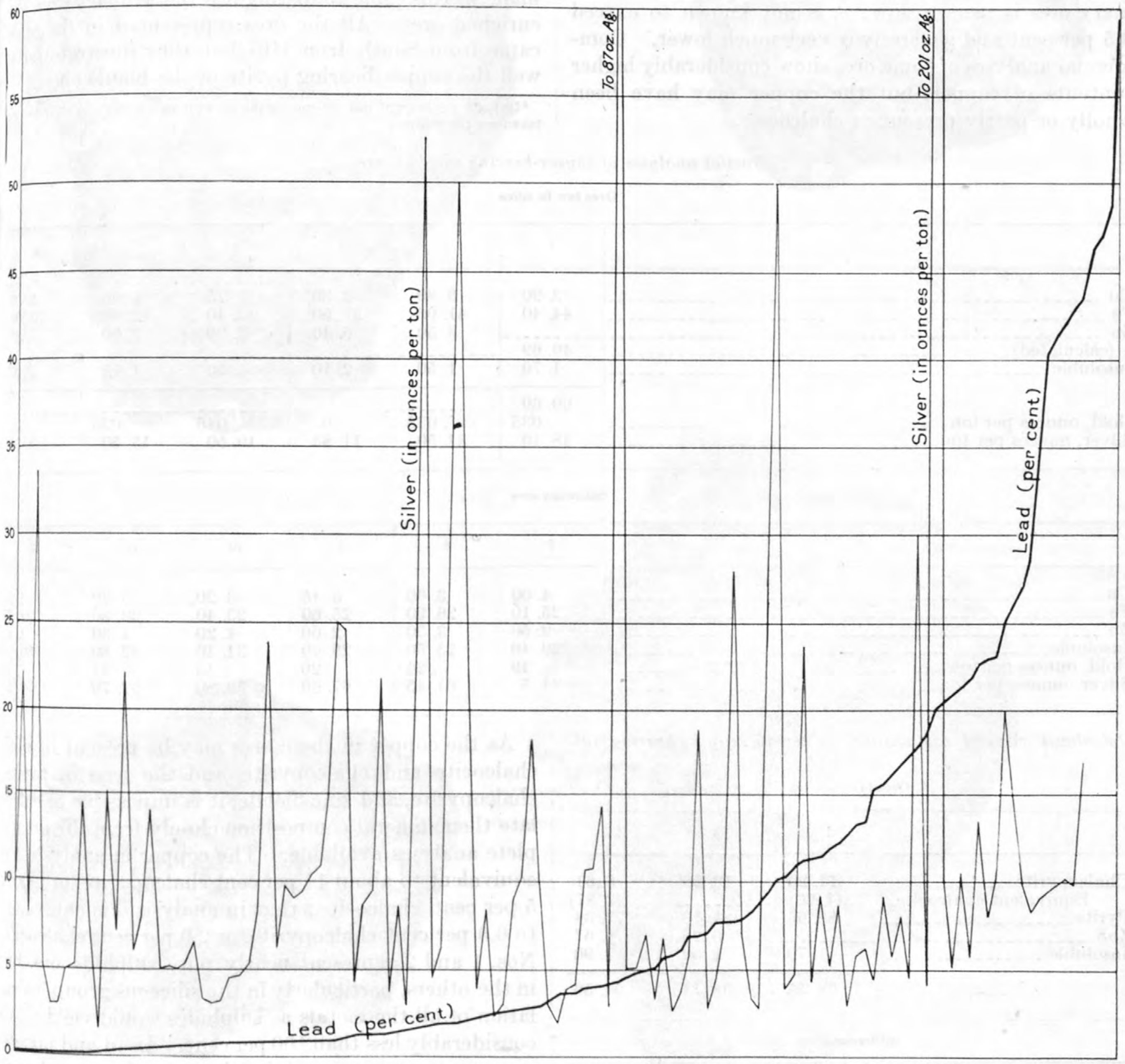


FIGURE 58.—Diagram showing lack of relation between silver content of sulphide ores and percentage of galena in the ores

chalcopyrite, in most places too small for detection by commercial methods of analysis, and that locally the chalcopyrite may be sufficiently segregated to constitute a primary copper-bearing sulphide ore; that the existence of secondary chalcopyrite, though possible, has not been proved, and that chalcocite of undoubted secondary origin is present in most ores that contain copper in commercial quantity.

The percentage of copper in the undoubtedly primary ores is usually low; it is not known to exceed 3.5 per cent and generally is very much lower. Commercial analyses of some ores show considerably higher contents of copper, but the copper may have been wholly or partly present as chalcocite.

The blanket ores in general are notably low in copper, as compared with the lode ores, which contain considerable though unevenly distributed quantities of chalcopyrite and which, owing to their nearly vertical positions, have afforded greater opportunities for downward enrichment with chalcocite.

The copper ores are in part very siliceous and may conveniently be divided into two classes according to silica content, as in the table below. No attempt is made in this table to distinguish the primary from the enriched ores. All the ores represented in the table came from South Iron Hill, but they illustrate fairly well the copper-bearing pyrite of the blanket ores.[6]

[6] Irving's manuscript did not specify the mines from which these samples were taken nor the analysts.

Partial analyses of copper-bearing sulphide ores

Ores low in silica

	1	2	3	4	5	6
Cu	3. 90	3. 80	3. 80	3. 25	2. 90	2. 30
Fe	44. 40	41. 90	37. 50	42. 40	42. 80	38. 00
Zn		3. 50	6. 40	3. 60	3. 00	5. 80
S (calculated)	49. 69					
Insoluble	1. 70	1. 50	2. 10	1. 60	1. 70	1. 90
	99. 69					
Gold, ounces per ton	. 035	. 035	. 03	. 045	. 035	. 035
Silver, ounces per ton	48. 10	31. 50	11. 85	19. 50	15. 50	8. 35

Siliceous ores

	7	8	9	10	11	12
Cu	4. 00	3. 60	3. 45	3. 20	3. 20	3. 00
Fe	25. 10	26. 90	25. 60	23. 40	22. 30	24. 50
Zn	2. 50	3. 30	2. 60	4. 20	4. 30	4. 80
Insoluble	29. 40	25. 50	29. 40	31. 10	32. 80	30. 00
Gold, ounces per ton	. 19	. 24	. 20	. 13	. 13	. 10
Silver, ounces per ton	41. 5	61. 45	67. 60	39. 80	52. 70	50. 20

Calculated mineral composition of certain copper-bearing sulphide ores

Ores low in silica

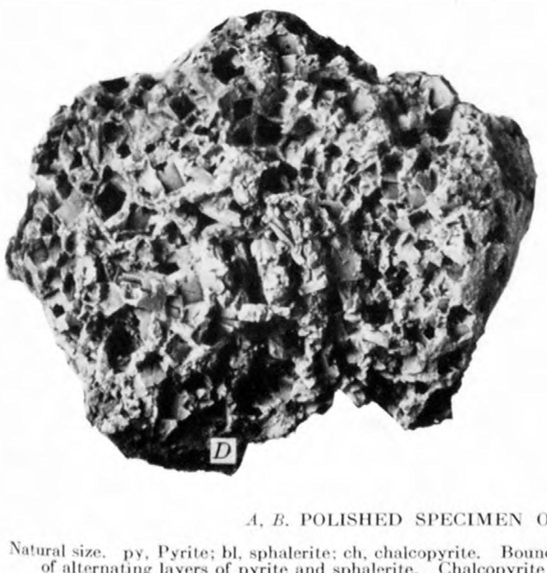
	1	2	6
Chalcopyrite	11. 20	10. 28	6. 61
Equivalent chalcocite	(4. 90)		(2. 87)
Pyrite	85. 65	81. 10	77. 38
ZnS		5. 26	8. 67
Insoluble	1. 70	1. 50	1. 90
	98. 55	98. 14	94. 56

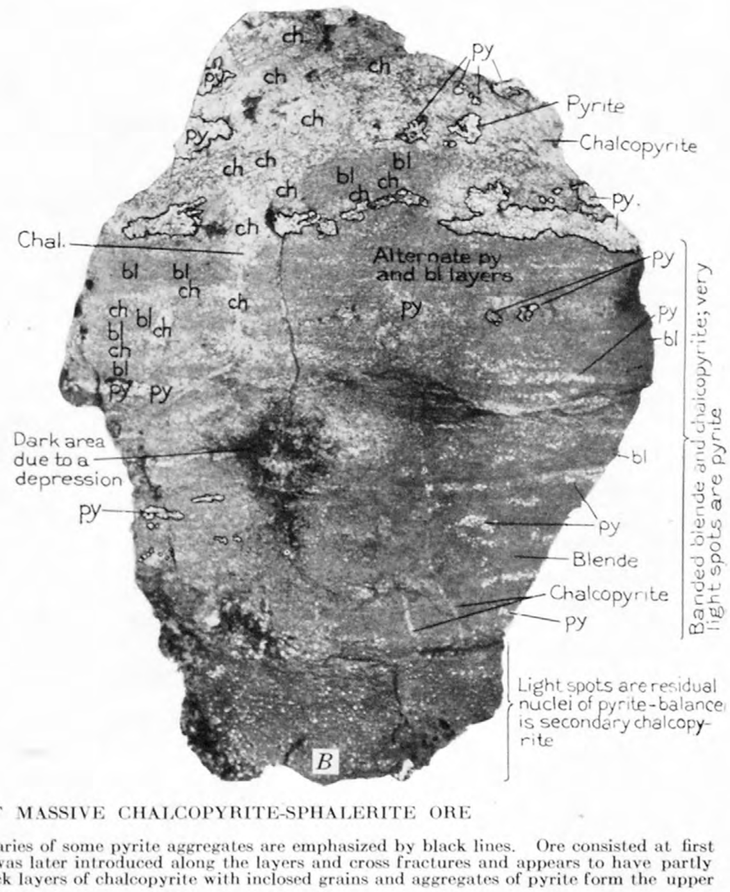
Siliceous ores

	7	11
Chalcopyrite	11. 56	9. 18
Equivalent chalcocite		(3. 98)
Pyrite	46. 43	41. 99
Sphalerite	3. 70	6. 43
Insoluble	29. 40	32. 80
	91. 09	90. 40

As the copper in these ores may be present in both chalcocite and chalcopyrite, and the iron in pyrite, chalcopyrite, and zinc blende, it is impossible to calculate their mineral composition closely from the incomplete analyses available. The copper in analysis 1 is equivalent to about 11 per cent chalcopyrite, or nearly 5 per cent chalcocite; that in analysis 6 is equivalent to 6.6 per cent chalcopyrite, or 2.9 per cent chalcocite. Nos. 1 and 2 represent nearly pure sulphide ore, but in the others, particularly in the siliceous group, calculation of all the metals as sulphides would yield totals considerably less than 100 per cent. Lead and manganese were not reported in these analyses and were evidently negligible.

There are no constant relations in these analyses between the precious metals and copper, though ores clearly enriched in copper usually contain more gold and silver than the corresponding primary ores. The gold and silver contents of the siliceous ores (Nos. 7 to 12) are distinctly higher than those of the ores low in



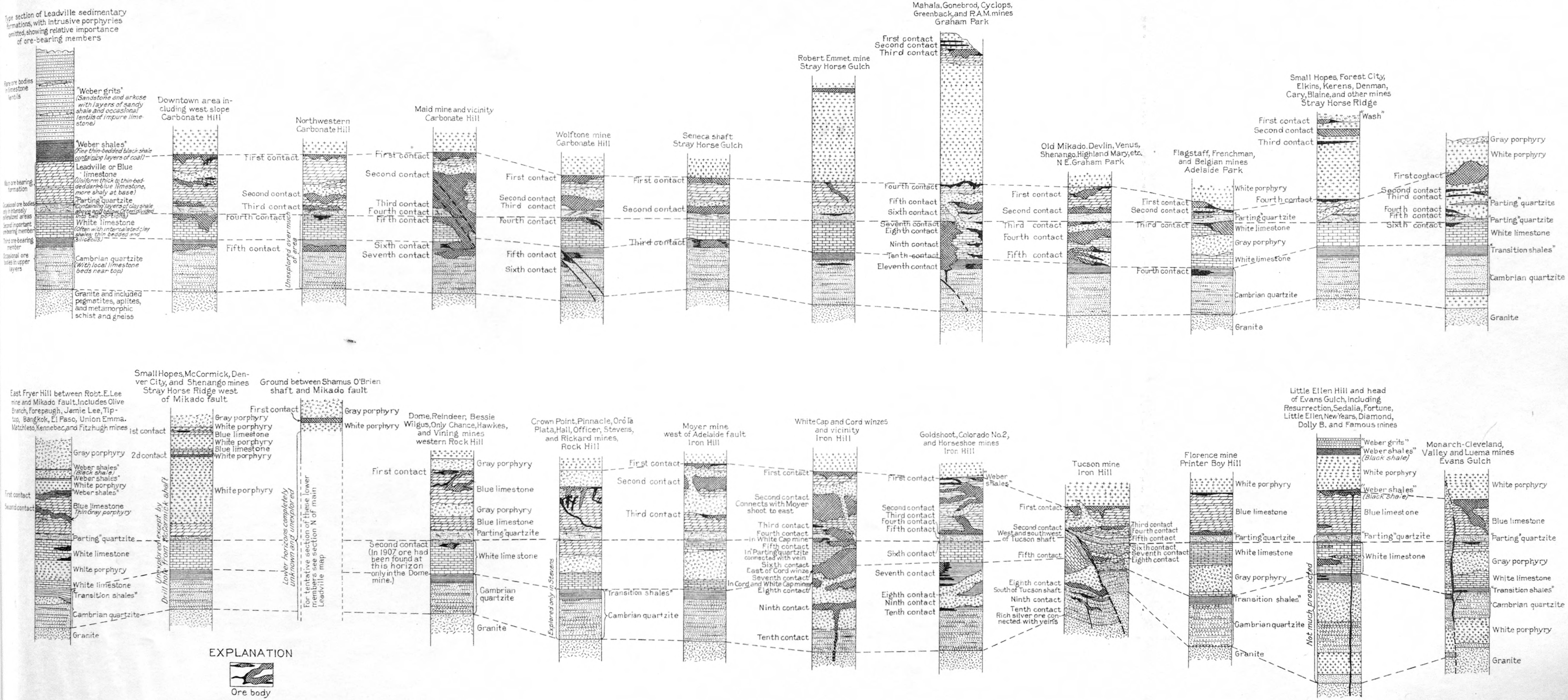


A, B. POLISHED SPECIMEN OF MASSIVE CHALCOPYRITE-SPHALERITE ORE

Natural size. py, Pyrite; bl, sphalerite; ch, chalcopyrite. Boundaries of some pyrite aggregates are emphasized by black lines. Ore consisted at first of alternating layers of pyrite and sphalerite. Chalcopyrite was later introduced along the layers and cross fractures and appears to have partly replaced the layers of pyrite but not those of sphalerite. Thick layers of chalcopyrite with inclosed grains and aggregates of pyrite form the upper and lower parts of the specimen

C. PYRITE CRYSTALS IN LIMESTONE AT THE MARGIN OF A MASSIVE REPLACEMENT BODY OF PYRITE

D. JASPEROID HONEYCOMBED WITH CUBIC CAVITIES LEFT BY THE LEACHING OUT OF PYRITE CRYSTALS, FROM OXIDIZED LODE ORE, IBEX MINE



COLUMNAR SECTIONS SHOWING POSITION AND RELATIVE SIZE OF BLANKET ORE BODIES IN DIFFERENT PARTS OF THE LEADVILLE DISTRICT, COLO.

Vertical scale

0 500 1000 1500 FEET

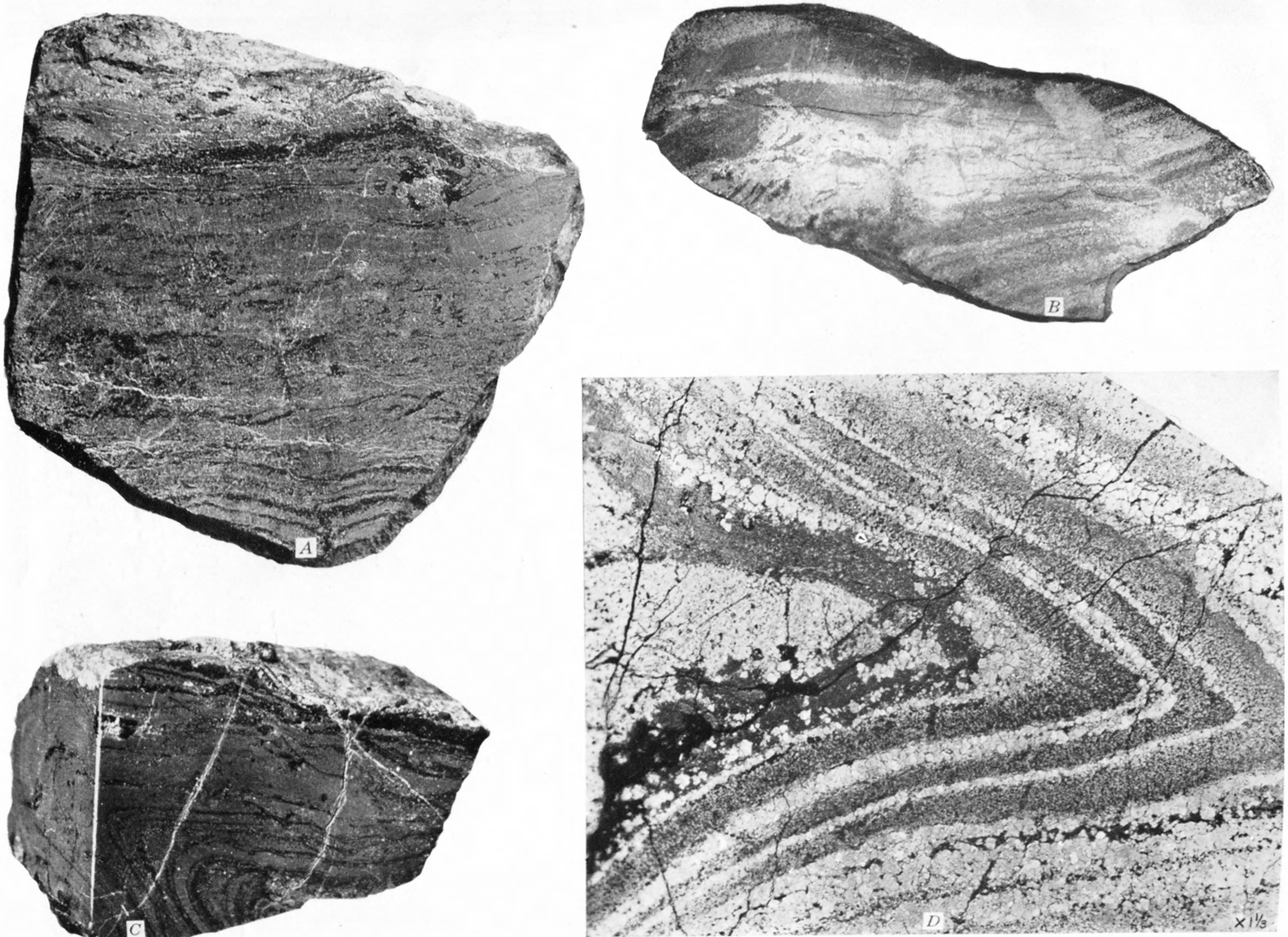
ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

A. IRREGULAR CONCENTRIC BANDING IN FINE-GRAINED PYRITE-SPHALERITE MIXTURE

B. PYRITE-SPHALERITE BANDING SHOWING FRACTURES ACROSS PYRITE BANDS FILLED WITH SPHALERITE, ALSO ISOLATED MASSES OF SPHALERITE IN THE MIDST OF PYRITE LAYERS

C. CONCENTRIC BANDING OF SPHALERITE-PYRITE ORE

D. BANDING OF PYRITE-SPHALERITE MIXTURE FROM SOUTH MOYER MINE



A. BANDING IN PYRITE-SPHALERITE ORE

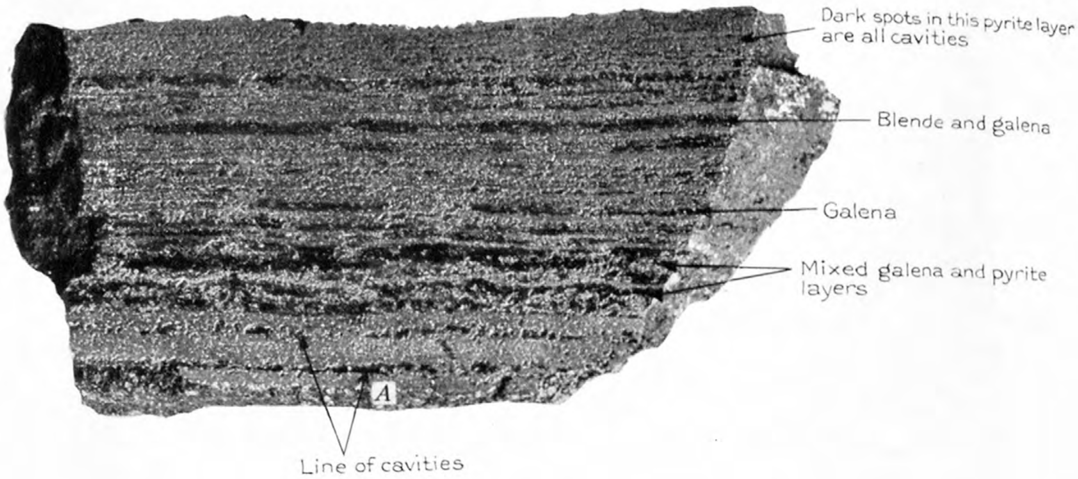
B. MINIATURE FAULTING IN BANDED PYRITE-SPHALERITE ORE

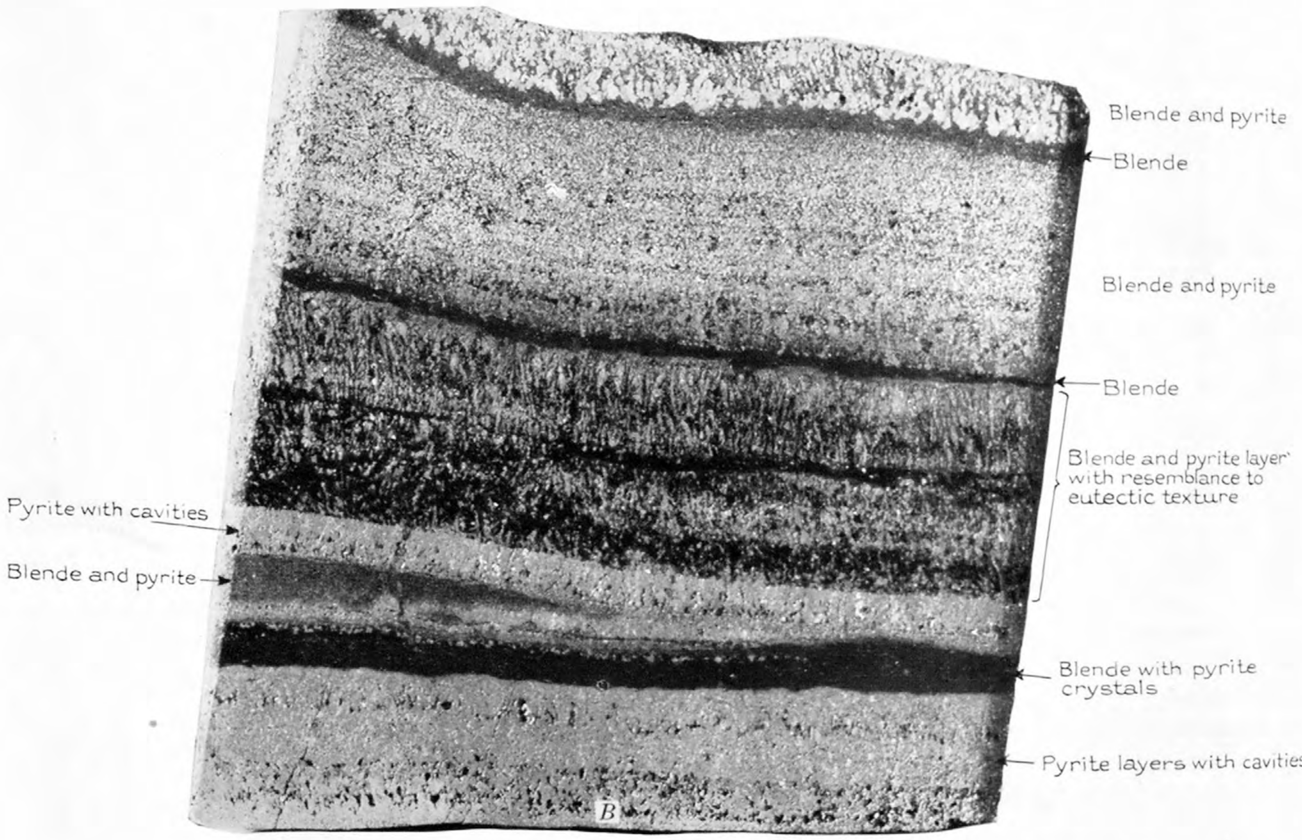
C. BANDING IN PYRITE-SPHALERITE ORE, WITH TWO FACES POLISHED TO SHOW CONCENTRIC BANDING

D. CONCENTRIC BANDING IN COARSE-GRAINED PYRITE-SPHALERITE MIXTURE

A. MINIATURE FAULTING IN FINE-GRAINED BANDED PYRITE-SPHALERITE ORE

B. MINIATURE FAULTING IN BANDED ORE





A. BANDED STRUCTURE IN GALENA-SPHALERITE MIXTURE REPLACING WHITE LIMESTONE BEDS

B. COARSER VARIETY OF BANDING THAN THAT SHOWN IN *A* silica, but the high percentages of precious metals may be due to enrichment.

The siliceous copper ores do not differ materially from those of a more basic character except for their higher percentage of quartz. They are mainly obtained from fissurelike extensions of the blankets and are further discussed under the vein ores, but they also occur as local modifications within blanket bodies. None of them were observed by the writer.

TEXTURE AND STRUCTURE

The chalcopyrite has four modes of occurrence—(1) as minute specks scattered through the dense pyrite; (2) as larger irregular masses filling vugs among crystals of pyrite; (3) as irregular patches occupying portions of minute veinlets in the solid masses of pyritic ore; (4) forming a large proportion of the ore mass. The minute specks are sufficiently numerous in places to impart a slightly deeper yellowish tinge to the pyrite, even though the percentage of copper is very low. They are too small for their relations to adjoining pyrite grains to be clearly determined.

In the second mode of occurrence the chalcopyrite partly incloses pyrite and is clearly later. In some places it is intimately mingled with dense black blende in such a way that the two appear contemporaneous, the sphalerite, like the chalcopyrite, partly inclosing those pyrite crystals which project into the open cavities. As all the blende in the ores is confidently believed to be primary, the same inference for this contemporaneous chalcopyrite appears justifiable.

In the minute veinlets the chalcopyrite is mingled with blende and galena and all three are clearly later than the pyrite though not the result of sulphide enrichment.

Chalcopyrite forming a large portion of the ore is comparatively rare but was observed in the Little Vinnie mine, on Breece Hill, and in the Maid of Erin mine, on Carbonate Hill. In the Little Vinnie mine the chalcopyrite is reported to have been massive, with many large cellular vugs. These vugs were filled with a mixture of pyrite cubes, manganosiderite, and a few well-developed crystals of marmatite. This occurrence of chalcopyrite older than pyrite and zinc blende is contrary to the usual relations just described. This ore carries 68 ounces of silver to the ton but no noteworthy amount of gold.

In the Henriett-Maid mine a banded solid mass of chalcopyrite, zinc blende, and pyrite was found. It was much altered, containing sulphates both of copper and of iron in the cavities, and was rendered iridescent by coatings of bornite on all the cavities and fractures, so that at first glance it may be mistaken for solid bornite. Chalcopyrite was the only original copper mineral present. A polished specimen of this ore is represented by Plate 58, *A*, *B*.

In this specimen the chalcopyrite occurs partly as layers and partly as fracture fillings. Thick layers are present at the top and bottom, and the fracture fillings extend from them, cutting rather sharply across the layers of blende but spreading along and partly replacing the layers of pyrite. This relation represents a late phase of primary deposition, just as the sulphides as a whole represent a later stage than the manganosiderite, and is similar to the relation of zinc blende to pyrite and of galena to both pyrite and blende shown in Plate 60, *B*.

Mixed Sulphide Ores

CHEMICAL AND MINERAL COMPOSITION

The mixed sulphides are the commonest ores of the blanket ore bodies and occur in all parts of the Leadville district. They have been developed in greatest quantity in North and South Iron Hill, East Carbonate Hill, and Graham Park and in considerable quantity in Breece Hill, Little Ellen Hill, Fryer Hill, and East Fryer Hill. They consist of mixtures of pyrite, sphalerite, and galena with usually subordinate quantities of quartz and manganosiderite or ferruginous dolomite, together with residual shaly material and sericite from the alteration of included shale or adjacent porphyry. In some places they contain notable quantities of chalcopyrite. They differ in no essential particular from the purely arbitrary types with dominant iron, lead, or zinc sulphides hitherto described, into which they pass by imperceptible stages, but they offer some characteristic features of structure and paragenesis which can not be noted in the purer types and which are of great genetic importance.

Only a few commercial analyses of the mixed sulphides are available, but these show the range of metal contents and approximate mineral constituents. The source of the samples represented by the analyses was not recorded.

Partial analyses of mixed sulphide ores.

	1	2	3	4	5	6	7	8
Fe	17.80	16.80	16.60	16.0	15.40	15.30	15.20	14.50
Pb	17.80	22.60	10.70	15.0	21.40	23.10	23.00	27.40
Zn	23.40	21.50	24.50	24.00	24.60	24.00	24.50	23.05
Mn	.50	.50	---	---	.50	.60	.70	.60
Ag	.104	.045	.186	.038	.036	.36	.027	.034
Insoluble	1.45	1.20	3.40	---	2.00	2.80	1.75	2.10
Gold, ounces per ton	.03	.05	Trace.	---	.05	.02	.05	.03
Silver, ounces per ton	30.40	13.50	54.30	11.00	10.50	10.35	7.95	9.95

Approximate mineral composition of mixed sulphide ores

	1	2	3	4	5	6	7	8
Pyrite	29. 65	28. 20	26. 66	25. 56	24. 28	24. 06	23. 66	22. 70
Galena	20. 56	26. 11	12. 35	17. 34	24. 73	26. 68	26. 56	31. 67
Zinc blende (marmatite):								
ZnS	34. 87	32. 04	36. 52	35. 77	36. 66	35. 77	36. 52	34. 35
FeS	6. 29	5. 78	6. 59	6. 45	6. 61	6. 45	6. 59	6. 20
MnS	. 79	. 79	--------	--------	. 79	. 95	1. 10	. 95
Argentite	. 06	. 03	. 11	. 03	. 02	. 02	. 01	. 02
Insoluble	1. 45	1. 20	3. 40	(a)	2. 00	2. 80	1. 75	2. 10
	93. 67	94. 15	85. 63	85. 15	95. 09	96. 73	96. 19	97. 99

a Not determined.

If galena rises much above 25 per cent and can be profitably concentrated, the ore is likely to be classified commercially as lead ore, especially if the zinc blende, which has not been readily separated from the pyrite by processes in use up to 1926, is not in excess over the pyrite. Mixed sulphides consisting mainly of pyrite and blende, with pyrite in excess, with less than 5 per cent lead, and with too little gold and silver to pay for shipment, have not been profitably treated, and large quantities of them have accumulated on the mine dumps awaiting a profitable process of treatment. New processes applied to these ores in 1926 have yielded encouraging results.

TEXTURE AND STRUCTURE

The texture and structure of the mixed sulphides offer features of unusual interest. There are three well-marked varieties of structure which may best be separately described—massive structure, cellular structure, and banded or layered structure.

Massive structure is exhibited by nonporous granular aggregates of the different sulphides which show no especial regularity in the relative size and distribution of the grains. Such aggregates are similar to the massive varieties already described and generally pass gradually into lead, zinc, or iron sulphide.

The ore having cellular structure is filled with irregular cavities, invariably lined with crystals of one or all of the component sulphides, together with carbonates and, locally, quartz. In these cellular mixtures some of the cavities are rather large, but more commonly they are only a fraction of an inch in diameter and are scattered throughout the ore mass without regularity. In some ores the cavities may be so numerous that the ore becomes a porous aggregate of nearly complete crystals of the different sulphides only slightly held together.

There are two kinds of banded or layered structure. One is due to preservation of the banded character or bedding of the original rock which the ore has replaced. This structure is less commonly perceptible in the mixed sulphides than in the purer varieties but may be seen on close inspection along large faces of ore. On freshly broken faces of ore a series of parallel shadowy bands appear. After the face is covered with the dust that collects on the walls of stopes, the banding is brought out by the adherence of the dust to certain layers of the ore. The other kind of layering or banding is generally independent of bedding but closely related to fracturing and permeability.

The parallel layers when seen in broken ore appear in part nearly or quite free from curvature (pls. 60, *D;* 63, *A, B*) and in part markedly and completely curved (pls. 60, *A, B, C;* 61, *C, D*). Less commonly they consist of different sets of layers in unconformable contact. (Pl. 54, *A, B.*) In places they are fractured or faulted and recemented by sulphide minerals. (Pls. 61, *A, B;* 62, *A, B.*) The layers where well exposed in the stopes are seen to have an ellipsoidal, spherical, or several-sided form. The ore that is marked by roughly circular bands on the walls of stopes has been called "ring ore." The "rings" have a maximum diameter of 10 feet or more. They consist for the most part of alternating layers of pyrite and zinc blende, but layers of galena are prominent in places, and similar layers of chalcopyrite have been found in the Henriett-Maid mine. (Pl. 58, *A, B.*)

The relations of these concentric bodies to the inclosing limestone leave no doubt that they are replacement deposits formed by reaction between the limestone and solutions which spread from fractures and open bedding planes into the rock. The process is analogous to that which accounts for Liesegang's rings. These rings were regarded by Ostwald[7] in 1897 as due to reaction between a solution diffusing from a central point and a substance contained in the medium through which diffusion took place. Reaction progressed until the solution became supersaturated with one of the products of reaction. Deposition of this product then took place, forming the first ring, and continued until the solution became undersaturated. Reaction was then resumed as the solution continued to diffuse, and in due time a second ring was formed. Repetition of the process continued as long and far as the solution could diffuse. Owing to progressive depletion of the original reacting constituent of the solution, a greater and greater distance had to be covered before supersaturation with the

[7] Ostwald, Wilhelm, Zeitschr. phys. Chemie, vol. 23, p. 365, 1897.

product of reaction could take place, and the successive rings were deposited farther and farther apart.

Experiments on rhythmic banding have been continued by Liesegang and others. The medium used in the earliest and most of the later experiments was gelatin containing some compound which could react with the diffusing solution; but it has been shown that other material, such as sand and diatomaceous earth containing pores or interstices of capillary size, may also serve as a medium. Liesegang[8] in 1913 published a general account of processes and laws of diffusion, discussing experimental results obtained by himself and others, and results of certain geologic processes, including the replacement of limestone. In 1914 Dreaper[9] published the results of some instructive experiments on diffusion through diatomaceous earth, and in 1917 Stansfield,[10] besides reviewing the most important contributions to the subject, showed how the thickness and distribution of the rings were dependent on relative concentrations and rates of diffusion. Ostwald's explanation that the rings were due to rhythmic attainment of supersaturation has been questioned, particularly by Hatschek,[11] but it is strongly supported by Stansfield and others cited by him.[12]

Experimental work thus far has differed from natural rhythmic replacement of carbonate rocks, in that the reacting substances have diffused in an inert medium, whereas the carbonate rock is both reagent and medium. The small quantity of organic matter, particularly in the Blue limestone, may have contributed to the reaction, but the important factors were the carbonate minerals themselves and ability of the solutions to permeate along boundaries between grains and microscopic cracks. Variations, shape, and size of the layers are attributed to variations in permeability and composition of the carbonate rock and to differences in concentration of the invading solution.

The simplest case imaginable occurs where solutions spread to both sides of a fracture and produced ore with layers parallel to the fracture (fig. 59, A). Where the opening along which the solutions arrived was a

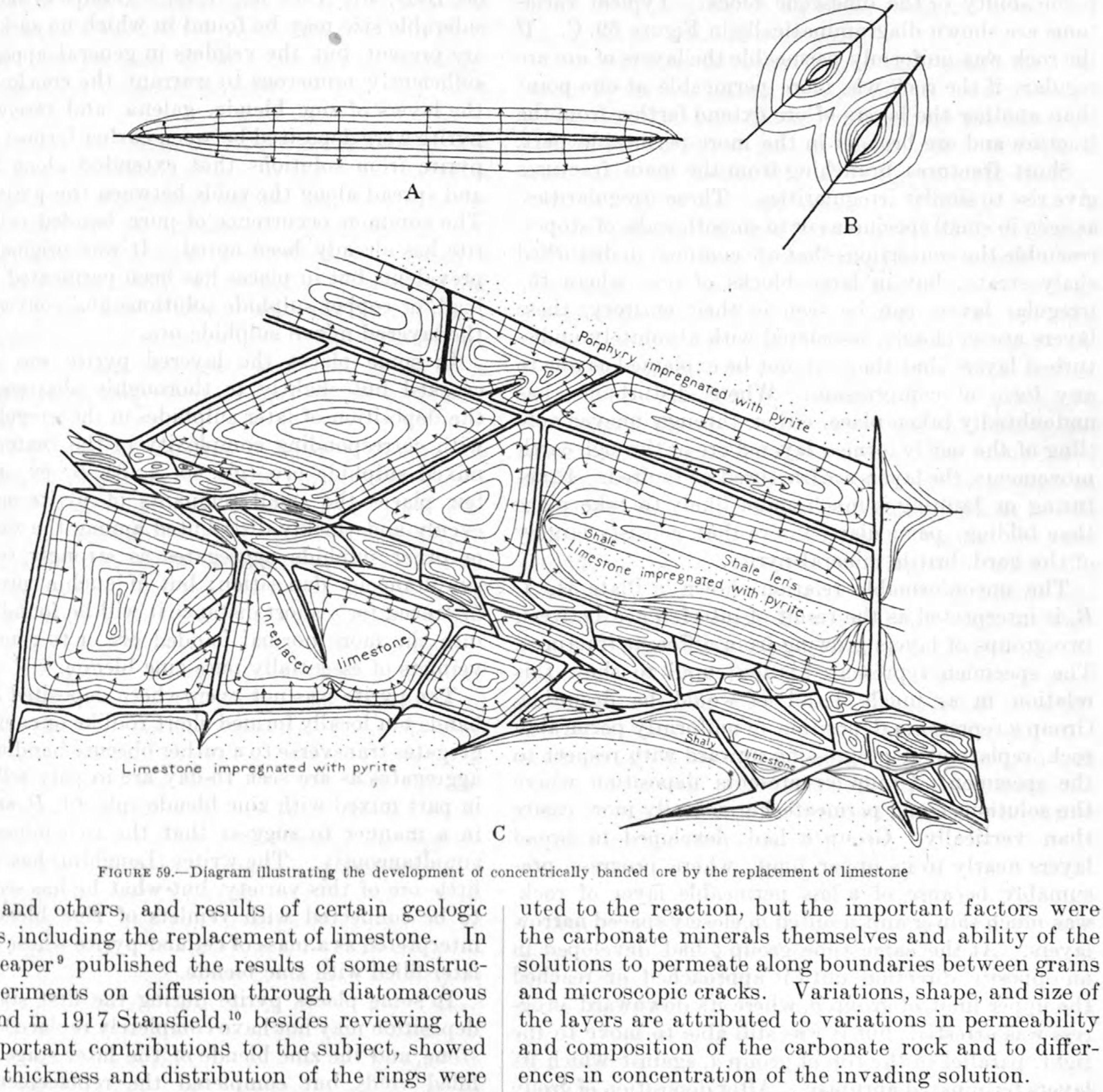


FIGURE 59.—Diagram illustrating the development of concentrically banded ore by the replacement of limestone

[8] Liesegang, R. E., Geologische Diffusionen, 1913 Pp. 138, 148-149, 145-155 are of particular interest in connection with rhythmic replacement of limestone. Reviewed by Adolph Knopf (Econ. Geology, vol. 8, pp. 803-806, 1913).

[9] Dreaper, W. P., Precipitation and stratification in the absence of gels, and their bearing on the formation of mineral deposits: Inst. Mining Met. (London) Bull. vol. 22, 1914, pp. 381-391.

[10] Stansfield, J., Retarded diffusion and rhythmic precipitation: Am. Jour. Sci., 4th ser., vol. 43, pp. 1-28, 1917.

[11] Hatschek, E., Zeitschr. Chemie Ind. Kolloide, vol. 10, p. 124, 1912.

[12] Stansfield, J., op. cit., pp. 3-6.

pipelike enlargement of a fracture, the layers formed concentrically around the "pipe" (fig. 59, B). If two or more "pipes" were sufficiently close together, the layers from each grew together into complicated forms resembling intricate contortions of shaly or schistose rock.[13] The great masses of layered ore, however, are more complicated and may consist of a number of spherical, elliptical, or irregular units. Each unit is bounded by intersecting fractures along which the solutions moved and represents a replaced block of limestone. The dimensions of the units depend upon the distribution of the fractures and the uniform or variable permeability of the limestone block. Typical variations are shown diagrammatically in Figure 59, C. If the rock was uniformly permeable the layers of ore are regular; if the rock was more permeable at one point than another the layers of ore extend farther from the fracture and are broader in the more permeable part.

Short fractures branching from the main fractures give rise to similar irregularities. These irregularities, as seen in small specimens or in smooth walls of stopes, resemble the contortions that are common in disturbed shaly strata; but in large blocks of ore, where the irregular layers can be seen in their entirety, these layers are so closely associated with absolutely undisturbed layers that they can not be explained as due to any form of compression. Where disturbance has undoubtedly taken place, either through uneven settling of the newly formed layered ore or through earth movements, the layers are fractured or faulted. Fracturing or faulting is much more likely to take place than folding, particularly in ore that consists largely of the hard, brittle mineral pyrite.

The unconformable relation shown in Plate 54, *A*, *B*, is interpreted as the result of interference between two groups of layers growing from different fractures. The specimen represented is too small to show this relation in as much detail as would be desirable. Group *a* represents deposition in uniformly permeable rock, replacement progressing upward with respect to the specimen. Group *b* represents deposition where the solutions could permeate horizontally more easily than vertically. Group *a* had developed in broad layers nearly to its upper limit, where progress, presumably because of a less permeable layer of rock, was much slower and resulted in closely spaced narrow layers. At the same time group *b* had developed in an opposite direction until it approached or reached the upper limit of group *a*, where its downward progress was arrested; but it was still able to move to the right, parallel to the top of group *a*, against which its layers terminated abruptly. After deposition of group *b* was completed the ore was fractured across the layers of both groups and recemented.

Where only two ore minerals are present they appear at first glance to have been deposited in rhythmic alternation—a layer of pyrite followed by one of blende and by another of pyrite; but the relative thicknesses of the different mineral layers vary considerably, as shown in several of the accompanying illustrations (pls. 54, *A*, *B*; 60–63), and the rhythmic relations could not have been perfect. Moreover, where a third mineral, such as galena, is prominent in some parts of a layered mass and not in others the apparent rhythmic relations are further disturbed. Close inspection of the ore, however, shows that the layers of zinc blende or galena are connected with veinlets of the same mineral that cut across the layers of pyrite (pls. 60, *B–D*; 61, *A–C*; 62, *A*, *B*). Lumps of ore of considerable size may be found in which no such veinlets are present, but the veinlets in general appear to be sufficiently numerous to warrant the conclusion that the layers of zinc blende, galena, and rarely chalcopyrite were deposited between earlier formed layers of pyrite from solutions that extended along fractures and spread along the voids between the pyrite layers. The common occurrence of pure banded cellular pyrite has already been noted. It was originally more prevalent, but in places has been permeated by zinc, lead, or copper sulphide solutions and converted into the layered mixed sulphide ore.

In some places the layered pyrite was not only cracked but slightly to thoroughly shattered before the deposition of later sulphides in the irregular voids, with corresponding complexity in the texture of the mixed sulphide ore (pls. 60, *A*; 61, *B*; 62, *A*). In a few places the small remnants of pyrite may be so evenly and thickly distributed among the zinc blende or other sulphide aggregates as strongly to suggest simultaneous deposition; but if such a mixture can be traced for a short distance it will be found to grade into the more normal banded ore or to connect with veinlets of essentially pure zinc blende.

The pyrite was not everywhere deposited in simple bands but locally formed short rodlike or columnar aggregates transverse to a rather obscure banding. Such aggregates as are seen to-day are in part cellular and in part mixed with zinc blende (pls. 61, *D*, and 63, *B*) in a manner to suggest that the two minerals grew simultaneously. The writer (Loughlin) has seen very little ore of this variety, but what he has seen proves to be connected with veinlets of zinc blende and is interpreted as a mass of cellular pyrite whose cells were later filled with zinc blende.

In some places pyrite during the first stage of ore deposition may not have completely replaced the limestone, and the zinc blende of the later stage not only filled voids but completed the replacement. Such conditions would give an excess of zinc blende, which would inclose isolated crystals or small aggregates of pyrite. Other local variations in physical conditions could multiply the variations in texture of mixed sulphide ores, but it is believed that all, if closely studied and traced to contacts with the more ordinary varieties,

[13] Liesegang, R., op. cit., p. 138. Knopf, Adolph, Geology of the Seward Peninsula tin deposits: U. S. Geol. Survey Bull. 358, p. 46, 1908.

can be interpreted as due to successive stages of deposition—first, pyrite; second, zinc blende alone or in great excess over other sulphides; third, either galena or chalcopyrite alone or in excess over other sulphides. The writer has found banded ore containing pyrite, blende, and galena in which the minerals were clearly deposited in three successive stages. The layers of blende were connected with veinlets of blende that crosscut the pyrite layers, and the layers of galena were connected with veinlets of galena that cut not only the layers of the other two minerals but the veinlets of blende as well. Layers of chalcopyrite connected with veinlets that crosscut blende and pyrite and appear to replace part of the pyrite are shown in Plate 38, *A*, *B*. The presence of both galena and chalcopyrite in the same mass of layered ore has not been noted.

These successive stages of deposition agree with the relative order of crystallization in the other varieties of sulphide ore. They also help to explain the segregation of relatively pure masses of blende and galena. The solutions of the second or third stage must have moved where opportunity allowed. If they could not escape from the places where the rock had already been replaced by pyrite they filled voids in the pyrite; if they could escape and reach a mass of replaceable rock they formed the relatively pure shoots of bleend or galena.

To judge from the relative quantities of sulphide minerals in the Leadville district the original ore-forming solutions contained, besides silica and other nonmetals, iron in great abundance, considerable zinc, less lead, and very little copper, besides minute quantities of other metals. The principal gangue minerals, quartz and manganosiderite, were deposited for the most part by the replacement of dolomite or limestone before the sulphides except for a small amount of pyrite. When conditions permitted the deposition of sulphides in large quantity pyrite was the most concentrated and the least soluble constituent of the solution. Its deposition was caused by reaction with the carbonate rocks, but the volume of rock dissolved was greater than the volume of pyrite deposited. As the solutions permeated the rock from the feeding fractures solution took place until equilibrium between solution and rock had been reached or slightly exceeded and pyrite was deposited. Deposition continued until the solution became undersaturated again, and solution of carbonate rock was resumed until pyrite was forced once more to precipitate. Solution and deposition alternated more or less rhythmically while the solution advanced into the rock until an unreplaceable barrier was reached or the supply of pyrite was exhausted.

Whether a eutectic point between pyrite and zinc blende can exist in so complex a solution is not known. If one does, it is evidently reached only when the ratio of pyrite to zinc blende is very low. The nearly pure masses of zinc blende all contain pyrite, some of which may have been deposited at the same time as the blende and some of which may represent the first (pyritic) stage of sulphide deposition. The second stage took place when the solution had become supersaturated with zinc blende. All layers of zinc blende were deposited simultaneously, or as soon as the voids between pyrite layers became filled with saturated solution. There was no rhythmic alternation between solution and deposition, except where remnants of unreplaced carbonate rock were reached, and even there banding was not very conspicuous, as replacement of carbonate rock by blende was not marked by any great decrease in volume.

The relations between blende and galena and between pyrite and galena were similar to those between pyrite and blende. Blende was nearly all deposited before deposition of galena began. If a eutectic or triple point existed it was after the solution had lost nearly all of its zinc and iron.

The relations between pyrite and chalcopyrite were also similar to those between pyrite and galena. If simultaneous deposition took place it was only after the solution had been almost depleted of iron in excess of that needed to form chalcopyrite. The relations between zinc blende and chalcopyrite were similar. So far as the layered ore is concerned the chalcopyrite was formed during a later stage than the blende, but much of the blende contains microscopic inclusions of chalcopyrite, which must have been deposited with it. The outer parts of blende crystals in vugs partly inclose chalcopyrite in such a manner as to suggest that the growth of the two minerals overlapped. From this relation as contrasted with that between blende and galena it may be inferred that sulphide solutions containing considerable copper, iron, and lead would deposit chalcopyrite first but would begin to deposit galena also before the deposition of chalcopyrite approached completion. No evidence was found that would suggest the shattering of earlier formed sulphides by crystal pressure of those formed later, nor was any conspicuous amount of replacement of earlier by later sulphides noted.

ORES CONTAINING BISMUTH

Ores with high contents of bismuth and silver and usually with high content of gold also have been found only in small quantity. The most noteworthy occurrences have been in the Lilian, Ballard, and Tucson mines, but assays show that bismuth is present in several other mines, principally in oxidized ore. The only original bismuth mineral thus far identified is the sulphide bismuthinite in a microscopic intergrowth with argentite and galena. This intergrowth was formerly called "lillianite" or "schapbachite." (See p. 170.) It was first found in the Lilian mine, but the writers have had no opportunity to study it there.

In the Tucson mine it coated crustified ore which lined cavities in Cambrian quartzite, as described in detail in chapters 8 and 13 (pp. 170, 289). In the Ballard mine nuclei of the same intergrowth were found in the centers of lenticular bunches of yellow ocherous oxidized gold ore. This ocherous ore was also accompanied by thin lenses of bluish to whitish bismutite.

The ores containing bismuth have not been systematically worked for that metal, and little information beyond the descriptions of the component minerals is available concerning them. Exploration has, however, proved the presence of bismuth in appreciable quantities, particularly in the oxidized ores of Breece Hill and also of Iron and Carbonate hills. In most of the samples assayed the bismuth content was less than 1 per cent, but in exceptional samples it was as high as 9 per cent. The samples consisted mostly of yellow earthy material and evidently contained the yellow oxide, bismite, but some of the exceptionally rich samples were described as "blue clay" and evidently contained the basic carbonate, bismutite.

The content of gold, silver, and lead in these oxidized samples was strikingly low, in contrast to the sulphide ore, and showed no relation to bismuth. Gold in most of the samples amounted to 0.02 ounce to the ton or less, and silver, with few exceptions, amounted to less than 5 ounces to the ton. An exceptionally rich sample contained 0.4 ounce of gold and and 76.5 ounces of silver to the ton and 0.13 per cent of bismuth.

RELATION OF VEINS TO BLANKET ORE BODIES

The preceding discussion has set forth in some degree the manner in which minor blanket ore bodies connect with the veins either as lateral offshoots or as upward terminations. The ores that have been mined from these connecting blanket masses are nearly all similar to those within the veins and different from the ores that form the large blankets in the western part of the district; but gradations between the two kinds of blanket ores have been established at a few places.

For a long time, however, no apparent connection between the two kinds of blanket ore had been found or appreciated, and there was an inclination to regard them as distinct in origin. They were so regarded by Moore[14] and, tentatively by Irving, but evidence brought to light after Irving's last visit to the district favors the view that all the ores were formed at essentially the same time. As the present writer (Loughlin), however, has not been able to examine places cited by others as affording evidence against this view, he does not regard the question as finally answered and leaves the reader to draw conclusions from the following summary of the evidence on both sides.

The available analyses (pp. 193–201) show that the main blanket ores in the western part of the district, whether oxidized or not, are nearly all relatively high in silver and low in gold. Where completely or partly oxidized they have been enriched in silver but not in gold or copper. There are notable exceptions, however, some of which serve as connecting links between the silver ores of the blankets and the gold-copper ores of the veins. The "gold ore shoot" in Iron Hill,[15] which was unusually high in gold, though no visible gold was found in it, was remarkable for lying between shoots of the ordinary silver-lead oxidized ore. It has not been accessible in recent years, but its position and the details of its outline (pl. 26, section M–M′, and fig. 56) suggests that it may be more directly connected than the other shoots with the Tucson fault, which served as a channel for ascension of the original ore-forming solutions. This suggested relation is similar to the proved relations between gold-copper ores and zinc-lead ores in the Tucson mine (figs. 18 and 20). There typical sphalerite-galena ore replacing White limestone extended to the fault, where it graded into pyrite-chalcopyrite ore enriched by chalcocite, gold, and silver in a siliceous gangue. The pyritic copper ore evidently favored a siliceous environment—either quartzite, Gray porphyry, or gouge derived from them—but it did not extend far into the limestone before it gave way to the sphalerite-galena ore. The ore bodies of the Tucson mine are described on pages 289–292.

The Cord vein (figs. 21–23) presents the strongest evidence of direct connection between the two kinds of ore. At the lower levels it lies between walls of Cambrian quartzite and is a typical siliceous pyritic ore, containing irregularly distributed gold and copper. Its highest-grade ore is in part clearly enriched by chalcocite but in part without visible sign of enrichment. Similar ore is found in Gray porphyry sills and also in the Parting quartzite; but where the vein crosses beds of White limestone it spreads out and forms blankets of sphalerite-galena-pyrite ore, which have their longest axes along the vein. There is no evidence that the vein differs in age from the connected blankets. These ore bodies are described on pages 287–289.

Similar evidence may have been exposed in and near the Wolftone mine along the Tucson-Maid reverse fault. Veins of rich ore containing copper have been worked there and apparently were connected with large replacement bodies of ordinary zinc-iron-lead sulphide ore, but no adequate account of the relations has been preserved. The connection of blanket ore bodies with the mineralized Tucson-Maid fault has been shown by Spurr.[16]

On the seventh level of the Greenback mine a vertical vein in a branch of the Tucson fault between Cambrian quartzite and upturned beds of the overlying "transition shales" contained ore that resembled

[14] Moore, C. J., Recent developments at Leadville, Colo. (discussion of paper by G. M. Butler entitled "A Leadville fissure vein"): Econ. Geology, vol. 7, pp. 590–592, 1912.

[15] Blow, A. A., The geology and ore deposits of Iron Hill, Leadville, Colo.: Am. Inst. Min. Eng. Trans., vol. 18, p. 168, 1890.

[16] Spurr, J. E., The ore magmas, vol. 1, p. 353, 1923.

the ore of the Winnie-Luema vein in the kind and distribution of its minerals. It was visibly enriched in copper, but no assay records of it were obtained. It lay directly below the large blankets in White and Blue limestone that formed the principal ore bodies of the mine. The ore between the lower blanket and the accessible part of the vein was said to have been considerably enriched in silver. Much of the ore in these blankets was low-grade pyrite with local shoots of zinc-lead ore. The predominance of pyrite so near the vein is in harmony with the general evidence of the distribution of the ores, but the condition of the workings, when visited in 1919, prevented a thorough study of the ore bodies.

The absence of zinc-lead ore in the blankets connected with veins in the eastern part of the district has been cited as evidence that these blankets are not to be correlated with the large blankets in the western part; but zinc-lead ore was observed in the Golden Eagle workings and in the 20–a vein of the Ibex mine, in Breece Hill. The veins in the Golden Eagle workings (fig. 55) are mostly too small to be productive themselves, although their mineral composition is typical of the enriched pyritic veins; but they serve as leads to small blanket bodies that replace thin-bedded shaly White limestone between rather closely spaced sheets of porphyry. The smallest of these replacement deposits are mere bulges along the narrow veins and do not differ from the veins in mineral composition unless in having a greater percentage of quartz. The larger blankets are also of similar composition for a short distance from the veins, but farther away they change almost abruptly into massive sphalerite-galena ore carrying a few ounces of silver to the ton and very little gold. The effect of siliceous rock on the ore solutions was evidently not overcome until a considerable quantity of carbonate rock had been replaced.

Careful scrutiny of the junctions of veins and blankets in the Golden Eagle workings proved that the minerals in both were deposited at the same time. Irving's observations on the 20–a vein of the Ibex mine are especially significant. This vein was found on the tenth level and was followed upward nearly to the seventh level, where it terminated in a blanket. The vein consisted of coarse-grained pyrite and chalcopyrite enriched by chalcocite. The blanket, on the contrary, was very low in copper minerals but contained 25 to 35 per cent of zinc blende. Complete analyses of the two varieties of ore are not available.

The miners in Breece Hill, producing gold ore that may contain also considerable copper and silver, stop mining when this ore passes into the sphalerite-galena ore, which evidently does not pay for the cost of mining and treating. This sphalerite-galena ore is essentially identical in character with the zinc-iron-lead sulphide ores of Iron and Carbonate hills, but the ore shoots are smaller. The fact, therefore, that the principal ores mined from the blankets connected with veins in the Breece Hill area are the gold and gold-copper ores does not prove that there are no zinc-iron-lead ores present.

The absence of extensive blanket bodies connected with the larger veins is attributed to physical conditions. A comparatively thin layer of gouge along the vein wall serves as an effective seal to keep the solutions within the fissure. The absence of replacement bodies in the White limestone along the veins in the Luema mine (figs. 104 and 105) may be due to this cause, although it must be admitted that the limestone has not been intensively prospected for replacement bodies that have been fed through minor fractures connected with the main vein. The White limestone is so shaly in the Breece Hill area that it is not particularly favorable for extensive replacement, and it is split into so many thin layers by porphyry sills that the formation of thick blankets is further prevented.

There have been few opportunities to study blankets along the veins in Blue limestone. The positions of blanket stopes in the Blue limestone of the Ibex mine, however (pl. 57), strongly indicate their connection with veins. The oxidized ore mined from them was lead carbonate, some of which was rich in gold. The Little Jonny stopes near the Ibex No. 1 shaft have been famous for the gold mined from them in the early days, and shoots of zinc carbonate ore directly connected with some of these stopes have been mined since. One feature of this zinc ore is the presence of aurichalcite, the basic carbonate of zinc and copper. There thus appears to have been much zinc and lead as well as gold and copper in the original ores of these blankets.

Two facts very difficult to reconcile are the direct connection of blankets of siliceous gold ore with the southern part of the Winnie-Luema vein and the lack of connection between the old stope of lead carbonate and the northern part of the vein. It is possible but can not be proved that here, as in certain other similar stopes, the mining of the siliceous ore was stopped where the zinc blende became dominant. The old lead carbonate stope was not accessible when the Luema mine was studied in 1913. A minor vein of mixed sulphide ore (fig. 104) was followed toward the blanket stope but became too poor for working or pinched out before the stope was closely approached. The stope extended nearly to the vein but is not known to have reached it at any point. The immediate source of the ore in the blanket body has not been found, and the occurrence lends little support to either view regarding the relative ages of the lode ores and the large blanket deposits of zinc-iron-lead ore.

G. M. Butler[17] in discussing the deposition of the ores in the Luema mine suggested that the blanket deposit could have been fed through narrow fissures connected with the main vein, and he was at first inclined

[17] Butler, G. M., A Leadville fissure vein: Econ. Geology, vol. 7, pp. 315-323, 1912; Colorado School of Mines Quart., vol. 8, pp. 1-8, 1913.

to regard the blanket and the main vein as contemporaneous, but Moore[18] contended that they were of different ages and cited places where blanket bodies had been cut through and locally enriched by later veins. According to information furnished by Moore to Irving, the Ella Beeler east vein, in the Iowa Gulch area, cuts directly across a blanket ore body at the top of the White limestone, and the ores are distinct and show no connection with each other; but no description of the intersection or of the composition of the ores is furnished, and there is some question as to whether the siliceous pyritic ore along the vein is so different from the zinc-lead ore (or lead carbonate ore?) in the blanket as to afford a presumption that the vein actually cut the blanket.

The preceding paragraphs may be summarized as follows: Several veins and connected blankets in the eastern part of the district have been proved to be contemporaneous, and in some of them the siliceous pyritic gold and gold-copper ore in and near the veins have been found to pass into and not cut across zinc blende or mixed sulphide in the blankets. The Cord vein and its connected blankets afford similar proof in the western part of the district, and the transition between siliceous gold-copper ore and zinc-lead sulphide ore in the Tucson mine is also proved. At other places in both parts of the district the same relations are suggested, but records are inadequate for proof.

The comparatively small size of the blankets in the eastern part and the great number of veins near them favor the inference that both are contemporaneous, but the great number of large blankets and the scarcity of veins in the western part are not so easily explained. The scarcity of exposed connections between these blankets and veins is partly due to methods of development, particularly of the "first contact," by inclines along thoroughly oxidized ore bodies, partly to the fact that small veins cut beneath the ore bodies have been overlooked or have offered no incentive for exploration because of their small size. Exploration has been sufficient in places, however, to demonstrate the absence of persistent veins beneath some of the large blanket ore bodies.

No veins have been found associated with the blankets between sills of White porphyry at Fryer Hill. These blankets, however, were thoroughly oxidized and the presence of underlying veins was greatly obscured. Furthermore, during Emmons's first survey very little work had been done beneath those ore bodies, and in later years any evidence that may have existed has been concealed by timbering and waste filling. Recent explorations in the White limestone of East Fryer Hill disclosed one fissure along which the limestone was impregnated by a little quartz and pyrite, but no persistent vein was found, and it is concluded that the ore-forming solutions, whatever their source, must have traveled for considerable distances along bedding planes or "contacts."

Similar remarks apply to other large ore bodies, particularly in the oxidized zone, and Emmons, who had searched for mineralized fissures beneath them but who died before the significant evidence of the Cord and Tucson mines was disclosed, was justified to a considerable degree in discrediting the controlling effect of fissures on the distribution of ore bodies.[19] The elongate shapes and parallel arrangement of the ore bodies, however, strongly indicate that fissures or shattered zones served as channels for circulation of the ore-forming solutions beneath impervious cappings. These fissures, as shown in chapter 5 (pp. 63, 81), were local features formed at the time of the Gray porphyry intrusions and subsequent to the period of folding and reverse faulting. The different degrees to which the different rocks yielded to these stresses account for the presence in the Blue limestone (dolomite) of fractures that do not continue into or through the adjacent porphyry sills or the shaly beds at the top and base of the Parting quartzite. Only the major faults and fissures were continuous through all the formations, and it was only where they were sufficiently closed or deflected by the more flexible rocks that conditions were favorable for replacement of the limestones. At such places the ore-forming solutions could be deflected along bedding planes or along local fractures or shattered zones between shale beds or porphyry sills until they were stopped by some barrier, and the resulting ore body might be a considerable distance from the trunk fissure through which the solutions rose. To trace the courses followed by the solutions would be no simple matter even if mine workings had been driven for that purpose, and to trace them in the workings that exist is impossible.

As the viscous porphyry intrusions were deflected for long distances from the trunk conduits, it is quite conceivable that the more fluid ore-forming solutions were deflected even farther. They clearly rose through trunk fissures like the Cord vein and through the fissured ground along the Tucson-Maid fault. Portions of them were doubtless deflected from these trunk channels at different horizons and followed available channels at those horizons in directions quite different from those of the trunk channels. Thus the ore bodies of the Carbonate Hill area are believed to have been mostly if not wholly deposited by solutions that rose along the Tucson-Maid fault zone and by more or less devious paths reached the "contacts," which they followed eastward to Graham Park and westward to the Downtown area. They may even have followed the "first contact" northward through the Small Hopes ground to Fryer Hill; but it would not be surprising if another local source of supply were found somewhere beneath Fryer Hill and beneath the pyritic ore in the mines of East Fryer Hill, similar to those in the New Mikado and Penrose mines (pp. 274, 277), which supplemented those from the Tucson-Maid fault zone.

[18] Moore, C. J., Econ. Geology, vol. 7, pp. 590-592, 1912.

[19] Oral communication to J. D. Irving.

CHAPTER 10. GENESIS OF THE HYPOGENE ORES

To one who has read the foregoing chapters it will be obvious that the authors believe the ores to have been deposited by magmatic waters. The evidence on which their belief is based is similar to that presented in several reports on mining districts during the last 15 or 20 years and does not add anything strikingly new to advance our knowledge of ore genesis. For this reason there is a temptation to dismiss the subject of genesis without further comment; but as the present conclusion differs radically from that expressed by Emmons in his monograph and by some later writers, it is worth while to give as clear a picture as possible of the origin of the ores and the relations of different kinds to one another, and this review of the evidence will be practically helpful in the search for new ore bodies.

Emmons's conclusion that the ores were formed by replacement of the wall rocks has since been substantiated by so much evidence both at Leadville and elsewhere that no further argument as to this feature of the problem is necessary. Deposition in open spaces took place also but was very subordinate to replacement. Emmons believed the ores to have been derived from the porphyries, particularly the White porphyry, which was the thickest and overlay the most extensive ore bodies. As the veinlike offshoots extending downward from the main blanket ore bodies pinched out within a short distance, he had no reason at that time for believing that the source of the ore was deep seated. Furthermore, the porphyries were found to contain minute quantities of the metals contained in the ores and appeared to furnish definite evidence as to the source of the metals; but later examination of these porphyries in the light of advancing petrographic knowledge proved that they were considerably altered, and that the metals present were the result of infiltration and not primary constituents. Emmons had accordingly revised his views and by 1907 [1] had recognized the possible deep-seated source of the ores; but he very properly maintained that the solutions that deposited the blanket ore bodies, particularly those of the Carbonate Hill and Downtown areas, had not moved directly from their deep-seated source to the place of deposition but had been deflected for considerable distances from their undiscovered vertical channels by the porphyry sills. Whether the solutions were of magmatic or other origin he left as an open question.

The vein in the Maid of Erin mine in the Tucson-Maid fault zone had been discovered by that time, but no definite significance had been attached to it. The strong evidence in the Tucson and Cord mines had not been exposed. After George Argall's description in 1910 of the Tucson reverse fault and the ore associated with it, Emmons corresponded with Argall on the subject, but he died soon afterward, without having had an opportunity to revisit the district. Irving wrote that in his discussions with Emmons he noticed a gradual change of view regarding the origin of the ores at Leadville but could not state with certainty the view finally held.

Blow [2] was one of the best-qualified critics of Emmons's earlier views, owing to his detailed observations, particularly in the southern part of Iron Hill. He emphasized the close association of ore bodies with dikes of Gray porphyry and concluded that the source of the ore was dependent on the dikes. His conclusions also were necessarily drawn prior to developments of critical importance in the White limestone, which proved that the supposed dikes were only offshoots from sills and that the function of these offshoots, like that of the dike in Fryer Hill described by Emmons, was to serve as barriers to migration of solutions along the strata.

RELATION OF ORES TO PORPHYRIES

As shown in chapters 5 and 6 (pp. 96, 108), the intrusions of the earlier White porphyry and later Gray porphyry were followed by a period of folding and reverse faulting, and this in turn by another period of fissuring and faulting which preceded the period of important ore deposition. Owing to these two intervening periods of disturbance, there was no very direct connection between the Gray porphyry sills and the ore. Outside of the Leadville district, however, some stocks and batholithic masses of monzonitic rock have been found that were intruded after the folding [3] and were either contemporaneous with or slightly older than the fissuring and minor faulting. These stocks appear to be the intrusive bodies most closely related to the ores of central Colorado in origin, and the grouping of the high-temperature or "contact-metamorphic" ore bodies of the Leadville district around the Breece Hill stock implies that this stock also is the principal center of mineralization at Leadville and may therefore contain

[1] Emmons, S. F., and Irving, J. D., The Downtown district of Leadville, Colo.: U. S. Geol. Survey Bull. 320, pp. 69-72, 1907.

[2] Blow, A. A., op. cit., pp. 145-181.

[3] Crawford, R. D., A contribution to the igneous geology of central Colorado: Am. Jour. Sci., 5th ser., vol. 7, pp. 365-388, 1924.

rock intruded subsequent to folding. Such an intrusive rock would be similar in appearance to that in the Gray porphyry sills, and any slight differences must be largely obscured by alteration. Failure to recognize it may have been due to this reason, to the few underground exposures, and to the fact that the significance of a stock crosscutting the sills was not realized when the ground was studied.

The high-temperature deposits, distinguished mainly by magnetite and silicate gangue minerals, might be regarded as "contact-metamorphic" deposits in the strict sense, as they replace limestone along porphyry contacts; but those in the Ibex and Comstock workings, the only ones whose outlines are well defined, are in contact with sills and not with the main stock, and, locally at least, they exceed the adjacent sills in thickness. It is therefore more probable that they were introduced after the intrusion of the sills and that the sills merely served as impervious barriers that forced the magnetite solutions, as they forced the later sulphide solutions, to spread along the limestone.

No local conduits through which the magnetite solutions reached the limestone have been recognized, though they might be found if the magnetite deposits were thoroughly developed. The solutions presumably spread from the upper part of a magma column in the Breece Hill conduit soon after the magma had consolidated. Where they reached limestone and became trapped by adjacent porphyry sills they replaced the limestone, depositing silicates first, then magnetite and specularite, and, after the temperature became sufficiently low, siderite and sulphides. The intergrowths of magnetite and siderite and the textural relations of pyrite and quartz to magnetite are proof that the magnetite and the sulphide-quartz deposits had a common source, but the quantity of sulphide that can be regarded as forming direct extensions of magnetite deposits is evidently small. The scarcity of sulphides, siderite, and quartz deposited with magnetite implies either that the ratio of sulphides to iron oxides was low or that high temperature was maintained long enough to permit the constituents of the sulphides to escape with other volatile matter through the porphyry barriers, so that when the temperature became sufficiently low they were deposited farther from their source than the oxides. Although the magnetite bodies themselves are of considerable size, they are few compared with the sulphide bodies of the later stage of ore deposition, and it is therefore concluded that the quantity of solution generated in the upper part of the stock and set free soon after its consolidation was relatively small.

After consolidation of the magma had continued for a considerably longer time and a correspondingly large quantity of ore-forming solution had accumulated in the magma reservoir, fissuring and minor faulting took place which permitted this solution to rise to and above the level of the magnetite deposits; but by the time the solution had reached that level its temperature had become lowered to or below the point where magnetite and specularite were stable in the presence of large quantities of sulphur, so that pyrite was deposited in their stead. For the same reason quartz was deposited instead of silicates, both replacing country rock and filling cavities. Where fissures happened to cut the magnetite deposits the pyrite and quartz formed veins through the magnetite, cementing its shattered parts and probably replacing it to a minor extent; but no evidence of replacement in large quantity has been noted. The silicates accompanying the magnetite, however, were altered to hydrous minerals, principally serpentine. Where fissures failed to penetrate the magnetite deposits the siliceous pyritic ore replaced limestone beneath a capping of magnetite, as in the Penn mine.

CAUSE OF DIFFERENCES IN MINERAL COMPOSITION

Differences in mineral composition of the sulphide deposits were determined largely by the kinds of rock through which the solutions passed. The original composition of the solutions obviously can not be fully determined but is approximately indicated by the constituents of ore and gangue minerals that were not present in the original rocks. The presence of a few other elements or "mineralizers" is also suggested. The constituents and the deposits in which they are present are as follows:

Recognized constituents of ore-forming solutions of the Leadville district

[x, Present in considerable quantity; (x), present in minor quantity; ?, doubtfully present]

Element	High-temperature deposits	Moderate-temperature deposits
Oxygen	x	x
Silicon	x	x
Aluminum	x?	x?
Iron	x	x
Magnesium	x	------
Sodium	?	(x)
Potassium	?	x
Water	x	x
Sulphur	x	x
Manganese	(x)	x
Zinc	(x)	x
Lead	?	x
Gold	?	x
Silver	?	x
Bismuth	------	(x)
Arsenic	------	(x)
Tungsten	------	(x)
Carbon	(x)	x
Fluorine	------	?

HIGH-TEMPERATURE STAGE

If the original solution had been allowed to cool slowly out of contact with any rocks or other reagents until it became supersaturated none of the high-temperature minerals might have been formed, as the lowest temperatures at which magnetite and such anhydrous silicates as wollastonite and pyroxene could form might have been passed before the solution became saturated with them; but supersaturation was hastened by reaction with the wall rocks, particularly limestone. It is conceivable that the newly consolidated monzonitic rock in the stock was in approximate equilibrium with the solution near its place of origin, and that no reactions between the two took place in any considerable quantity. It is well known that such reactions do take place in igneous rocks—for example, granitic and monzonitic rocks have been partly replaced by tourmaline, cassiterite, and other minerals typical of high-temperature deposits; but no replacement deposits containing these minerals have been recognized in any of the igneous rocks at Leadville. The monzonitic rock may have been corroded along fissures during the high-temperature stage, enriching the solution in certain constituents; or there may have been a partial change of its feldspar to muscovite, or of pyroxene, a minor constituent, to hornblende; but such reactions would have removed only an insignificant amount of water and perhaps a part or all of the fluorine from the solution.

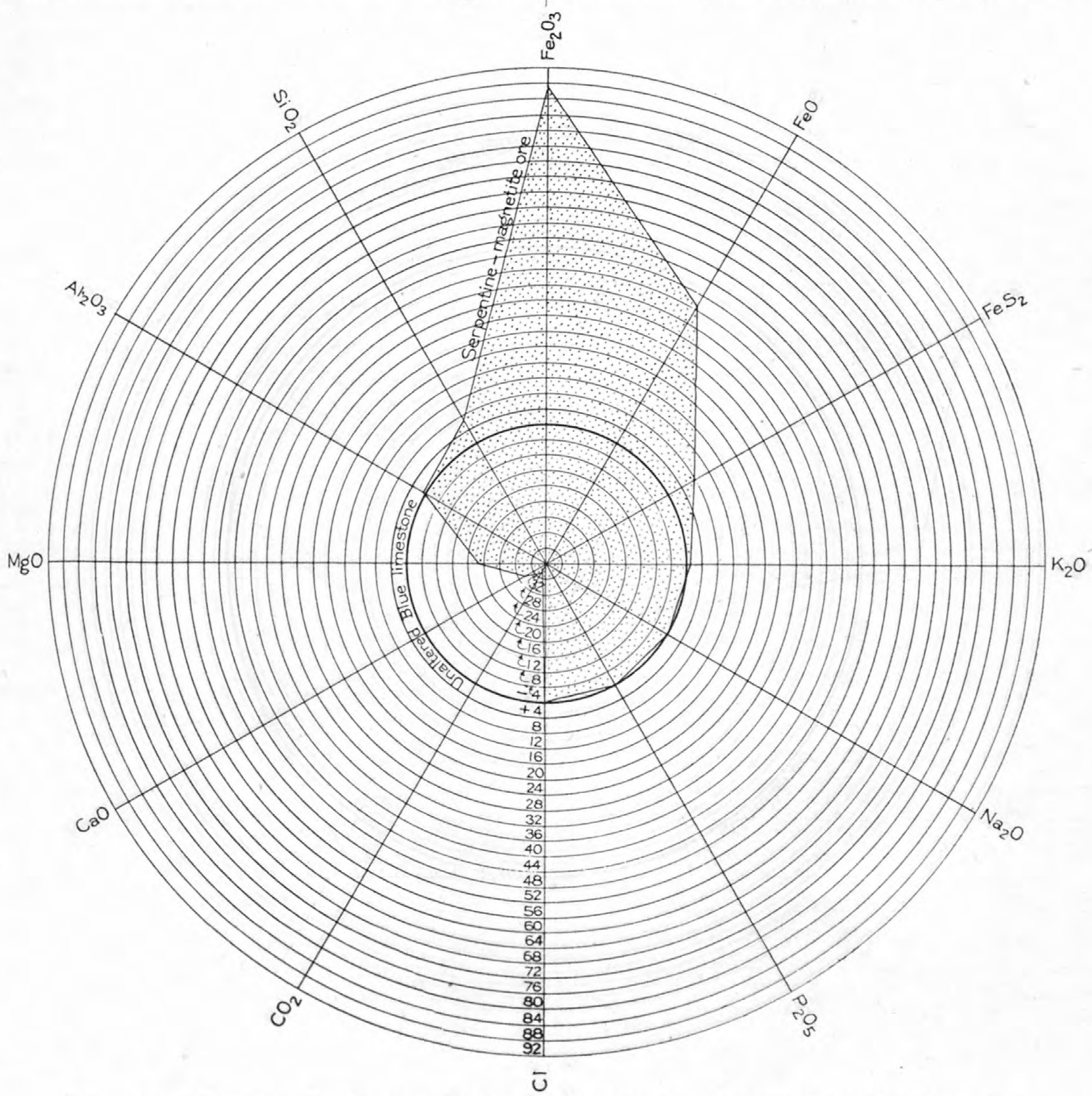


FIGURE 60.—Diagram showing gains and losses that have occurred in the replacement of Blue limestone by magnetite ore

The influence of limestone or dolomite, however, was far more important. Although these rocks may persist at high temperature when kept under sufficient pressure to prevent escape of their carbon dioxide and protected from chemical reagents, they are unstable in the presence of ore-forming solutions. When these solutions come into contact with limestone reaction quickly supersaturates them with respect to their more abundant and less soluble original constituents, and minerals are deposited whose identity depends mainly upon the temperature existing at the time. Where the temperature was highest in the Leadville district silicates of magnesia and lime were deposited, accompanied perhaps by some mineral containing alumina. Comparison of the analyses on pages 35 and 178, illustrated in Figures 60 and 61, indicates that the resulting deposit contained more magnesia and more alumina than could have been supplied by an equal volume of dolomite; but the alumina in that particular sample may have been supplied by shaly beds just above the Parting quartzite. When the temperature had lowered sufficiently, magnetite was deposited along with the silicates or filled interstices among silicates already formed. When the temperature had lowered still further, magnetite continued to form without conspicuous quantities of silicates. Specularite accompanied the magnetite at some stage of the process, presumably a late stage, but too little is known of the local paragenesis of the two minerals to warrant a more definite statement.

The lowering temperature at length reached a point where magnetite and specularite could not form in the presence of carbon monoxide and sulphur,[4] which the solution contained in considerable quantities, and the iron combined with these substances to form siderite, pyrite, or both. Conditions at this transition stage were marked by certain minor variations, the effects of which are expressed in the composition and texture of the ore. For example, magnetite or specularite was in equilibrium with siderite at the transition point and could crystallize along with it; or the solution, first permeating a mass of limestone, was quickly cooled below the transition point and deposited siderite by replacing limestone, whereas a later supply of solution, reaching the same place but cooling less rapidly, was still above the transition point and deposited magnet-

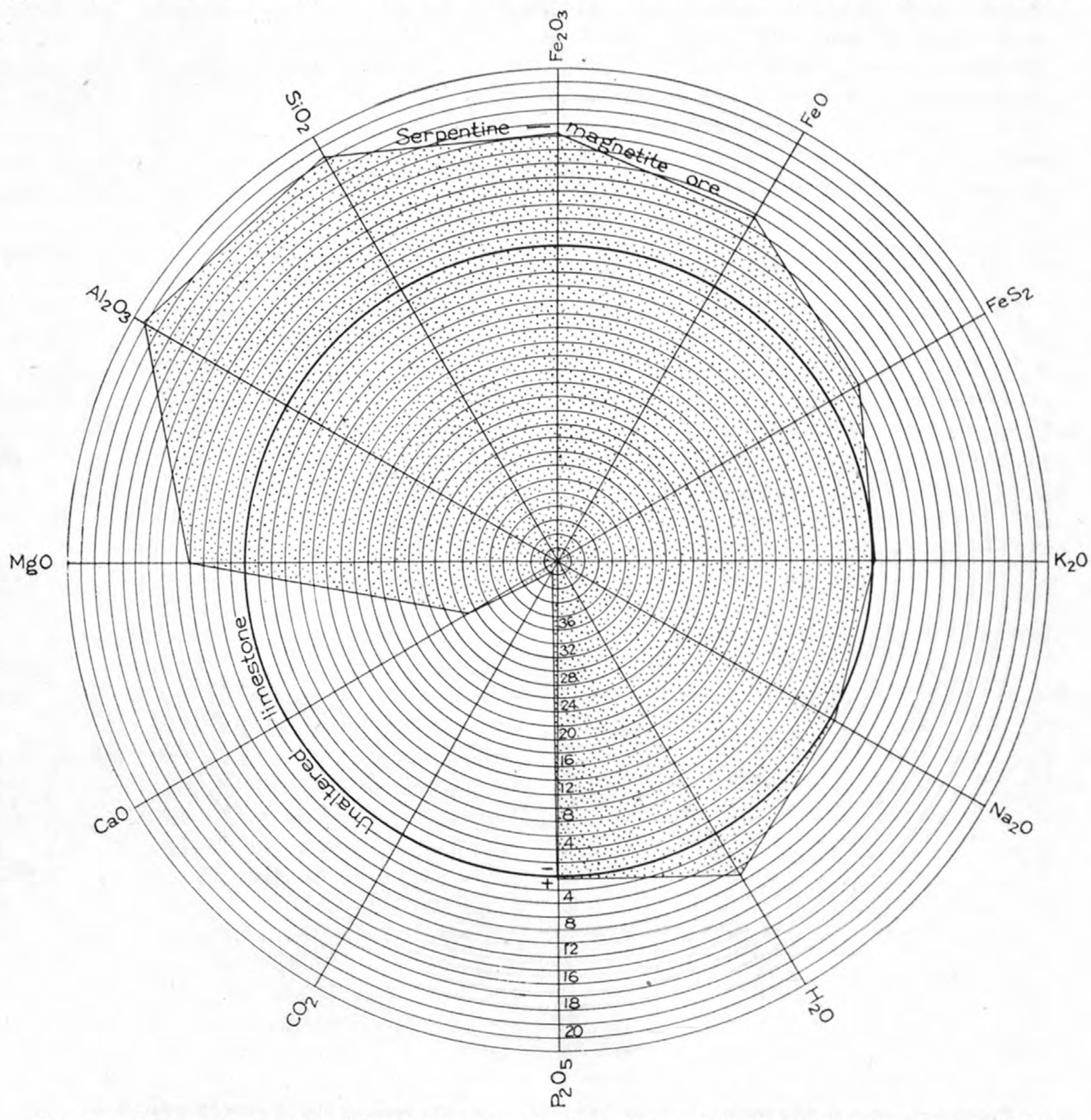


FIGURE 61.—Diagram showing gains and losses that have occurred in the replacement of Blue limestone by serpentine-magnetite rock

[4] Butler, B. S., A suggested explanation for the high ferric oxide content of limestone contact zones: Econ. Geology, vol. 18, pp. 401-403, 1923.

ite by replacing the siderite. Magnetite when once formed was evidently very resistant to resorption by the solution below the transition temperature or to replacement by the minerals that could crystallize below that temperature. These comments also apply in a general way to the relations between specularite and siderite and between either magnetite or specularite and pyrite, although specularite has been clearly replaced by pyrite to some extent. (See pl. 46, *C*.)

erals in the porphyry. Alteration products such as sericite and pyrite in porphyry adjacent to magnetite deposits in limestone are essentially identical with those adjacent to sulphide deposits produced during the following moderate-temperature stage. It may therefore be inferred that the porphyry was relatively immune to reaction during the high-temperature stage, although sericite may have begun to form then, but was conspicuously altered during the moderate-temperature stage, when pyrite, hydrous silicates, and carbonates were more stable than the original minerals of the porphyry. (See fig. 62.)

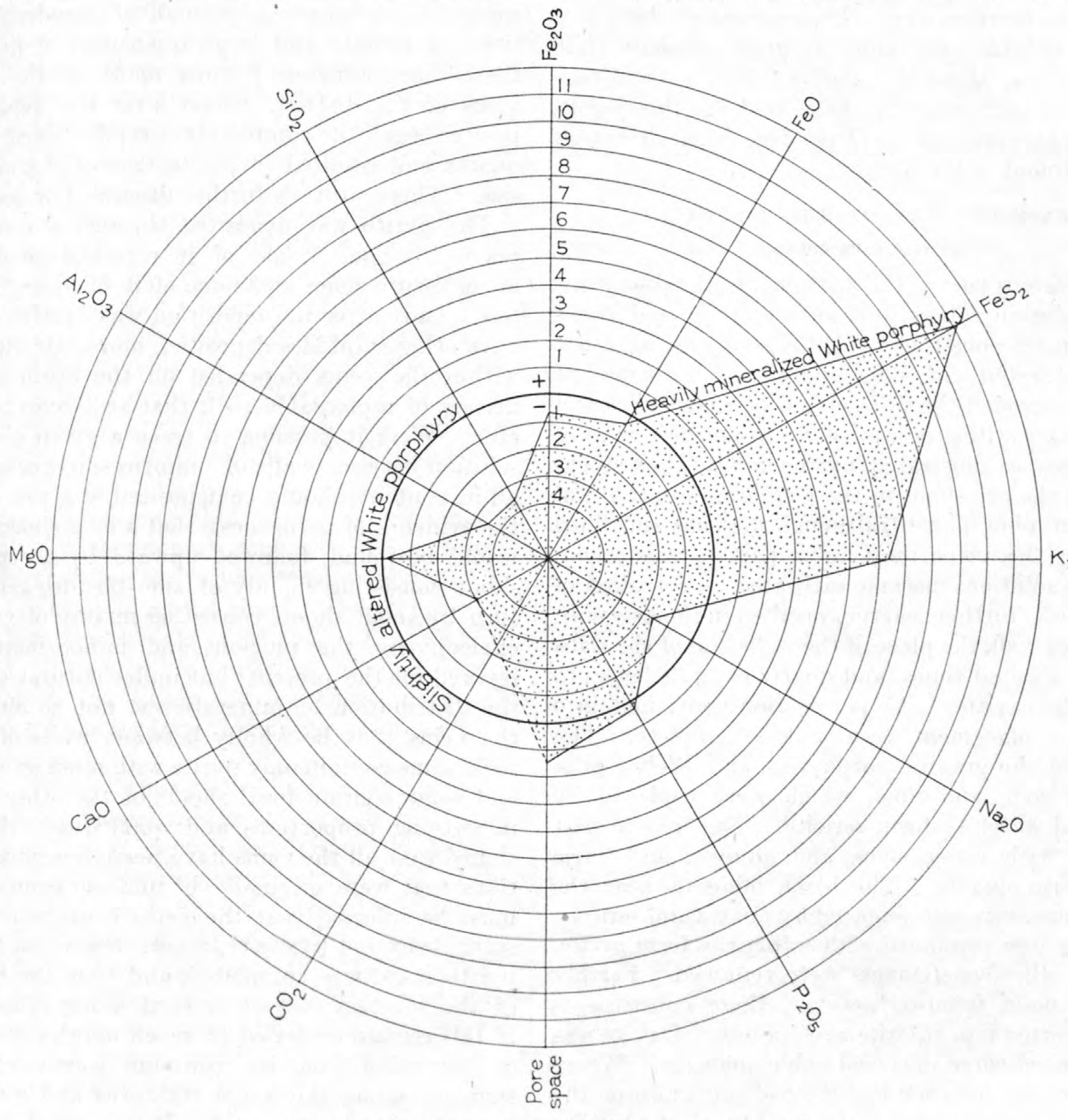


FIGURE 62.—Diagram illustrating alteration of White porphyry near ore bodies

Further deposition of metallic minerals took place during the moderate-temperature stage. It is true that chalcopyrite, zinc blende, and galena have been described as present in or adjacent to magnetite deposits, but they crystallized after the magnetite and specularite and for the most part after the pyrite.

The part of the solution that escaped into the adjacent porphyry sills while the limestone was being replaced by high-temperature minerals is not known to have formed any characteristic high-temperature min-

MODERATE-TEMPERATURE STAGE

The deposits formed at high temperature have been found only in the limestones of the Leadville district, but those formed at moderate temperature are present in all the rocks of the district, either as veins or as "blankets." As already stated, the larger deposits of this group were formed at a distinctly later time than those of the high-temperature group, and the solutions that deposited them presumably ascended from a deeper source in the magma chamber after the upper part of the Breece Hill stock and the rocks around it had cooled considerably. They may have started their journey at high temperature, but by the time they reached the lowest levels exposed by mine operations they had been cooled nearly or quite to moderate temperature. They ascended along any opening available and under so great pressure that they penetrated along the smallest fractures and permeated the intervening blocks of rocks so thoroughly that not a specimen of porphyry free from alteration has been found in the district.

EASTERN PART OF THE DISTRICT

IN SILICEOUS ROCKS

In the eastern part of the district considerable quantities of solution followed fissures and sheeted zones or faults in siliceous rocks. If the solutions were not already saturated with silica and alkalies they may at first have corroded the siliceous rocks, taken silica and other rock constituents into solution, and left vugs of various sizes, as illustrated by the South Ibex stockwork, and the ore shoot in the Cambrian quartzite of the Tucson mine (p. 289), although the vugs and filled cavities in the veins may be in part of this origin. When the solutions became saturated by corrosion of the wall rocks further reaction resulted in replacement. Dense silica took the place of the walls and of the slabs of rock in sheeted zones, and quartz crystals began to grow in the cavities. As permeation continued into the walls replacement became less complete. The feldspars in the granite, porphyries, and Weber grits lost their soda and lime, which were replaced by potash and water to form sericite. The lime in part combined with water, silica, and alumina and ferric iron to form epidote. The black minerals near the main fissures were also replaced by quartz and sericite, while their iron combined with sulphur to form pyrite, and their other constituents were removed. Farther from the main fissures, however, these constituents were converted into chlorite and epidote. Calcite was also deposited there in considerable quantity. Where permeation of the rock was intense and uniform the three stages of alteration—thoroughly silicified walls, followed by a narrow zone of quartz-sericite rock, and this in turn by a broad zone of quartz-sericite chloritic rock (propylite)—are distinct; but where the reactions have been less vigorous either of the first two zones may be inconspicuous or absent.

Only certain constituents of the solution, notably water, sulphur, potassium, carbon dioxide, and to a less extent silica, were able to penetrate the siliceous rocks and take part in the reactions. The other constituents continued their journey along the main fissures and more permeable bedding planes until conditions were right for their deposition. The courses followed were irregular owing to pinches and swells and linings of gouge, so that the solutions, although ascending as a whole, were locally forced to follow horizontal or downward directions, and the positions and shapes of ore shoots formed by them varied accordingly.

The quartz that began to crystallize in the openings was soon accompanied by small to considerable quantities of sericite and large quantities of pyrite, and these three minerals formed many of the principal veins of the district. Soon after the deposition of pyrite began it completely overshadowed that of quartz and resulted in pyrite masses of considerable size. This feature is further discussed on page 218.

The pyrite was deposited through a considerable vertical range. Some of it replaced country rock along fissure zones and some of it filled or lined cavities. Only after its deposition was nearly completed were other sulphides deposited, and their distribution within the veins depended on the openings or the masses of replaceable rock that still remained available. Were it possible to trace a given quantity of solution between walls of uniform siliceous rock until all its contents should be deposited, it is probable from the evidence of paragenesis that a long shoot of pyrite would be found, followed upward by a considerable shoot consisting mainly of zinc blende, and that in turn by small shoots consisting mainly of galena and chalcopyrite, the precious and minor metals being ignored for the present; but under natural conditions the distribution of minerals was not so simple. Of the veins that lie wholly between walls of siliceous rock, some contain only pyrite with more or less quartz and some contain local shoots of the other sulphides in varying proportions and quantities. If it is assumed that all the veins have been deposited by solutions that were originally of uniform composition, it must be inferred that the veins containing no other sulphide except pyrite represent deposition before the pyrite stage was completed, and that the remainder of the solution moved onward along minor cracks. If this remainder failed to reach another fissure zone of favorable size its contents were scattered as stringers along the minor fractures and were lost so far as mining is concerned. If it succeeded in reaching another favorable fissure zone the remainder of the pyrite was deposited, and if further progress of the solution was retarded or prevented by a "tightening" or pinching of the fissure zone the other sulphides were deposited wherever there was opportunity. The siliceous rock is not so readily replaced by these sulphides as by pyrite; but so long as it continued to be attacked by the solution after the saturation points of the sulphides had been reached replacement was a necessary consequence. As the bulk of the zinc blende was deposited before the galena, it crystallized partly in the interstices among the less compacted crystals of pyrite and partly as relatively pure lenses. The galena followed, either filling interstices in the pyrite and zinc blende or forming relatively pure lenses.

The occurrence of the chalcopyrite is less readily explained. Where the four sulphides are present together it evidently grew after the pyrite and during or after the late stages of zinc blende; but by far the most of it has been recognized in close association with pyrite where zinc blende is absent. It is suggested, therefore, that pyrite was the strongest precipitating agent for copper, and that chalcopyrite was not deposited in considerable quantity until the solution, largely depleted of zinc blende, chanced to circulate along a previously formed mass of pyrite.

In the foregoing discussion it has been assumed for the sake of simplicity that only one wave of solution passed along a fissure zone in uniform siliceous rock. It is probable, however, that in places the solution arrived in installments and that the successive installments reaching a given level were cooler and cooler, or more and more depleted of pyrite. It is conceivable, therefore, that shoots of zinc blende and galena may have been deposited by the later installments of solution upon or within earlier formed shoots of pyrite. It is also conceivable that a fissure once completely filled with minerals may have been reopened by recurring minor disturbances and admitted new supplies of solution, which could renew deposition of pyrite where zinc blende or galena had already been deposited. The possible variations in conditions are many, but on the whole the sequence of deposition outlined in the preceding paragraphs accords with the observed facts.

The Garbutt vein may serve as an example of veins formed wholly between walls of siliceous rock during the pyritic stage of deposition. Other sulphides are present in negligible quantity, and the bulk of them were evidently carried above the present surface of erosion or into ground that has not been developed. The Winnie-Luema vein represents the veins formed at more advanced stages, when zinc blende and galena were deposited in large quantity, partly between walls of siliceous rock but partly in contact with limestone, which hastened the reactions.

IN LIMESTONE

With few exceptions the solutions came into contact with limestone walls before their pyritic stage of deposition was far advanced. The degree to which they reacted with the limestone varied with physical conditions. Where the open character of the fissure persisted into quartzite or porphyry above the limestone there was little or no resistance to deflect the solutions into the limestone. Gouge along the walls of faults also protected limestone from attack by the solutions in some places. Under such conditions reaction was confined to the immediate walls but took place more readily where these were of limestone than where they were of silicate rock, so that the veins thicken where they cross limestone. Where the fissure tightened in the porphyry or shale above the limestone large quantities of solution were deflected into the limestone, and the degree of permeation depended upon the number of accessible bedding planes and minor fractures and the permeability of the limestone itself under the pressure that existed.

The kind of ore deposited depended upon the changing character of the solution. Where deposition was in its early stages quartz and pyrite replaced the limestone. If the remainder of the solution could escape from the limestone soon enough no subsequent deposition of other sulphides took place in the limestone, and the replacement body was identical in composition with the adjacent vein. This condition applied to the smaller bulges along the veins and to several of the larger replacement deposits in limestone on Breece Hill, particularly below the third Ibex level. The ground there was so thoroughly fractured that the solution was commonly able to pass through the limestone before reactions were completed. Descriptive data on the pyritic replacement deposits in limestone in the Ibex mine, however, are incomplete, and were thorough reexamination of the stopes possible it might be found that mining in some places stopped not against unreplaced limestone but against zinc blende that had too low a content of precious metal to pay for mining.

Where the solutions remained in limestone sufficiently long deposition of pyritic ore was completed and was followed by that of zinc blende or mixed sulphides.

So far as the rather scattered available evidence shows, this condition was more generally reached at low levels in the northern or northwestern part of Breece Hill than in the central and southern parts and was apparently due as much to the more advanced stage of deposition as to the confining of solutions in the limestone for unusually long intervals. At the higher levels the Weber (?) formation and the thick sheet of Gray porphyry were effective barriers that confined the solutions until zinc blende, galena, and minor minerals had been deposited.

WESTERN PART OF THE DISTRICT

The western part of the district was farther from the source of the earlier ore-forming solutions than Breece Hill and vicinity and was not so complexly fissured prior to mineral deposition. There is no evidence there pointing to more than one period of ore deposition, as any solutions corresponding to the first period at Breece Hill had been cooled to the lower limits of the high-temperature range by the time they reached the limestone. The small amounts of magnetite and specularite found with manganosiderite in the Tucson and Wolftone mines imply that deposition began at the transition between high and moderate temperatures, but the vast bulk of the ore and gangue with which they are associated seems to have been deposited in the second period of ore formation.

The solutions were similar to those in the Breece Hill area and ascended along different channels, only a few of which have been located. The channels now revealed in the Tucson, Wolftone, and Maid of Erin mines may have been slightly nearer the source than the others, as suggested by the magnetite and specularite and by the abundance and size of the ore deposits. This evidence is too scant to carry strong conviction, but it accords to a considerable degree with the distribution of the ore bodies.

As the solutions that first rose along these channels were either too hot or too little concentrated in silica and sulphur to deposit quartz and pyrite, the first extensive reaction was the replacement of the limestone by manganosiderite. This process continued until lowering temperature permitted the deposition of pyrite and quartz, which replaced the manganosiderite. The other sulphides that were deposited after the pyrite also replaced manganosiderite. The dissolved manganosiderite moved onward to points where it could again replace limestone and form a border or casing around the sulphide ore bodies.

Manganosiderite, to judge from its modes of occurrence, was deposited through a considerable range of temperature and concentration. It was formed before pyrite and was also deposited in interstices of ore after the deposition of pyrite and zinc blende had been completed, but it was unstable in the presence of solutions saturated with these sulphides. In this respect it is similar to dolomite and calcite. The manganosiderite formed at one time may differ in its ratio of iron, manganese, and magnesia from that formed at another, but it has been impractical to get pure samples representing different stages of deposition.

After the pyrite-quartz stage was reached ore deposition proceeded in normal order. Siliceous pyritic ore was deposited along and near crosscutting fissures or the more permeable bedding planes and was followed in succession by pyritic ore with low silica content, zinc blende, galena, and minor minerals, as already described. These successively later minerals were deposited wherever opportunity offered, either in relatively pure shoots or as streaks and interstitial filling among the earlier minerals, and gave rise to the different varieties of "blanket" ore. The details of the process of replacement whereby the layered and other structural variations of ore were developed are sufficiently considered in chapter 9 (pp. 202–205).

The marked difference in the proportion of "blanket" ore bodies to veins in the western and eastern parts of the district is due to structural conditions, as shown on pages 206–208. At Breece Hill porphyry intrusions are more numerous and complex than elsewhere, and intense fissuring and minor faulting have affected the strata from the Cambrian quartzite up to the Weber (?) formation. In the western areas porphyry intrusions below the top of the Blue limestone are less numerous and comparatively simple, and persistent fissures and premineral faults are relatively few. The Cord fissure extends from the pre-Cambrian granite up into the Blue limestone but is narrow compared with such faults as the Ibex No. 4, Garbutt, and Winnie-Luema. The Tucson fault has a considerable throw and is prominent at and below the White limestone, where it is steepest; but it is not conspicuous in the Blue limestone, where it parallels the bedding. Mineralized fractures above the Tucson fault and at many other places are minor cracks, sufficient to permit the migration of large quantities of solution but unaccompanied by enough shattering to permit the formation of pronounced veins of great vertical range. The solutions after passing through the lowest formations rose along inconspicuous fractures until they were deflected by impervious barriers, beneath which they moved for long distances.

The extensive deposits of the Iron Hill, Carbonate Hill, and Downtown areas clearly lend themselves to this explanation, and the principal channels through which they were fed are recognized; but those of Fryer Hill and East Fryer Hill, though of generally similar structure, have not been traced to any trunk channels. It has been suggested (p. 208) that solutions rising in the vicinity of the Tucson-Maid fault at Carbonate Hill circulated eastward and northward to the Small Hopes ground; but it requires some stretch of the imagination to believe that they continued farther and wound their way through the extensively mineralized ground to the north and northwest before they became depleted of their metal contents. Furthermore, the presence of siliceous pyrite ore, or its oxidized equivalent, in the deposits of East Fryer Hill strongly suggests the presence of nearer sources of supply. The small amount of exploration below the Blue limestone in these areas, however, has been disappointing and has not disclosed any trunk channels comparable with the Tucson-Maid fault zone or the Cord vein. Absence of such channels has led some to the conclusion that the ore was derived from the White porphyry, as originally stated by Emmons; but the similarity of the ores to those of other parts of the district supports the belief that more thorough development of the lower formations would disclose some local trunk channels.

SEGREGATION OF PRECIOUS AND MINOR METALS

There has been so little opportunity to study the relations of hypogene or primary minerals containing the precious and minor metals to the more common minerals of the deposits that the drawing of very positive conclusions regarding their occurrence is not warranted. Although small amounts of arsenopyrite, tennantite, tetrahedrite, and other minerals have been reported from certain of the deposits, it has not been possible to study their associations, and the only minerals that can be considered here are bismuthinite, argentite, and gold.

The only satisfactory information regarding bismuthinite is that obtained in the lower levels of the Tucson mine. There deposition took place almost exclusively in cavities, and the succession of minerals was unusually clear. Galena and a little chalcopyrite followed zinc blende and were followed in turn by the intergrowth of bismuthinite and argentite called "lillianite." The few specimens studied microscopically suggest that the intergrowth began during the last part of the galena stage, so that the three minerals are intergrown to some extent. The fact that "lillianite" has been found at only a few widely scattered places in the Leadville district is interpreted as an indication that the solutions contained only minute quantities of bismuth and silver, and that opportunities to deposit them in visible masses were exceptional. Ordinarily the solutions after depositing galena were either held back by porphyry or shale barriers and deposited the bismuthinite and argentite in the interstices of the other ore minerals, or they escaped through the barriers and scattered the two minerals in inappreciable quantities along their course. This explanation agrees with the fact that minute quantities of bismuth were found in complete analyses of the Leadville ores and the bullion, skimming, and chamber dust derived from them.[5] It may be inferred that if bismuth were as regularly looked for as silver it would be found to be as widely and irregularly distributed.

This explanation also implies that silver in the form of microscopic argentite is more closely associated with galena than with zinc blende or pyrite but that it bears no fixed ratio to lead. Solid masses of galena that could not be permeated by the remaining solution can hardly contain interstitial argentite, but permeable masses may contain considerable. Any circumstance that would permit the remaining solution to permeate masses of pyrite, zinc blende, or mixed sulphides could similarly account for the presence in some of them of sufficient silver to pay for mining.

The fact that at least a little silver is present in practically all samples of the ores assayed suggests that the sulphide minerals may contain small amounts of silver in solid solution,[6] the amount of silver varying with the temperature and concentration of the solution at the time of deposition. It is very doubtful, however, if such variations would be sufficient to account for the wide variation of silver content in sulphide ores that bear no evidence of supergene enrichment. The explanation offered in the preceding paragraph best accords with the few available facts regarding the occurrence of silver in the primary ores of Leadville.

The distribution of gold is more difficult to explain, as no visible gold of undoubted primary origin has been found in the ores of the district. The primary sulphide ores contain a few hundredths of an ounce of gold to the ton, which may be attributed to solid solution, but siliceous pyritic ore locally contains considerably more. Some samples of pyritic ore that contain an ounce or more of gold to the ton contain considerable silica, but others equally rich, taken close by and within a siliceous ore body, consist almost entirely of pyrite; furthermore, some of this rich gold ore contains more copper than usual, and some contains little or none. It therefore appears that gold, like copper, was precipitated from solution by pyrite or silica or both. It can not be definitely stated at what stage gold was deposited, but its extremely small quantity suggests a late stage. The relatively high content of gold in the bismuthinite-argentite ore of the Tucson mine must also have been deposited at a late stage. Gold deposited by a solution that permeated large masses of pyritic ore somewhat evenly would be too thinly scattered to be of commercial value; but where considerable quantities of solution passed along a narrow course through pyrite or quartz gold was deposited in relatively large quantity. Conditions for local primary concentration were more favorable in the veins than in the large blanket ore bodies; but most of the vein ores owe their present gold content largely to enrichment, which also could take place more readily in the veins and obscure the origin of the primary gold.

ORIGIN OF "FLINT" AND MINOR GANGUE MINERALS

In parts of the Downtown and Fryer Hill areas barite and dense quartz (jasperoid or "flint") are prominent results of mineralization, and the same minerals form the principal gangue in the Continental Chief, Liddia, and doubtless other mines beyond the eastern

[5] Guyard, Anthony, U. S. Geol. Survey Mon. 12, pp. 616, 694, 696, 712, 715, 1886.

[6] Nissen A. E., and Hoyt, S. L., On the occurrence of silver in argentiferous galena ores: Econ. Geology, vol. 10, pp. 172-179, 1915.

limit of the Leadville district. Vugs containing ankerite or dolomite are minor features of ore bodies in several parts of the district, and white streaks and patches of dolomite ("zebra rock") are common in the Blue limestone near the ore bodies. A thorough review of the origin of the ores must account for these as well as for the more abundant ore and gangue minerals.

The jasperoid or "flint" is the most difficult to explain, as its abundance in poorly metallized areas far from the known centers of mineralization as well as in close association with extensive ore bodies implies deposition during and after the intensive deposition of sulphides, whereas the sulphides themselves, as already shown, were mainly deposited after the quartz in the veins and adjacent parts of blanket ore bodies.

The deposition of abundant silica at two distinct stages separated by one in which the sulphides were deposited abundantly may, however, be no more improbable than a similar separation of the two stages at which manganosiderite was deposited. It may be inferred that the solutions first became saturated with silica and began to deposit it at a temperature too high for the existence of sulphides. Thus masses of silica may exist, as in certain other districts, in close association with high-temperature deposits and distinctly earlier than sulphide deposits. When the temperature had lowered to the point where the sulphides could form they became more insoluble than quartz, were deposited instead of quartz, and even replaced quartz to some degree. So long as this condition continued massive sulphides low in silica were formed. Any silica replaced by the massive sulphides moved onward and again replaced the limestone, forming borders around the ore similar to the borders of manganosiderite. Manganosiderite is cut by veinlets of quartz accompanied by a few sulphide grains and is doubtless replaced by quartz to some extent, but the two minerals commonly form separate masses. The problem of their relations to each other was evidently not fully appreciated during the first and second surveys of the district, and was furthermore considerably obscured by oxidation; but from the evidence available the manganosiderite replaced limestone at and near the centers of intense mineralization, and the dense quartz or jasperoid was deposited farther from those centers. Thus the ore bodies along the Tucson-Maid fault in the Tucson mine are surrounded by manganosiderite, whereas those along the "first contact" above it are bordered or floored by jasperoid. Similarly manganosiderite is abundant around the ores near the same fault in the Maid of Erin and adjacent mines, while jasperoid is prominent farther west, in western Carbonate Hill and the Downtown area. In the Fryer Hill area manganosiderite has not been recognized in abundance, but the ores are accompanied by "floors" or borders of jasperoid, and oxidized iron-manganese ores are relatively high in silica, especially at East Fryer Hill. Owing to the thorough oxidation of the ore bodies that have siliceous floors the suggestion has been made that floors of jasperoid are of supergene origin, but their presence in places where oxidation is negligible prevents general application of such an interpretation. The jasperoid itself is impregnated and stained by products of oxidation, and cavities in it are lined or partly filled with layers of chalcedony or finely crystalline quartz.

Many of the old rich stopes of lead ore are bordered by these masses of jasperoid. Oxidation has prevented the determination of the original proportion of galena to pyrite and zinc blende in the original ores of these stopes, but it would accord with the above reasoning if the original ore shoots farthest from the centers of intensive deposition had a higher proportion of galena than those near the centers. The "hard carbonate" ore, which consists of jasperoid impregnated with cerusite, favors such a suggestion.

Barite could not be formed until the solutions had cooled to a temperature at which the sulphate radicle was stable.[7] This was evidently after the stage of intensive sulphide deposition, as barite is very scarce in these ores and has been found only in vugs. It was mainly carried in solution to the outer parts of the large bodies of massive sulphides and deposited either in relatively pure bunches of crystals or as crystals disseminated through jasperoid. It has been seen by the writer in so few places, however, that no effort to account for these differences in mode of occurrence is made. At these few places the ores are oxidized or partly oxidized, and the exact relations of barite to the sulphides can not be determined, but the ores containing much barite are lead ores, and in the least oxidized ores the voids that may represent former zinc blende and pyrite are in much smaller ratio to galena than in the mixed sulphide ores that are relatively free from gangue. The galena in the baritic ores had crystallized after the barite. In some places the temperature at which barite could form may have been reached before there had been enough reaction with the wall rocks to precipitate much of the pyrite, to say nothing of zinc blende. Under such conditions barite and pyrite could have been deposited simultaneously, and if

[7] Butler, B. S., Primary sulphate minerals in ore deposits: Econ. Geology, vol. 14, pp. 596-608, 1919.

the supply of barite had been sufficient that stage could have been followed by simultaneous deposition of barite and zinc blende with subordinate pyrite and finally by barite and galena. Actual observations, however, though few and scattered, indicate that the ores containing considerable barite were not formed until the stage of intensive deposition of pyrite and zinc blende was nearly finished.

Some, if not all, of the baritic ores contain considerable silver. Emmons[8] stated that in the early days the miners in the Fryer Hill area regarded barite as a good indication of silver. This association accords with the conclusion that silver sulphide was deposited mainly at the end of the galena stage and in relatively abundant quantity in the interstices of the lead ores; but the concentration of silver during the subsequent period of oxidation has obscured the relations of primary silver to baritic ore.

The only other primary gangue minerals to be accounted for are the carbonates—ankerite, dolomite, and calcite. The first two are found in the ores in extremely small quantity and only as linings of vugs. Dolomite is also present as "zebra rock" in the Blue limestone near the ore bodies. Calcite of hypogene origin is even more scarce. The relations of ankerite to dolomite have not been established, but both mark a late stage when the power of the solution to attack the dolomitic limestones of the district had ceased. The white dolomite in the porous patches of "zebra rock" is practically identical in composition with the original dolomite of the Blue limestone, minus the dark carbonaceous coloring matter. This and a part of the original dolomite were leached out, leaving the remainder to recrystallize as white dolomite, and the process marked the point where the solution, already heavily charged with magnesium and calcium carbonates that had been replaced by ore, became saturated and had no further effect on dolomite. If the solutions continued their course into high-calcium limestone they may have replaced the limestone with dolomite, but there are no high-calcium limestones in the vicinity. As calcite would not be deposited from such a solution until after deposition of dolomite was completed, its virtual absence from the primary sulphide ores of the district is readily understood.

What became of the solutions after they completed the deposition of the ore and gangue minerals is of no practical interest to those occupied with the mining of the ores. In their reactions with the porphyries and other siliceous rocks they had taken into solution relatively large quantities of lime and soda, moderate quantities of silica and alumina, and small quantities of magnesia and iron. From the dolomitic limestones they had dissolved large quantities of magnesia, lime, and carbon dioxide. They doubtless retained considerable of their original sulphide and sulphate radicles. In their upward course through the siliceous rocks above the Blue limestone they had little reacting power, but any small veins of carbonate with minor quantities of other minerals may be attributed to them. Eventually they may have reached the surface, 10,000 feet above the present surface, as mineral springs.

[8] Emmons, S. F., U. S. Geol. Survey Mon. 12, p. 451, 1886.

CHAPTER 11. THE OXIDIZED ORES

The oxidized ores, though for a long time the principal source of metal, have for some years been contributing less than the sulphides to the total output of Leadville. They still furnish a considerable part of the district's production, however, as new bodies are occasionally found, and old stopes are from time to time reworked for material that was formerly of too low grade for mining. The oxidized ores of the blanket bodies show a wider variation in mineralogic character than the sulphides, as the elements in the original sulphides have been redistributed, and a single sulphide, such as pyrite, has yielded a number of different minerals on oxidation.

As the different classes of sulphide ore grade into one another and are distributed in a most complicated way, it is to be expected that the oxidized ores derived from them have an equally complicated distribution. Oxidized ore shoots containing essentially one metal and others containing a mixture of metals are present, but the processes of oxidation have had a tendency to separate the metals further, particularly lead from zinc.

The distinct classes of ore and their sources of derivation are listed below. Their gradations into one another are made clear in the descriptions that follow.

Iron-manganese and manganese oxide ore, derived from manganosiderite.
Iron oxide ore, derived from pyrite ore low in silica.
Oxidized siliceous gold and silver ore, derived from siliceous pyritic ore.
Lead carbonate ore, derived from massive galena and mixed sulphides.
Lead-iron sulphate (plumbojarosite) ore, derived from mixed sulphides.
Oxidized siliceous lead ore, derived from siliceous mixed sulphides.
Zinc carbonate and silicate ore, derived from massive zinc blende and mixed sulphides.
Oxidized siliceous copper ore and copper sulphate ore, derived from siliceous pyrite-chalcopyrite ore.
Oxidized bismuth ore, derived from bismuth sulphide ore.

The oxidized copper and bismuth ores are present as minor segregated deposits in ore of other kinds and need no further attention. The little that is known about the bismuth ores is stated on page 206, and that about the copper ores on pages 199–201 and 268.

OXIDIZED MANGANESE AND IRON ORES

CLASSES AND GENERAL CHARACTER

The group of oxidized manganese and iron ores includes three commercial classes—high-grade manganese ore, manganese-iron for the manufacture of spiegeleisen or ferromanganese, and iron or iron-manganese ores for smelter flux. There is no marked difference between the last two, however, and the use to which the ore is put depends mainly on the relative demand from steel plants and smelters. This group of ores is abundant in Printer Boy, Rock, Iron, Carbonate, Fryer, and Yankee hills and in the Downtown district and is present also in other parts of the region. It constitutes a part of the "vein material" that surrounds the shoots or channels of lead carbonate ore, as shown by Emmons, but the relations of the iron and manganese ores to the rest of the "vein material" have not been systematically studied. According to Emmons[1] and Ricketts[2] this "vein material" is mainly an impure mass of iron and manganese oxides with more or less silica and clayey materials. Much of it is too impure to be mined for its iron and manganese content, except at a few places where it contains an unusually large amount of silver, and grades into oxidized siliceous silver ore.

According to Ricketts, who concentrated his studies on the Morning Star and Evening Star mines of Carbonate Hill, the lower half of the mineralized ground is composed largely of iron and manganese oxides, dark brown to black and slightly mottled. Farther up large quantities of siliceous material occur, especially in the "first contact" deposit. These mixtures of iron and manganese oxides are in part compact, in part loose. The loose variety is found near the top of the zone of gangue rather than in the middle; it is also found near the bottom and in many places forms seams in the limestone and around "boulders" of unreplaced rock. The greater part of the material is compact and deep blackish brown. It has a well-marked jointed structure and in many ways resembles stained limestone. This description suggests that a part at least of the hard variety may have been zinc carbonate, which, however, is brown rather than blackish brown; but Ricketts's analysis, quoted below, is that of a siliceous iron-manganese oxide ore. It also seems possible that the hard variety represents a replacement of Blue limestone (dolomite) by iron and manganese oxides, whereas the soft variety represents oxidation of manganosiderite where black and of pyrite or mixed sulphides where brown.

The following analysis corresponds most closely to certain analyses in the group representing fluxing ores (p. 223) but also meets the requirements of ore for steel plants.

[1] Emmons, S. F., U. S. Geol. Survey Mon. 12, atlas sheets of Iron, Carbonate, and Fryer hills, pp. 407–408, 451, 1886.

[2] Ricketts, L. D., The ore deposits of Leadville and their modes of occurrence as illustrated in the Morning and Evening Star mines, p. 26, Princeton, 1883.

Analysis of typical specimen of compact iron-manganese oxide ore

[Ricketts, L. D., op. cit., p. 27]

Silica	10.73
Ferric oxide	46.22
(Equivalent iron, 32.35.)	
Alumina	.06
Manganese dioxide	31.18
(Equivalent manganese, 19.64.)	
Lime	1.20
Magnesia	.68
Water	9.98
Phosphorus pentoxide	.05
Sulphur trioxide	.03
Carbon dioxide	.54
	100.67

Emmons did not give systematic descriptions of the "vein material" of Rock, Iron, and Carbonate hills. Iron and manganese, however, were abundant in the ore zones of South Iron Hill, but they were relatively scarce in the vicinity of the Adelaide mine, at the north end of Iron Hill, where jaspery material containing 5 per cent of iron oxide was abundant.[3] Iron-stained vein material, "Chinese talc," and black jasperoid were abundant in the southern part of Carbonate Hill,[4] and black iron was abundant on the east side of the ore shoot in the Carbonate mine.[5] Iron-stained "vein material" was abundant in the Excelsior mine at the top of Carbonate Hill[6] and replaced practically all the Blue limestone in the mines of northern Carbonate Hill.[7] At the main shaft of the Evening Star it was exceptionally thick and exceptionally rich in manganese.[8] Emmons also noted that the "vein material" was more siliceous close to the lead carbonate stopes. Developments had not progressed sufficiently at the time to afford opportunity for thorough study of the distribution or origin of the vein material.

Emmons's observations on the vein material in Fryer Hill were more extensive.[9] There too it had almost completely replaced the portion of the Blue limestone between the upper and lower sheets of White porphyry. In the main part of the hill it has a relatively high content of iron; in the eastern part, in and around the Robert E. Lee mine, it is very siliceous. In the main part of the hill the silica is black and chertlike, in some places forming solid bodies and elsewhere thoroughly shattered, with its fractures filled with clay. The iron is mostly present as brown oxide, locally mixed with the red oxide. In several places it was comparatively free from silica and valuable as a flux, as in the Amie mine, where it also contained 10 to 12 ounces of silver to the ton and was more cheaply mined than the magnetite-hematite ore of the Breece iron mine.[10] This ore in the Amie mine was the only vein material cited by Emmons as being utilized primarily for its iron and manganese content, but Guyard[11] stated that one of the local smelters was supplied with iron flux from the Silver Wave mine, in Carbonate Hill. The chertlike silica was much less conspicuous in the Amie mine than in the mines to the west or to the southwest. Much of the iron material in Fryer Hill was cavernous, with druses of quartz, cerusite, and locally pyrolusite. It graded into practically pure silica. The "black iron" contained not more than 10 per cent of manganese and did not approach a pure manganese mineral in any large quantity except in the Dunkin mine and the adjoining workings of the Climax No. 3.

During the interval between Emmons's first and second surveys of the district the shoots of oxidized lead-silver ore were largely worked out and the workings became inaccessible. Descriptions of the ore bodies written in this interval gave scant attention to the distribution of different grades of iron and manganese ore. When these ores were mined intensively during the World War they were examined by several geologists and mining engineers, but no descriptions giving a satisfactory idea of the distribution of the ores of different grades were published. In the absence of such descriptions an approximate idea of the distribution and character of the ores can be gained from lists of producing mines and analyses of the ores.

HIGH-GRADE MANGANESE ORE

High-grade manganese ore was shipped from the Carbonate (Edna) and A. V. mines in 1918–1924. The shipments from the A. V. mine averaged 38 per cent of manganese, and much from the Carbonate contained more than 40 per cent. To judge from the process of derivation of the high-grade manganese ores, they should be comparatively scarce and occur in small bodies. The only considerable sources of manganese are the masses of manganosiderite, in which iron exceeds manganese. Manganese is ordinarily more readily retained in solution by descending waters than iron, but both are readily precipitated in the presence of oxygen. Where considerable quantities of manganosiderite were replaced by zinc carbonate or dissolved by water containing free acid the iron and manganese were carried in solution until the waters became supersaturated or until precipitation in large quantity could take place by reaction with dolomite or limestone. Where exceptional conditions permitted deposition of the iron while the water continued to move onward with its manganese, the manganese could be deposited later in bodies of high-grade ore. The ideal place to look for such high-grade bodies would

[3] Emmons, S. F., op. cit., pp. 407–408.
[4] Idem, pp. 412, 416.
[5] Idem, pp. 419–420.
[6] Idem, p. 427.
[7] Idem, p. 429.
[8] Idem, p. 433.
[9] Idem, pp. 444 et seq.
[10] Idem, p. 472.
[11] Idem. p. 646

be along the lower margins of thoroughly oxidized vein material; but a number of local factors, particularly the presence of such unfavorable rocks as porphyry, quartzite, or shale in contact with or close by the original bodies of manganosiderite, would prevent the accumulation of high-grade manganese ore in its ideal position. Intelligent search for the high-grade manganese ores can be made only in the light of a thorough knowledge of the distribution of the other ores in the vicinity, of the local structural features that control the circulation of ground water and favor or hinder the deposition of the material which it contains. So much important information about the old shoots of oxidized ore was left unrecorded that it is now very difficult if not impossible to gain the detailed knowledge necessary for intelligent prospecting.

MANGANESE-IRON ORE FOR FERROMANGANESE AND SPIEGELEISEN

Ore containing 16 to 35 per cent of manganese was shipped to manufacturers of steel in 1918–1924 from several mines in the Carbonate Hill, Fryer Hill, and Downtown areas and from one mine each in Iron and Rock hills. Analyses of these ores are given below:

Commercial analyses of manganese-iron ores shipped to steel plants in 1918

[Per cent]

Area and mine	Mn	Fe	SiO_2	H_2O
Rock Hill:				
Nisi Prius mine	[a] 30.0	19.0	12.0	15.0
	23.62	14.20	12.17	15.0
Iron Hill:				
Iron Silver Mining Co.	[a] 30.0	18.0	12.0	16.0
	19.59	22.69	7.30	14.0
Downtown:				
Capitol (Northern) and Clipper claims [b]	[a] 34.1	19.4	10.6	15.0
	[a] 30.8	17.9	14.3	15.0
	27.64	20.6	17.06	17.6
	21.65	20.2	6.18	16.5
Home Extension mine	[a] 31.00	12.0	13.0	15.0
Downtown mines	27.2	21.56	9.0	10.8
Carbonate Hill:				
Crescent mine	21.38	18.26	8.12	18.2
Yankee Doodle mine	20.8	19.0	8.20	18.0
Star Consolidated mine	20.2	19.1	12.6	19.7
Catalpa mine	19.5	18.5	9.1	19.4
Fryer Hill:				
Jason mine	[a] 26.5	27.8	8.2	13.2
All Right and Fairview claims [c]	17.3	22.4	14.8	12.0

[a] These samples, if the analysis is recalculated on a dry basis, contain 35 per cent or more of manganese and could therefore qualify as high-grade manganese ore.
[b] Different lots from these claims contained 0.031 to 0.055 per cent of phosphorus.
[c] Different lots from these claims contained 0.038 to 0.063 per cent of phosphorus.

Analyses of ores from Carbonate Hill collected by S. F. Emmons in 1894 showed 31 to 33.5 per cent of manganese, 16.7 to 18 per cent of iron, 8 to 11 per cent of insoluble matter, and 6 to 8 ounces of silver to the ton. An average of a year's shipment from one mine in Carbonate Hill, reported by the Empire Zinc Co., was 25 per cent of manganese, 25 per cent of iron, 1 to 3 per cent of lead, 5 per cent of insoluble matter, and 5 to 20 ounces of silver to the ton. The principal requirement at eastern steel plants is that manganese-iron ore for ferromanganese must contain more than 25 per cent of manganese and less than 8 per cent of silica, although ores with more silica have been purchased. The Colorado Fuel & Iron Co. at Pueblo has used ores containing as little as 13 per cent of manganese, but such ores are limited to a very local market.

Nothing definite is known of the extent of these ore shoots, as none of them were being worked when the writers were in the district. The present writer (Loughlin) had an opportunity to examine briefly some of the stopes in the Star Consolidated mine, incidental to other work, but not to map them in detail. These stopes compared with those of other ores were small and irregular. The ore was soft and black and contained hard residual lumps and streaks of chert or jasperoid and seams of clay. According to J. B. Umpleby,[12] who visited the district in 1917, the Fairview or All Right No. 1 property contained a fairly homogeneous mass of ore 120 feet thick. Its areal extent had not been proved, though the workings at the time penetrated an area measuring 200 by 75 feet, and similar ore had been found 275 feet farther west in the old Fairview shaft, 400 feet to the north in the Jason lease, and 300 feet to the north in the All Right shaft.

FLUXING ORE

Analyses of the ores used for fluxing are more numerous and complete, but information on the extent and distribution of the ore shoots and their relations to ore bodies of other kinds is as meager as that on the group of ores just considered. Representative analyses made on samples of these ores from lots shipped in 1917 and 1918 are given in the following table:

[12] Min. and Sci. Press, Nov. 24, 1917, p. 758 (reprinted from press bulletins of U. S. Geol. Survey).

Analyses of iron-manganese fluxing ores

(Reported by smelting companies)

Area and mine	Mn	Fe	SiO_2	Au	Ag	Pb	Cu	S
	Per cent	*Per cent*	*Per cent*	*Ounces per ton*	*Ounces per ton*	*Per cent*	*Per cent*	*Per cent*
Rock Hill:								
Nisi Prius	19.3	16.7	16.3	0.001	9.4	0.65	0.03	-------
La Plata	7.0	27.8	23.4	.06	8.0	3.7	-------	-------
Iron Hill:								
Iron-Silver	6.6	41.5	7.9	.03	7.0	1.6	.05	-------
Do	8.5	29.4	21.0	.01	5.5	8.0	.03	-------
Downtown:								
Downtown Mines	29.0	27.1	12.3	.003	6.0	2.7	.25	-------
Do	25.2	24.4	8.5	-------	5.0	1.0	-------	-------
Do	20.5	30.3	4.7	-------	2.95	1.2	-------	-------
Capitol (Northern)	24.4	20.6	14.4	-------	10.3	2.45	-------	-------
Do	25.7	21.0	6.0	-------	10.2	5.9	-------	-------
Carbonate Hill:								
Leadville Consolidated group	30.0	15.0	12.4	-------	9.3	1.0	-------	-------
Do	10.0	29.3	16.6	.006	4.4	3.5	-------	-------
Star Consolidated	17.1	33.0	9.5	-------	4.5	.65	-------	-------
Western Mining Co	12.0	34.0	9.0	-------	3.7	5.3	-------	-------
Big Chief	4.1	44.0	6.9	-------	1.95	8.35	-------	-------
Do	12.0	31.0	10.9	-------	4.0	8.00	-------	-------
Castle View	8.9	32.0	8.3	-------	3.8	13.1	-------	-------
Seneca	18.9	37.4	3.0	-------	4.25	1.4	-------	-------
Do	8.4	28.1	20.7	-------	23.1	11.95	-------	-------
Fryer Hill:								
Fairview	20.7	27.0	10.7	-------	4.85	1.6	-------	-------
All Right	23.0	29.0	6.3	-------	1.6	.35	-------	-------
Chrysolite	6.5	25.0	40.2	-------	14.45	2.8	-------	-------
Do	14.6	31.4	16.5	-------	4.85	.4	-------	-------
Little Chief	16.8	32.6	10.4	-------	4.1	1.0	-------	-------
Do	3.1	39.7	26.0	-------	6.7	2.1	-------	-------
Dunkin	8.3	40.9	17.7	-------	6.1	.2	-------	-------
Matchless	9.0	39.0	11.0	-------	7.0	-------	-------	-------
East Fryer Hill:								
Little Silver	5.7	36.8	22.0	-------	4.85	1.0	-------	-------
Do	7.2	39.5	20.1	-------	17.4	-------	-------	-------
Bangkok and Cora Bell	3.65	25.4	33.05	-------	19.2	.4	-------	11.6
Do	8.0	44.4	15.02	-------	5.25	-------	-------	.1
Forepaugh	7.8	41.6	17.2	-------	8.4	.3	-------	-------
Do	5.9	36.7	26.9	-------	25.15	-------	-------	-------
Tip Top	7.3	38.9	20.7	-------	14.05	-------	-------	-------
Do	8.1	42.8	13.5	-------	5.65	.5	-------	-------
Denver City	7.0	42.9	14.1	-------	3.45	.4	-------	-------
Do	5.9	38.1	20.4	-------	11.35	None.	-------	-------
Quadrilateral	5.3	44.6	11.1	.01	8.6	.6	-------	-------
Do	1.4	45.1	19.1	-------	3.6	.8	-------	-------
Iowa Gulch:								
Le Compton	9.3	27.8	23.7	-------	9.2	1.8	-------	-------
Do	2.3	39.3	22.5	-------	5.25	2.1	-------	-------

The foregoing analyses of fluxing ores, compared with those of ores shipped to steel plants, are on the whole lower in manganese and higher in iron and silica, but the disposal of the better grades of ore is more likely to be governed by the relative demands of smelters and steel plants than by the indicated differences in composition. They are probably higher in lead and silver, though no direct comparison can be made. The silica is high in the ores of Fryer Hill and particularly East Fryer Hill; it is also higher in the few analyses of ore from Rock Hill than in those from the Carbonate Hill and Downtown areas. The ores high in iron and low in silica and manganese (Carbonate Hill) suggest derivation from massive pyrite; those high in iron and manganese and low in silica (Downtown) suggest derivation from mixtures of manganosiderite and pyrite; those with high iron and silica and low manganese (East Fryer Hill) suggest derivation from siliceous pyritic ore. All these varieties grade into one another, and all originally contained small to negligible amounts of galena, as well as zinc blende. The lead has remained in the oxidized ore, but the zinc has been entirely removed. With increase in lead these ores grade into lead ores—in fact, the few that contain 5 per cent or more of lead could be classified as lead ores, as the lead in excess of 5 per cent is paid for by the smelters. Lead below 5 per cent is figured as manganese, because it can not be recovered at a profit but adds to the fluxing power of manganese and iron. Silver above 5 ounces per ton and gold above 0.05 ounce per ton are also paid for. With increase in silver and gold the siliceous iron-manganese ores grade into siliceous gold-silver ore.

SILICEOUS ORES

Siliceous ores valuable for their content of gold and silver may be considered in two general groups—those in the "vein material" associated with the lead carbonate blanket bodies in the western part of the district, and those in the veins and connected blankets in Breece Hill and vicinity.

The distribution of the "vein material" is described on page 221. Most of the siliceous matter ("jasperoid," "chert," "flint," or "quartz") in the vein material can not be regarded as ore, although it commonly contains a few ounces of silver to the ton, but as there is no sharp difference in general appearance between this material and high-grade ore they are both included in the following description. According to Ricketts,[13] this "siliceous gangue," as seen in Carbonate Hill, exists in large bodies and great variety. It occurs as a rule near the lead carbonate ore shoots, both above and below them, and is rarely found any considerable distance away from them. Above these shoots and along the contact with White porphyry it is very pure, much of it appearing as a spongy white material with hard cherty cores. In the Lower Waterloo and Forsaken ground a large sheet of disintegrated rock with many external features of quartzite overlies the "second contact" ore body in the Blue limestone.

The great bulk of the siliceous gangue is below the lead carbonate ore shoots and forms large though ill-defined and irregular bodies. It is much more common under the "first contact" than under the "second contact" shoots. It everywhere contains a high percentage of iron. In its purest form it exists in local concretionary deposits of hard red jasper embedded in softer, more impure material. These hard masses are cut by relatively few joints, but as the percentage of silver decreases and iron oxide and lead carbonate appear in quantity, a regular joint structure breaking the rock into small angular blocks becomes characteristic. The most common variety of this gangue has from 30 to 50 per cent of silica, and the rest consists of iron oxide, lead carbonate, and a little water. The specimen represented by the analysis in column 1 below was unusually rich in silver, which was present almost entirely as coatings of horn silver along the joints. Its percentage of lead entitled it to consideration as a lead ore under present methods of classification, but it was mined for its silver content. Gradations are present from material containing such comparatively low percentages of lead to practically pure lead carbonate.

Analyses of siliceous ores

	1	2	3	4
Insoluble	[a] 39.50	8.20	21.10	80.00
Ferric oxide	35.67	54.14	7.30	13.91
Manganese		22.36	65.98	.10
Lime	.50			
Carbon dioxide	3.44			
Water	3.46	12.71	4.22	5.98
Zinc oxide		2.56	1.00	
Lead oxide	15.46			
Silver chloride	1.44			
Silver		.031	.012	0.012
Gold		None.	None.	Trace.
	99.47	100.001	100.012	100.00

[a] Silica.

1. Siliceous silver-lead ore, Morning Star mine. Ricketts, L. D., op. cit., p. 27.
2. "Siliceous hematite," Chrysolite mine. U. S. Geol. Survey Mon. 12, p. 557, 1886.
3. "Iron ore," Kenosha mine. Idem.
4. "Hard carbonate," Scooper mine. Idem.

Emmons,[14] besides referring to extensive masses of low-grade to barren "chert" in southern Carbonate Hill and Fryer Hill, reported bodies of rich silver ore accompanied by little or no lead in both places. One of these was at the "first contact" in the Aetna claim near its boundary with the Pendery claim, but no further mention was made of its composition. The Climax mine contained near the Amie line an ore consisting of white siliceous sand, samples of which assayed as much as 1,600 ounces of silver to the ton and mill runs of which yielded 300 ounces of silver to the ton and little or no lead. Similar ore was found in the Dunkin mine. In the Matchless mine, near the Leonard shaft, rich ore, consisting of horn silver disseminated through an ocherous sandy mass, lay on the Parting quartzite or on a layer of chert immediately above it and abutted against the north side of the Gray porphyry dike. Cracks in the chert were coated with the same ore. This ore was abnormally low in manganese and was colored by red iron oxide instead of the usual brown variety. The Robert E. Lee mine, one of the greatest silver producers in the district, also contained a very siliceous ore free from lead and relatively low in iron. Its main ore body was immediately above the Parting quartzite, which is there just above the lower sheet of White porphyry. The ore body was almost perfectly continuous, ranged from a few inches to 25 feet in thickness, and was generally overlain as well as underlain by dark-blue "chert." The

[13] Ricketts, L. D., op. cit., p. 27.

[14] Emmons, S. F., op. cit., pp. 428, 442, 476.

rich ore was in some places a red sandy or clayey mass and in others a chert or siliceous iron oxide with its cracks and joints lined with horn silver. This ore also was generally characterized by a bright-red color and an absence of manganese. Concentration of this ore was evidently favored by downward migration of silver in solution during oxidation of the now eroded part of the ore body that formerly lay along the axis of the local anticline. The solution became confined to a channel in porous and shattered parts of the "cherty" zone and was dammed by the massive chert and the Gray porphyry sheet directly south of the No. 2 shaft. Exploration to the northeast and northwest found the ore more irregularly distributed through the ore zone and not so concentrated. At the time of Emmons's study in 1880 a layer of ore that consisted of barite thoroughly impregnated with horn silver was being followed. This variety was a local close associate of siliceous silver ore in Fryer Hill.

Southeast of Fryer Hill a siliceous ore of good grade containing horn silver was found in the May Queen mine at the Surprise shaft, and subsequent to Emmons's visit in 1880 some rich ore bodies were opened in the Forest City mine, farther east. Still farther east the Scooper mine yielded some very siliceous ore (called "hard carbonate") rich in horn silver. An analysis of low-grade siliceous ore from this mine is shown in column 4, page 224. Siliceous silver ores have probably been discovered in the oxidized zones of Iron and Rock hills, but no records of them have been found.

The siliceous ores thus far described contained considerable silver but very little gold. In Iron Hill, according to Blow,[15] the oxidized "vein material" along the porphyry contacts is more siliceous than that along the ore channels within the Blue limestone, and gold, if present at all, is more common near the porphyry contacts. No visible gold has been found. Both silver and gold are generally present in inverse proportions to the lead content. Copper, which is prominent in some of the gold ores of Breece Hill, is present in small quantity as carbonate and native metal. The yellow ocherous ore (basic ferric and lead sulphates), which underlies the lead carbonate shoots, has been invariably observed, in the gold-bearing shoots, to be the richest in gold. The "gold-ore shoot" in Iron Hill, so called because of the persistent presence of gold in all its ores, was continuously developed for 2,500 feet, but no detailed description or analysis of its ores was given. The Imes shoot, in Iron Hill, was also characterized throughout by the presence of gold. This shoot extended from the White porphyry down to the Gray porphyry sheet in the Blue limestone, and its gold content was greatest near the two porphyries. At the bottom of the oxidized zone the ore changed abruptly into sulphides low in silver and lead but containing 20 to 40 per cent of zinc and 0.2 to 0.8 ounce of gold to the ton and resembling in composition certain ores in the Winnie-Luema and other veins in the district.

No specific mention of gold in the oxidized zones of Carbonate and Fryer hills was made in the Leadville monograph, except an assay of "black iron" from the Chrysolite-Vulture No. 1 ground, which showed 0.2 ounce of gold and 7.8 ounces of silver to the ton.

In the North Iron Hill area gold was found in the ores of the Double Decker and Adelaide mines. That in the Double Decker was reported to be in Cambrian quartzite, the local surface rock, but no further information about it could be obtained by Emmons during his first survey. He stated that the ore in the Adelaide group was distinguished from that of most of the other mines in the district by a total absence of manganese and the small amount of iron oxide, a relatively low tenor in silver, and a more abundant occurrence of gold and copper, in which it resembled the ores of Breece Hill. Some of the ore in the Parting quartzite was comparatively rich in gold. Below this quartzite the upper 75 feet of White limestone was replaced by jasperoid containing about 5 per cent of iron oxide; below the jasperoid a sheet of decomposed, iron-stained Gray porphyry contained 1 to 5 ounces of silver to the ton and at one place, 330 feet below the surface, was impregnated with silicate and carbonates of copper and with some red oxide and native copper. These siliceous materials underlay two blanket deposits of lead carbonate in the Blue limestone; the lower, just above the Parting quartzite, was associated with iron-stained vein material, and the upper, above an upper sheet of Gray porphyry, was a remarkably pure white sand carbonate.

Considerable siliceous "vein material" has been found in Yankee Hill, but no records are at hand to show that it has been worked for its gold or silver content. Farther east, in the Great Hope mine, on the lower north slope of Breece Hill, the upper 60 feet of Blue limestone, according to Emmons's description,[16] was replaced by "iron vein material" with some "large" layers of dolomite. The "iron vein material" overlies either quartzite or more probably silicified limestone, as the Blue limestone was reported to be 96 feet thick in the Across the Ocean shaft, 200

[15] Blow, A. A., Geology and ore deposits of Iron Hill, Leadville, Colo.: Am. Inst. Min. Eng. Trans., vol. 18, pp. 157, 160, 163, 168, 169, 1890.

[16] Emmons, S. F., U. S. Geol. Survey Mon. 12, pp. 500–501, 1886.

feet to the south. A layer of galena 5 to 6 feet thick was reported at a depth of 105 feet, but the main ore of the mine was taken from the "quartzite," which, as well as the lower portion of the iron body, was impregnated with gold. The gold was very coarse. From 400 to 500 tons of "quartzite gold ore" averaging 1½ ounces of gold and 4 ounces of silver to the ton was said to have been taken from the mine, and one lot of 3,000 pounds was said to have yielded 31 ounces of gold to the ton. A dike of White porphyry, cut in the eastern portion of the workings, may have influenced the concentration of the ore at this particular point.

Very little work was done in the Great Hope mine between 1882 and 1922, when timbering of the shaft was begun by Thomas Gilroy[17] with a view to reaching a continuation of ore recently worked through the Rexall shaft. This shaft, 218 feet deep, is 225 feet to the southwest, on the same property. Small bunches of ore were found on the 200-foot level (altitude 10,649.6 feet) west of the Rexall shaft, but the main ore shoot, evidently a vein, was found 100 feet to the east of it. This shoot extended vertically upward through Parting quartzite, 40 feet thick, and spread out as a blanket, which was followed along its northward dip to water level, close to the second level of the Rexall shaft. A 70-foot raise from the 200-foot level was put up to connect with the Great Hope shaft and was reported to have cut a low-grade ore body 9 feet thick and 30 feet wide.

Smelter returns from small shipments by lessees in 1913 and 1914 are given in the following table:

Contents of dry ore shipped from the Great Hope mine from July, 1913, to March, 1914

Gross quantity (pounds)	Moisture (per cent)	Gold (ounces per ton)	Silver (ounces per ton)	Lead (per cent)	Iron (per cent)	Silica (per cent)	Manganese (per cent)	Sulphur (per cent)
89, 700	9. 3	2. 06	5. 0	3. 0	13. 0	60. 9	--------	--------
40, 660	6. 1	. 30	3. 6	--------	7. 6	67. 2	--------	--------
55, 680	8. 6	1. 28	9. 3	8. 2	13. 2	59. 2	--------	--------
207, 960	6. 9	. 72	5. 5	4. 5	9. 8	68. 8	2. 2	--------
45, 600	12. 3	1. 61	6. 5	4. 9	11. 4	61. 4	--------	0. 7
89, 080	13. 3	1. 52	3. 0	--------	11. 0	68. 8	--------	. 7
100, 760	11. 6	1. 63	5. 3	3. 2	13. 6	56. 0	--------	--------
116, 720	12. 3	1. 65	3. 3	--------	13. 6	63. 7	--------	--------

Assays of samples taken in 1917 mostly ranged from 0.04 to 5 ounces of gold and 1 to 10 ounces of silver to the ton. A few showed as much as 9.6 ounces of gold, one showed 31.30 ounces of gold and 20.4 ounces of silver, and another 37.40 ounces of gold and 32.6 ounces of silver.

A composite sample of ore from the Rexall workings, submitted by Mr. Gilroy, consisted mainly of jasperoid, somewhat honeycombed and stained brown and black by iron and manganese oxides. Small quantities of galena, pyrite, chrysocolla, malachite, and rarely visible free gold are present. The jasperoid is cut and impregnated by veinlets and grains of glassy colorless quartz; fine druses of quartz line many of the small cavities. Manganese oxide is present throughout as black spots and patches and small botryoidal coatings, some of them covered by the fine quartz druses. Galena is present as cubic grains impregnating jasperoid and as grains and granular masses associated with the vein quartz. Pyrite, present in minute grains, shows the same relations to the jasperoid and quartz. Pyromorphite forms druses of small to microscopic green prismatic crystals in cavities. Its finest-grained varieties are yellowish and may be confused with basic ferric sulphates. The few visible specks and flakes of gold show no consistent association with the other metallic minerals. Most of it is in massive quartz or jasperoid, some of it associated with manganese and some not. One small flake lay adjacent to a galena crystal in finely granular quartz; another lay in a little soft red iron oxide, suggesting original association with pyrite. No gold was found in cavities or fractures that cut the vein quartz or sulphide. The occurrence of the gold on the whole points to primary origin, although the possibility of enrichment is admitted. A few films of brown clay resembling zinc-bearing clay are present in cavities. The iron-stained jasperoid also resembles the low-grade zinc carbonate ore, but qualitative chemical tests failed to show any appreciable amount of zinc.

The paragenesis of the Great Hope ore was as follows: Jasperoid replaced Blue limestone and was accompanied by very little of the ore minerals. Presumably pyrite was thinly disseminated in it. The jasperoid was fractured, and the fractures and other cavities were filled by vein quartz accompanied by pyrite, galena, zinc blende (presumably), and gold. Oxidation removed the blende, oxidized the pyrite and galena to hydrous oxide and carbonate, and to some extent carried the iron and lead downward in solution, the iron replacing any limestone or dolomite, and the lead being deposited as phosphate or carbonate. Silver was presumably concentrated downward, as elsewhere

[17] Oral communication.

in Leadville. Gold in the presence of so much manganese and siliceous gangue was subject to downward concentration, and it is therefore reasonable to expect enrichment in gold below ground-water level.

Similar siliceous vein material was found in other mines in the northern part of Breece Hill during the early history of the district, but no definite records of the mining of oxidized siliceous blanket ores for gold and silver are at hand. The most productive of these deposits were doubtless in and near the Little Jonny mine.

The blanket ore bodies connected with the main vein in the Winnie mine are siliceous and in part oxidized, but no specific information regarding the oxidized ore is available.

The oxidized siliceous ore in or near a vein in the Ballard mine is described as an ocherous material and is represented by the following analysis.

Analysis of oxidized siliceous ore from the Ballard mine, Breece Hill

[W. F. Hillebrand, analyst]

Analysis		Calculated mineral composition	
SiO_2	76. 82	Quartz	74. 52
Al_2O_3	1. 87	"Kaolin"	2. 32
Fe_2O_3	8. 53	Jarosite	7. 01
MgO	. 17	Natrojarosite	8. 73
CaO (includes SrO)	. 11	Hematite	1, 92
Na_2O	. 56	Mimetite	1. 80
K_2O	. 71	Pyromorphite	. 81
H_2O-	. 56	Bismite	. 74
H_2O+	2. 64	Chrysocolla	.05
TiO_2	. 10	Silver	. 03
P_2O_5	. 22	Rutile	. 10
SO_3	4. 97	Rest	1. 02
V_2O_3	None.		
MnO	Trace.		99. 05
BaO	. 19		
Li_2O	Strong trace.		
PbO	1. 80		
CuO	. 02		
Bi_2O_3	. 74		
Ag	. 03		
As_2O_5	. 52		
	99. 84		

Although the ore was mined principally for gold, the content of the gold was too small to be determined by wet analyses, and no fire assay of the sample was made. The calculated mineral composition shows that the principal minerals besides quartz are the jarosites. The "kaolin" may include sericite, beidellite (leverrierite),[18] or any of the hydrous aluminum silicates. The silver may be present as horn silver, native silver, or argentojarosite, as in the jarosite ores represented on page 230.

OXIDIZED LEAD ORES

LEAD CARBONATE ORE

The lead carbonate ores, which were by far the most valuable products of the district during its earlier stages, were abundant in Rock, Iron, Carbonate, and Fryer hills, where they formed long, continuous shoots, principally along the upper middle parts of the ore zones. Smaller shoots of lead carbonate were found to the south and east of these hills. The ores as a whole contained considerable chlorobromide of silver, although the silver content varied widely. With increase in gangue material the lead carbonate ores graded into jasperoid or into iron-manganese ore, both of which contained varying quantities of silver (pp. 223–224). Two principal varieties have been generally recognized— "sand carbonates" and "hard carbonates."

SAND CARBONATES

The purest, largest, and best defined bodies of lead carbonate, according to Ricketts's description[19] and Emmons's maps and sections,[20] lay under the White porphyry. The purest bodies consisted almost entirely of granular cerusite crystals in readily crumbled masses, though in places they were firmly cemented. The individual grains were about the size of coarse sand and consisted of imperfect prismatic crystals. Because of their loose, sandy texture they have been called "sand carbonates." The color of these purest masses varied. A few, as in the Adelaide and Morning Star mines, were almost pure white; others were cream-colored, gray, grayish brown, dark bluish or greenish gray, and almost black. The coloring matter was commonly iron oxide and locally manganese oxide. The color bore no constant relation to the content of silver and rarely to that of lead, although Emmons[21] noted that the white sand carbonates in the Adelaide and Morning Star mines contained less silver than the stained varieties. In some places, notably the Upper Waterloo, Carbonate, Little Giant, and Yankee Doodle mines, the sand carbonate had a peculiar banded structure, due to the coloring matter, and parallel to the dip of the body.

[18] Larsen, E. S., and Wherry, E. T., Beidellite, a new mineral name: Washington Acad. Sci. Jour., vol. 15, pp. 465–466, 1925. Ross, C. S., and Shannon, E. V., The chemical composition and optical properties of beidellite: Idem, pp. 467–468.

[19] Ricketts, L. D., op. cit., p. 33.

[20] Emmons, S. F., U. S. Geol. Survey Mon. 12, atlas, 1886.

[21] Idem, pp. 404, 437, 452

Analyses of sand and hard lead carbonates

	1	2	3	4	5	6	7	8
Silica (SiO_2)	0.651	1.972		[a] 0.42	[a] 4.43	2.82	18.84	22.59
Alumina (Al_2O_3)	.444	1.415						3.99
Ferric oxide (Fe_2O_3)	.467	1.940				14.23	11.38	24.86
Ferrous oxide (FeO)	.299							.89
Manganese oxide (MnO)	.137	.074						4.03
Manganese dioxide (MnO_2)		1.386						}
Potash and soda (Na_2O+K_2O)								.98
Calcium oxide (CaO)	.303	.335			.80	Trace.	1.78	2.36
Magnesium oxide (MnO)	.068	.056						3.04
Lead oxide (PbO)	80.352	75.408	77.980	83.27	77.70	66.98	54.89	24.77
Carbon dioxide (CO_2)	14.700	14.251	10.181	16.30	14.56	13.07	10.83	5.58
Sulphur trioxide (SO_3)	Trace.	.486		.32	.28	.55		5.90
Phosphorus oxide (P_2O_5)	1.532	Trace.	6.480		1.22			
Antimony oxide (Sb_2O_5)		.121						56.02
Arsenic oxide (As_2O_5)	Trace.	Trace.						As .01
Chlorine (Cl)	.255	.288	.840		Trace.			.09
Water (H_2O)	.395	1.140			.50	1.52	1.61	5.53
Cobalt oxide (CaO)	Trace.	Trace.						
Zinc oxide (ZnO)		.095						Trace.
Silver (Ag)	.009	.777	.047	[b] .03	[b] .12	[b] .16	[b] 1.30	.31
Ounces per ton	(2.5)	(227)	(14)	(6.6)	(26)	(35)	(288)	(9.5)
Gold	Trace.	Trace.						Trace.
Ounce per ton	(0.05)							
	99.612	99.744		100.34	99.61	99.33	100.63	99.95
Less oxygen for chlorine	.057							
	99.555							

[a] Recorded as gangue. [b] Silver chloride.

1–5, Sand carbonates; 6–7, hard carbonates; 8, mixture of ores.
1. Adelaide mine. W. F. Hillebrand, analyst. U. S. Geol. Survey Mon. 12, pp. 599–600.
2. Little Chief mine. W. F. Hillebrand, analyst. Idem.
3. Waterloo mine. W. F. Hillebrand, analyst. Idem.
4. Upper Waterloo mine. L. D. Ricketts, analyst.
5. Lower Waterloo mine. L. D. Ricketts, analyst.
6. Morning or Evening Star mine (iron-rich ore). L. D. Ricketts, analyst.
7. Morning or Evening Star mine (moderately siliceous ore). L. W. McCray, analyst (quoted by L. D. Ricketts, op. cit.).
8. Average ore. T. Fluegger, analyst. U. S. Geol. Survey Mon. 12, p. 544

Analysis 1 represents remarkably pure ore which resembled white quartz sand. Recalculation shows the ore to have consisted of 85.6 per cent of lead carbonate, 9.75 per cent of the chlorophosphate pyromorphite, and 0.012 per cent of silver chloride, with a little iron oxide, clay, and carbonate gangue. Analysis 2 represents discolored lead carbonate accompanied by a little lead sulphate (anglesite or plumbojarosite) and probably antimonate, which was present as a yellow substance (bindheimite?), but with no pyromorphite. The silver is equivalent to 1.03 per cent of silver chloride. The gangue consists of iron and manganese oxides, clay, and carbonate. Recalculation of the partial analysis 3, which also represents a discolored ore, shows 61.78 per cent of cerusite, 32.07 per cent of pyromorphite, and 0.062 per cent of silver chloride; the small amount of gangue probably included some aluminum phosphate as well as clay. Analyses 4 and 5 represent the purest ore found by Mr. Ricketts under the White and Gray porphyries, respectively. No. 4, representing a grayish-white ore, conforms almost exactly to the theoretical composition of cerusite; No 5, representing a bluish-gray ore, shows the presence of nearly 8 per cent of pyromorphite with the cerusite. Both were poor in silver compared with the lead carbonate ores as a whole, and they illustrate the fact that where oxidation was most complete the silver content of the carbonate ore was least. In the Upper Waterloo the pure cerusite averaged about 15 ounces of silver to the ton, or 0.051 per cent.

The darker-colored sand carbonates are as a rule the richer, the dark-blue or grayish ore found in the Amie mine, according to Emmons,[22] containing 300 ounces of silver to the ton. Emmons[23] stated that the silver in the oxidized ores was all present as chloride or bromide, but Guyard[24] stated that where cerusite was tinged with black the color was due to "sulphuret of silver." No complete analyses of the less pure sand carbonates are available, but the following partial analyses designated "sand" by Guyard[25] show the iron content to reach 39.5 per cent and that of silica 32.5 per cent.

[22] Op. cit., p. 452.
[23] Idem, p. 545.
[24] Idem, p. 617.
[25] Idem, pp. 623–624.

Partial analyses of "sand" ore

Mine	Silver (ounces per ton)	Lead (per cent)	Iron (per cent)	Gangue (per cent)
Catalpa	83	43. 70	39. 50	27. 90
Chrysolite	75	42. 50	13. 70	14. 60
Little Chief	80	37. 50	14. 70	17. 50
Do	100	27. 50	15. 75	27. 50
Dunkin	50–100	1–13	34. 00	32. 50
Adelaide	20	44. 00	8. 00	15. 00
Chrysolite	72	34. 00	23. 00	16. 00
Morning Star	38	55. 00	5. 00	20. 00

These impure carbonates may consist of streaks of cerusite alternating with narrow streaks of iron oxide or sulphate or of siliceous material. Some seams of carbonate extended upward into the porphyry.

HARD CARBONATES

Where silica or iron oxide is abundant and solid enough to form a massive rock the ore is called "hard carbonate," a term that implies any hard rock with enough lead carbonate and silver to become ore. Typical hard carbonates are either dense or porous in texture and full of cavities. Their color varies through many shades of brown, red, and gray. According to Ricketts,[26] a perfect gradation existed from jasperoid with little or no lead to hard carbonate which contained 20 to 30 per cent of lead, and from hard carbonate to the pure lead carbonates already described. The hard carbonates do not occur in extensive sheets along the contact but rather as thick massive bodies of small area which underlie pure carbonate and extend downward into waste. Where the percentage of lead is unusually high (40 per cent or more) streaks or veinlets of pure, soft cerusite commonly extend through it, or druses of cerusite may line the small cavities. The ore richest in lead is of light-gray color and contains little iron. It is extremely solid and heavy and contains 80 to 90 per cent of lead carbonate, the remainder being mainly silica. Another relatively pure variety contains very little silica but much iron. This variety is deep red and not nearly as hard as the more siliceous variety. Such an iron-rich variety is shown in column 6 on page 228. Column 8 represents an average specimen of hard carbonate ore in all respects except that it is unusually rich in silver. This ore was deep reddish brown and very hard. It was broken by an unusually perfect jointed structure into small rectangular blocks. Horn silver deposited along the joints accounts for the high content of silver. A large amount of the silver in the hard carbonates occurred in these joints or on the walls of cavities and was generally visible in scales of horn silver. The ratio of silver to lead in the hard carbonates and impure sand carbonates is much higher than in the purer cerusite.

[26] Op. cit., p. 34.

Few samples of hard carbonate assaying 30 to 40 per cent lead contained less than 30 to 40 ounces of silver to the ton. Although the veinlets of cerusite in a hard carbonate are proof that a small amount of the lead content was infiltrated, the remnants of galena crystals in hard carbonate ores of different grades show that the bulk of the lead was derived in place from siliceous galena or mixed sulphide ore. A greater proportion of silver was evidently derived from the overlying purer carbonates.

Partial analyses of "hard carbonate" ore[a]

Mine	Silver (ounces per ton)	Lead (per cent)	Iron (per cent)	Gangue (per cent)
Catalpa	79. 00	33. 60	4. 25	41. 30
Chrysolite	47. 75	21. 90	25. 30	16. 40
Little Chief	25. 00	10. 00	29. 75	12. 50
Chrysolite	65. 00	20. 00–25. 00	23. 50	15. 00
Rock	18. 00	36. 00	18. 10	6. 50
Chrysolite	45. 00	16. 00	26. 00	18. 00
Morning Star	39. 00	43. 00	4. 00	35. 00
Morning Star	36. 00	40. 00	6. 00	24. 00

[a] U. S. Geol. Survey Mon. 12, pp. 621–624, 1886.

Partial analyses of hard carbonate ores are quoted above. Compared with those of sand carbonates they average somewhat lower in silver and lead but are very similar in their contents of iron and gangue. The hard or sandy character is evidently determined by the distribution of silica and iron minerals in the original ore and by the quantity of zinc blende or other minerals that could readily be removed by processes of oxidation. An ore consisting of 50 per cent of zinc blende, 20 per cent of pyrite, 10 per cent of galena, and 20 per cent of silica would on removal of the blende and oxidation of the pyrite and galena become a sandy mass consisting approximately of 25 per cent of cerusite, 35 per cent of limonite, and 40 per cent of silica, whereas an ore consisting of 10 per cent of zinc blende, 37 per cent of pyrite, 18 per cent of galena, and 35 per cent of silica would oxidize to a hard ore of essentially the same composition as the sandy mass.

Lead carbonate also occurs massive as isolated patches embedded in different varieties of hard gangue material—most commonly a dense heavy rock that consists of silica and iron oxide, breaks with a conchoidal fracture, and is sometimes spoken of as liver-colored rock. In some places the rock consists of a blue secondary silica, in which are scattered irregular cavities lined with quartz druses and irregular spots and masses of cerusite. Every gradation is to be found between the hard jasper-like liver-colored rock in which the cerusite is entirely lacking and massive cerusite in which there is but little iron and silica.

An average analysis of lead carbonate ores from every producing mine at Leadville just prior to 1880 is given in column 8 on page 228. The average percentages of lead, iron, and silver in this analysis agree precisely with the general composition of the mixed carbonate ore charged into the smelters of Leadville at that time.

These analyses of ores mined about 1880 may be compared with the following typical analysis[27] of lead carbonate ore mined on the fourth level of the Tucson mine in 1913: Lead, 14.9 per cent; iron, 22.8 per cent; manganese, 1.8 per cent; zinc, 2.3 per cent; insoluble matter, 32.1 per cent; silver, 13.7 ounces to the ton. The low content of both lead and silver and the high content of insoluble matter are noteworthy and doubtless reflect general improvement in methods of mining, metallurgy, and means of transportation.

LEAD-IRON SULPHATE ORES AND RELATED MATERIAL

Ricketts, Emmons, and Blow described yellow masses of basic ferric sulphate which underlay the lead carbonate ore and were remarkably persistent. According to Ricketts,[28] this material was not everywhere an ore, but it was so classed because it contained some lead and silver and in many places was rich. It resembles light-yellow ocher or clay and is plastic when wet but is usually dry and firm and has a perfect jointed structure. It has a rather shiny luster and a smoother feel than similarly colored siliceous iron oxide or lead carbonate. This material is represented by analysis 2 below, which was made before the hydrous lead-iron sulphate plumbojarosite was recognized by Hillebrand and Penfield[29] as a distinct mineral species. Analyses of similar appearing materials that contain variable quantities of plumbojarosite and related minerals are shown in columns 3, 4, and 5.

Analyses of lead-iron sulphate (plumbojarosite) ores

	1	2	3	4	5
PbO	19.72	19.50	8.27	4.27	13.32
CuO					.89
Fe_2O_3	42.44	44.40	42.98	46.70	31.08
Al_2O_3		.23	.20		2.26
Na_2O		.37	.83	1.68	.29
K_2O		.15	6.31	5.33	.55
Li_2O					Trace.
SO_3	28.29	25.07	27.81	30.53	20.81
H_2O-		} 8.99	10.12	10.54	.12
H_2O+	9.55				7.29
CaO			.64	.06	.05
MgO				.06	Trace.
Bi_2O_3				.08	.47
As_2O_5		.39	.42	.46	
P_2O_5		.11	1.58	.08	.10
SiO_2		.36	.30		21.13
Cl		.04	.26	.02	Trace.
	100.00	99.685	99.724	99.815	98.55
Ag, ounce per ton		0.075	0.004	0.005	0.19
Au				Trace.	

[27] Furnished by G. O. Argall, of the Iron-Silver Mining Co.

[28] Op. cit., p. 36.

[29] Hillebrand, W. F., and Penfield, S. L., Some additions to the alunite-jarosite group of minerals: Am. Jour. Sci., 4th ser., vol. 14, p. 213, 1902.

1. Theoretical composition of plumbojarosite ($PbO.3Fe_2O_3.4SO_3.6H_2O$).
2. Waterloo mine, under Gray porphyry. Sample collected by L. D. Ricketts; analysis by W. F. Hillebrand.
3. Morning Star (Forsaken) mine, under Gray porphyry. Sample collected by L. D. Ricketts; analysis by W. F. Hillebrand.
4. Maid of Erin mine, under White porphyry. Sample collected by L. D. Ricketts; analysis by W. F. Hillebrand.
5. Ibex mine. Analysis by W. F. Hillebrand.

Calculated mineral composition of certain lead-iron sulphate ores.

	2	3	4	5
Silver (native and combined)	0.08	0.004	0.005	0.19
Bismite			.08	.47
Scorodite		.92		
Mimetite	1.78		2.99	
Pyromorphite	.81	10.84	.68	
Excess lead oxide	2.00			.67
Plumbojarosite	79.17	2.26	13.57	63.33
Jarosite	2.00	67.13	56.11	5.01
Natrojarosite	5.82	12.61	26.19	3.88
Excess ferric oxide	6.77	3.20	.96	
Excess sulphate radicle (SO_3)		1.52		
Kaolin and silica	.63	.44		24.15
Gypsum			.17	
Lime and magnesia		.64	.06	.05
Excess water	.44	.68	.09	
	99.50	100.044	100.905	97.75

Comparison with the theoretical composition shown in column 1 shows that sample 2 represents almost pure plumbojarosite but is accompanied by small amounts of mimetite, pyromorphite, lead oxide, jarosite, natrojarosite, iron oxide, and clay. The calculated mineral composition, especially with respect to the minor constituents, is necessarily arbitrary, as different combinations are possible. For example, the arsenic may all be combined with iron and the excess lead oxide may actually be present as oxide or as carbonate; but the figures presented convey a fair impression of the character of the ore. Sample 3, representing material of similar appearance, is interpreted as essentially a mixture of pyromorphite and jarosite with small amounts of natrojarosite, hydrous ferric arsenate (scorodite), and basic ferric sulphate expressed as excess ferric oxide and sulphate radicle. Sample 4 is a mixture of jarosite, plumbojarosite, and natrojarosite with a little lead oxide, pyromorphite, and other minerals named above; analysis 5 represents plumbojarosite with considerable silica and aluminum silicate and a little bismite instead of ferric arsenate. The four analyses also illustrated the irregular distribution of silver in these ores. The silver may be present as native silver, horn silver, or the newly recognized basic sulphate, argentojarosite.

In the Upper Waterloo, according to Ricketts, large bodies of this yellow material beneath pure lead carbonate ore contained only a few ounces of silver to the ton and were too poor to mine. In the upper contact ore zone the material was rarely rich, except where it contained visible silver chloride. It was abundant in parts of the Lower Waterloo and Forsaken claims, chiefly beneath a branch of the lead carbonate shoot beneath the Gray porphyry. Here it contained from 30 to 100 ounces of silver to the ton, but no silver mineral was visible. A small exposure was found in 1913 at the bottom of an old lead carbonate stope, just above a small oxidized zinc stope in the Yankee Doodle mine. There it was called "contact matter," although it was known to contain considerable lead.

According to Blow [30] the yellow sulphate ore is found also in the deeper parts of the lead carbonate deposits of Iron Hill and that in the gold-bearing shoots has been invariably observed to be richer in gold than the other kinds of ore.

OXIDIZED ZINC ORES

Four varieties of oxidized zinc ore may be distinguished by differences in appearance and composition, although they are so intimately associated that all may enter into a single carload. The four varieties are (1) gray carbonate ore, (2) reddish-brown to brown carbonate ore, compact or filled with calamine pockets, (3) brownish-black to black carbonate-oxide-silicate ore, and (4) white to brown dense silicate ore (zinciferous clay or "talc"). The brown varieties, Nos. 2 and 3, are by far the most abundant.

GRAY CARBONATE ORE

OCCURRENCE

Gray carbonate ore was noted at a few places in the Maid of Erin mine and on the dump of the Chrysolite mine. At least two of the occurrences in the Maid of Erin were found immediately below pyritic sulphide ore. The others had not been developed, and their relations to other ores were not definitely known. An occurrence of grayish-brown to yellowish-brown ore on and below the Henriett fourth level, although not found immediately in contact with other ores, is doubtless below lead carbonate ore, as only lead carbonate ore has been found at so high a level in the vicinity. (See pl. 64 and section A–A′, pl. 65.) One of the deposits of gray ore contained an inclusion of manganosiderite, which had evidently escaped replacement. Further evidence of this replacement is given in the description of the microscopic features of the ore.

MEGASCOPIC FEATURES

The ore is of medium to light gray color where quite free from iron, but some specimens show more or less yellowish-brown iron oxide stains in places, and by increase in the amount of staining the gray ore grades into the reddish-brown to brown variety. The texture of the gray ore is very fine grained to dense (microgranular) for the most part, but small cavities or vugs ranging from minute pores up to holes an inch or two in diameter are irregularly scattered through it. In places these cavities are small enough and regularly enough distributed to suggest shrinkage accompanying replacement of the original rock; in others they appear to be enlargements of fractures; and in still others they are clearly the result of the leaching out of the more permeable portions of the ore. Cavities of the first two kinds have rounded edges where the carbonate ore has developed microscopic drusy surfaces. Those of the last kind have rough, corroded surfaces. No mineral grains of megascopic size were seen in the fresh gray ore, except a few specks of pyrite, zinc blende, and possibly galena, which were noted in two specimens. These sulphides occur in minute veinlets and scattered grains, just as they do in the manganosiderite. In the brownish-gray partly oxidized ore from the Henriett workings the fine-grained carbonate aggregate is traversed by veinlets of calamine.

[30] Op. cit., p. 169.

MICROSCOPIC FEATURES

In thin section (pl. 50, *C*) the gray carbonate ore is seen to be composed mostly of a uniform aggregate of very fine carbonate grains of high relief, typically high birefringence, and cloudy appearance. This aggregate is cut by veinlets of smithsonite that are characterized by a somewhat coarser grain and freedom from cloudiness. Smithsonite, optically similar to that in the veinlets, also forms minute rhombohedrons lining small cavities. A few minute diverging aggregates and single grains of calamine were noted filling small cavities, but the total amount of zinc in them is negligible. Incipient oxidation is marked by faint brown and black stains of iron and probably manganese oxides. A veinlet of calcite, distinguished from smithsonite by distinctly lower index of refraction, was noted.

The ore incloses small veinlets and patches consisting of varying proportions of quartz, sericite, pyrite, and locally zinc blende and galena. It also incloses scattered single grains of the same minerals. Many of these inclosed veinlets have a marked "wriggling" shape. Some are distorted and even appear to have been pulled apart. Some are penetrated or cut by veinlets of smithsonite. Small aggregates of pyrite also appear to have been pried apart by smithsonite veinlets. The quartz-sericite-sulphide veinlets and aggregates have the same features except for the distortions just described, as in the manganosiderite and are evidently all that is left of the manganosiderite body originally present.

Under high magnification the fine aggregate proves to be composed of countless anastomosing rows of clear, transparent granules inclosing small rounded bunches of clouded (more strongly absorptive?) granules. The anastomosing rows are so arranged as to indicate the outlines of former manganosiderite grains. In some thin sections the small clouded bunches have been removed by leaching and perhaps in part by the grinding of the section, leaving a porous mass of anastomosing rows of smithsonite. These pores may also be in part due to removal of grains or minute aggregates of quartz, sericite, and pyrite, but removal of these minerals certainly can account for only a minor part of the entire pore space. As this finely porous texture has been noted in specimens as well as in thin sections, there is no doubt but that it has resulted mainly from leaching.

This anastomosing structure indicates that the zinc solutions permeated the manganosiderite (or dolomite in some places) along the boundaries of grains and replaced the grains from their margins inward. The replacement was not strictly pseudomorphous, as the texture of the ore is markedly finer than that of the manganosiderite, even including the clouded bunches of granules inclosed among the anastomosing grains. An attempt to prove the assumption that the clouded bunches have stronger absorption and are therefore probably higher in iron than the anastomosing portions was unsuccessful, owing to the extremely fine grain of the ore.

If manganosiderite corresponding to analysis 1 (p. 236) had been completely replaced by gray zinc carbonate ore corresponding to analysis 2, the replacement should have been accompanied by about a 15 per cent shrinkage,[31] but evidence of shrinkage is obscured by factors other than the effects of partial leaching of the ore. The recrystallization that accompanied replacement may have distributed the shrinkage so as to render it inconspicuous, or it may have readjusted the material so that shrinkage was expressed by numerous small fractures. The fractures in the ore, whether due to shrinkage or to other causes, are now filled with the smithsonite veinlets, which may represent material recrystallized practically in place or additional material introduced after the direct process of replacement had practically ceased. Furthermore, deposition of the smithsonite veinlets appears to have caused expansion in certain places. The conclusion that the theoretical amount of shrinkage took place rests on the assumption that the zinc was introduced as some salt, presumably sulphate, which could react with manganosiderite (or dolomite) and deposit an amount of zinc carbonate exactly equivalent to the amount of manganosiderite replaced. It is probable that the zinc was largely introduced as sulphate, but the veinlets of second-stage smithsonite show that a part of it was introduced as carbonate and that disposition was not entirely the result of simple molecular interchange. The amount of shrinkage can therefore not be determined from the porosity of the ore in its present state, nor can it be closely estimated from the texture and structure of the ore.

[31] Specific gravity was not determined, as the zinc ore is much more porous than the manganosiderite. Porosity was not determined, as the pores and other cavities in the ore are obviously due in part to other causes than shrinkage. Published specific gravity of the several carbonates represented in the analyses varies according to impurities, and 15 per cent shrinkage is an approximate average based on these varying data. Theoretically the shrinkage may have amounted to as much as 17 or 18 per cent.

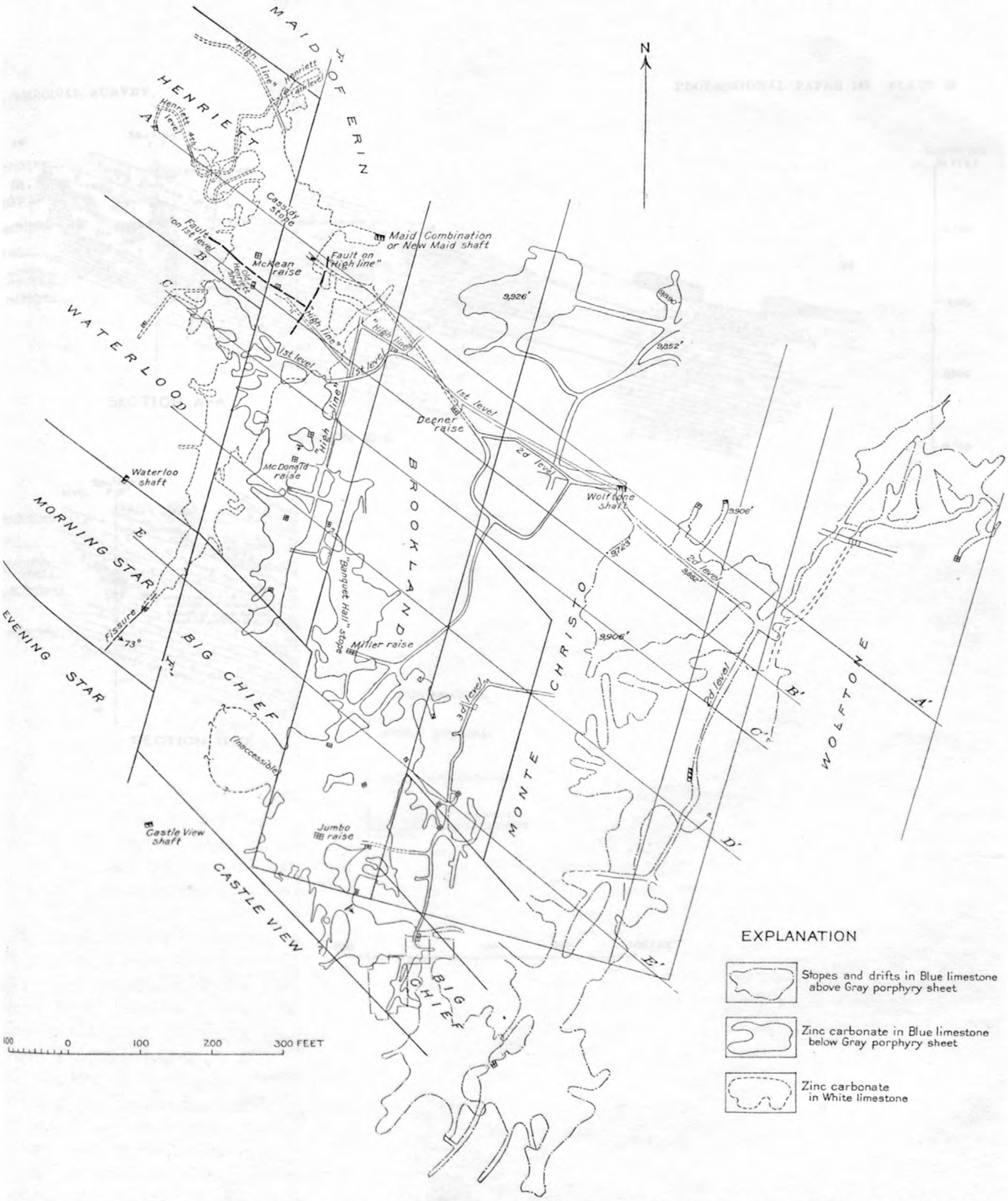
CHEMICAL COMPOSITION

The chemical composition of the gray ore is shown by analysis 2 (p. 236), made by R. C. Wells, of the United States Geological Survey, from material collected in the narrow stope on the first intermediate level above the second in the Maid of Erin mine, about 100 feet south of the New Maid (Maid Combination) shaft. The ore lay beneath a sulphide body and contained small stringers of sulphides; but these were avoided in the material analyzed, as were portions showing brown or black stains.

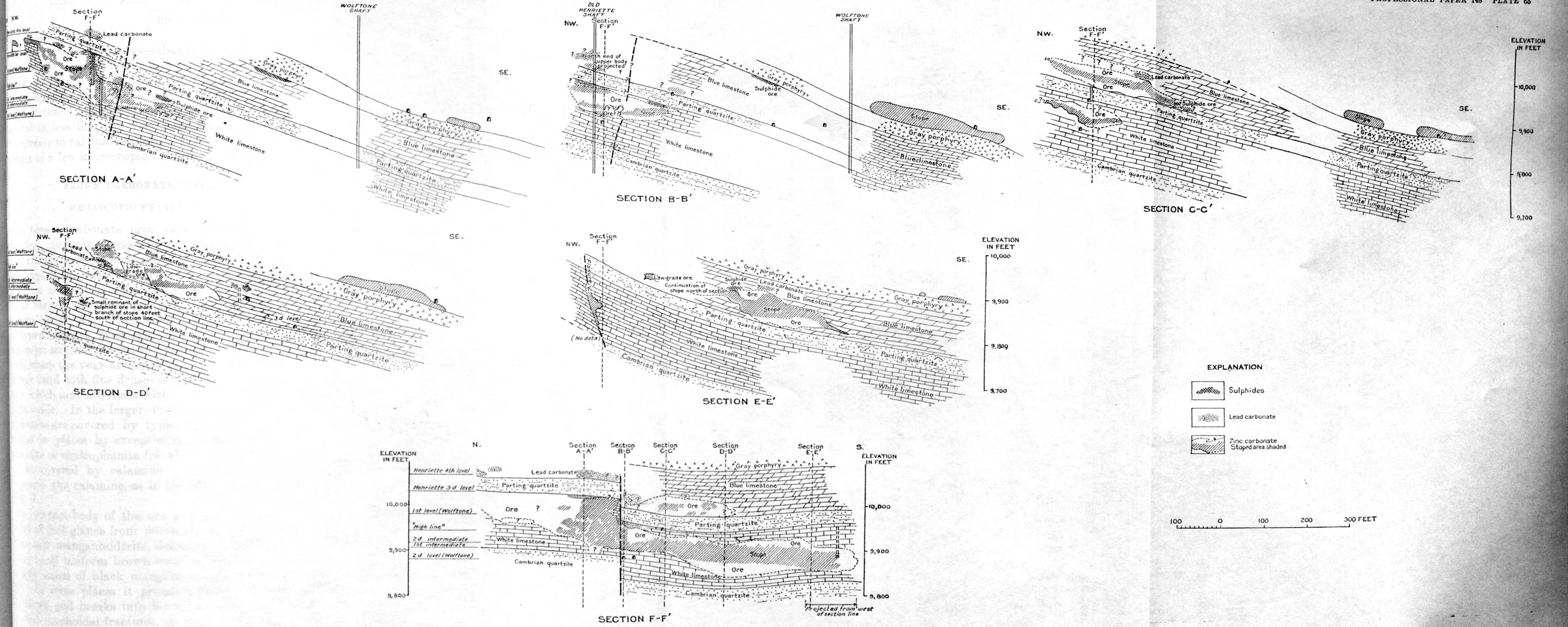
The silica and alumina in this analysis represent quartz and sericite, which together amount to about 2 per cent. The total absence of ferric oxide (Fe_2O_3) is noteworthy when this analysis is compared with analyses 3 and 4, of brown zinc ores. The ferrous oxide, magnesia, lime, manganese oxide, and zinc oxide are present as carbonates, but the total of their molecular ratios is a little in excess of the total carbon dioxide. If the excess is placed wholly in the manganese oxide, there remains an excess of 0.2 per cent, which is decidedly high in view of the color and microscopic composition of the material analyzed. No trace of any mineral containing phosphorus was noted, and the phosphorus pentoxide (P_2O_5) can not be definitely accounted for. If it were combined with enough lime to form apatite, a corresponding reallotment of carbon dioxide (CO_2) would almost balance the excess of manganese oxide (MnO); but this arrangement would demand the presence of 0.67 per cent apatite, whereas none was found in thin section. The water driven off above 110° C. (H_2O+) is also in excess over the amounts necessary to enter into sericite and possible hydrous manganese oxide, and the excess is interpreted as being so intimately inclosed in the ore that it is not driven off until temperatures above 110° are reached. In this connection it is interesting to note that all the P_2O_5 and more than half the H_2O+ shown in the manganosiderite analysis are in similar excess. Their presence both before and after replacement implies that they, like the quartz and sericite, were not affected by the solutions that introduced the zinc. The approximate mineral composition of the gray ore, based on microscopic study and the chemical analysis, is as follows:

Carbonates:		Sericite	0.8
$ZnCO_3$	76.5	Excess MnO	.2
$FeCO_3$	14.5	Excess P_2O_5	.3
$MnCO_3$	3.2	Excess H_2O+	.9
$MgCO_3$	1.0	Excess H_2O-	.5
$CaCO_3$	.5		
Quartz	1.1		99.5

If the carbonates are recalculated to 100 per cent, and the carbonates of the manganosiderite are similarly recalculated from analysis 1, the following comparative results are obtained:



PLAN OF ZINC CARBONATE ORE BODIES IN WORKINGS OF WESTERN MINING CO., CARBONATE HILL



SECTIONS THROUGH ORE BODIES SHOWN IN PLATE 64

Recalculated composition of manganosiderite and gray zinc ores

	Mangano-siderite	Gray ore	Difference (per cent)
$ZnCO_3$		79.88	+100.0
$FeCO_3$	51.49	15.14	−70.6
$MnCO_3$	38.15	3.36	−91.2
$MgCO_3$	10.12	1.06	−89.5
$CaCO_3$	.24	.56	+57.1
	100.00	100.00	

The percentage differences—that is, the gain or loss of the different constituents during the replacement process—are given in the third column, which shows that manganese and magnesia were very largely removed in nearly equal proportions, whereas iron was removed in less but still very considerable amount. The increase in calcium carbonate is attributed to the presence of a few microscopic veinlets in the gray zinc ore.

BROWN CARBONATE ORES

MEGASCOPIC FEATURES

The brown carbonate ores vary considerably in character. In some places they are hard and compact, without conspicuous vugs or with only very small vugs lined with fine druses of smithsonite (pl. 50, *B*); in others they are softer and may contain vugs of varying size lined or nearly filled with white calamine (pl. 49, *A*). Their color ranges from chocolate-brown to dark brick-red. The only crystals of megascopic size are present in vugs and veinlets. As a rule, where the vugs are small and relatively scarce, they are lined with fine druses of second-stage smithsonite, which may alternate with films of hetaerolite or iron oxide. In the larger vugs similar linings of smithsonite are covered by typical growths of calamine or in places by exceptionally large growths of hetaerolite or chalcophanite (pl. 49, *C*), which in turn may be covered by calamine. Aurichalcite may accompany the calamine, as in the Ibex mine. (See pl. 52, *B*.)

The compact body of the ore is not to be distinguished at first glance from much of the iron ore or iron-stained manganosiderite, dolomite, or limestone. It may be of uniform brown color or may be spotted with stains of black manganese oxide (hetaerolite?). In some places it preserves rather thin bedding planes and breaks into layers; in others it has a marked conchoidal fracture. It may be hard, or it may be soft and crumbly. Although compact brown zinc ore even of rather low grade may be readily distinguished from iron-stained dolomite or limestone by its higher specific gravity and finer grain, it can not be so distinguished from dense forms of iron ore. Again, soft porous ore can not in some places be surely distinguished from either porous iron ore or decomposed wall rock, owing to the relatively low specific gravity of all three materials. Calamine growths in vugs are not an absolutely sure indication of good ore; one of two samples containing equal quantities may be excellent ore and the other may be of too low grade to ship. These growths are due in part to a leaching of the brown carbonate to form the silicate, or to the deposition of calamine in cavities of stained and partly decomposed limestone. In one sample the soft brown material around the calamine pockets was found by R. C. Wells to contain only 14.1 per cent of zinc oxide (11.3 per cent of zinc), which on close inspection proved to be largely in the form of minute calamine crystals that had grown within the porous mass. Nearly all the zinc carbonate had been leached, and almost the entire zinc content of the material was contained in the calamine druses. In other specimens the carbonate ore was not leached, and the calamine was introduced from elsewhere, and here the value of the ore, already of good grade, was increased.

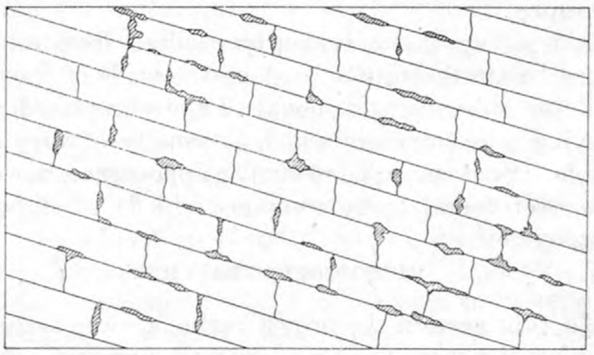


FIGURE 63.—Diagram showing distribution of calamine along bedding planes and cross fractures in brown zinc carbonate ores

Of the many specimens of compact ore collected, one, said to represent ore containing 22 per cent of zinc, proved on microscopic study to be composed almost entirely of iron oxide and silica with no conspicuous zinc minerals. Another, which was said to contain 30 per cent of zinc but whose texture gave it a close resemblance to the altered manganosiderite that borders some of the ore bodies, was found by George Steiger to contain 50.69 per cent of zinc oxide (40.72 per cent of metallic zinc), 2.38 per cent of insoluble matter (probably quartz and sericite), only 0.63 per cent of magnesia, and no lime. The specimen had a rather high specific gravity, but that could easily have been attributed to iron originally in manganosiderite.

The brown ore may include small bodies, patches, or seams of the zinciferous clay colored by a small amount of iron oxide. This clay may be distinguished from the brown carbonate by its characteristic properties described on pages 160–162.

Where the original bedding is preserved, thin streaks or bunches of calamine are distributed along the bedding planes and also along short cross fractures that connect bedding planes, as shown in Figure 63. This distribution of the calamine, which is well exhibited at several places in the Maid of Erin mine, is of interest in showing the courses followed by the zinc-bearing solutions, which evidently percolated along bedding planes, cross joints, and microscopic fractures and were thus able to react uniformly throughout a body of great horizontal and vertical extent. The process was evidently entirely metasomatic at first. Resulting shrinkage may have served to widen the openings along bedding planes and fractures and perhaps also to develop new contraction fractures, thus allowing percolation of additional solution through already replaced rock to lower levels and affording openings for the deposition of second-stage smithsonite and calamine. The gradation of linear fracture fillings of calamine into vugs, especially at junctions of fractures with one another or with bedding planes, points to the vuggy ore as the end result of the process just described—crisscross fractures and bedding planes having enlarged into vugs, and the smithsonite having been more or less completely converted into calamine.

A few vugs have evidently resulted from replacement by smithsonite only along the walls of fractures and the subsequent removal of the unreplaced rock, leaving a cellular ore which is usually of very good grade. Some material of similar appearance, however, has been found to be composed chiefly of silica and iron oxide.

MICROSCOPIC FEATURES

In thin section the brown carbonate ore is seen to consist of a very fine, even-grained aggregate of carbonate grains stained by iron oxide but with many microgeodes lined or filled with transparent carbonate grains. (See pl. 50, *A*.) The transparent grains under high magnification show characteristic acute rhombic terminations. Some of them appear pure, some have zonal inclusions (or alternating growths) of black manganese oxide (hetaerolite?), and others have similar inclusions of brown iron oxide. The last two occurrences indicate a breaking down of the ferruginous gray zinc carbonate of the first stage and its recrystallization in the second stage as purer smithsonite and iron or manganese oxides. Some of the vugs of second-stage smithsonite are surrounded by what appears to be pure iron or manganese oxide, a relation which also points to a breaking down of the impure zinc carbonate of the first stage, accompanied by segregation of the impurities. Throughout the mass of the ore the iron and manganese oxides show this tendency to segregate, the iron oxide having a weak tendency to form a network of hairlike veinlets and the manganese mineral a much stronger tendency to gather into spots or to fill distinct fractures.

The relations of the calamine to the rest of the ore may be illustrated by two contrasted examples. In one a small group of diverging calamine crystals filling a vug is surrounded by iron oxide, which is opaque except along the edges of the vug, where it forms translucent pseudomorphs after acute smithsonite rhombs. Here the zinc in the calamine was evidently formed largely at the expense of near-by smithsonite. In the other example a calamine veinlet cuts through a black spot of manganese oxide, proving that it was formed after the breaking up of the impure first-stage carbonate ore was well advanced; but there was no uniform accumulation of iron or manganese oxides along the vein, the margins of which are lined with clear smithsonite rhombs. Inclusions of brown carbonate ore in the vein show no evidence of leaching. The calamine, therefore, must have been wholly deposited by infiltrating solutions.

One thin section of a specimen of brown ore, taken beneath a sulphide body and very near a mass of gray carbonate ore that contained an inclusion of manganosiderite, is of especial interest in showing the relation of the brown to the gray ore. This section contains within the typical fine-grained carbonate a coarser grained remnant having a texture quite like that of manganosiderite but showing a relatively weak absorption, presumably due to partial or complete oxidation of the iron. The same section contains quartz-sericite veinlets in both the gray ore and the manganosiderite and it seems clear that the brown ore at this place is the oxidized product of the gray ore.

The great extent and uniformity of oxidation of the brown ore is a striking feature, as the few small bodies of gray ore appear to be the only remnants of the original zinc carbonate ore that have escaped oxidation. The ore as a whole must have been easily and uniformly permeable by oxygen, a character which indicates a very finely porous structure. It may be suggested that the porosity was developed during replacement of the original rock by gray zinc ore, but as already pointed out (p. 231) the factors influencing porosity in the present gray ore are too varied in their effects to permit a definite conclusion on this point, and the effects of oxidation add one more obstacle to its determination in the brown ore.

CHEMICAL COMPOSITION

In the light of microscopic evidence chemical analyses of the brown ores are not difficult to interpret. In the table on page 236 analysis 3 represents the sample of high-grade ore from the Maid of Erin mine which contains the microscopic quartz-sericite veinlets above mentioned and is clearly an oxidized product of gray ore, and analysis 4 an ore of lower grade beneath a sheet of Gray porphyry and between walls of dolomite (Blue limestone), from the first level of the New Dome No. 2 mine. Sample 3, in comparison to the gray zinc carbonate ore, represented by analysis 2, contains a larger amount of quartz and sericite. It also contains considerably more iron, and the iron is completely oxidized to the ferric state. Magnesia and lime are each a little higher, whereas zinc oxide and carbon dioxide are correspondingly lower. The absence of phosphoric acid is noteworthy, suggesting its removal in solution during the oxidation and breaking down of the gray carbonate ore. In the material for analyses 2 and 3 calamine druses were avoided. As the irregular distribution of calamine and of iron and manganese oxides renders strictly representative analyses out of the question, the determinations are made only to tenths of 1 per cent.

The calculated mineral composition of the ore represented by analysis 3 is as follows:

Carbonates:		Quartz	2.9
$ZnCO_3$	71.3	Sericite	2.5
$FeCO_3$	0.0	Limonite	15.7
$MnCO_3$	3.0	Excess MnO	1.1
$MgCO_3$	1.3	Excess H_2O+	.1
$CaCO_3$	.7	Excess H_2O-	.9
			99.5

The excess MnO and H_2O+ are present as black oxide, which is probably hetaerolite, but as the formula of that mineral is in doubt (p. 159) no attempt is made here to estimate its small percentage. Comparison with the mineral composition of the gray ore (p. 236) shows that whereas all the iron has been oxidized, the manganese remains mostly as carbonate. The magnesia and lime carbonates also have remained unaffected during the process of oxidation.

Analysis 4 represents an ore of lower grade and one deposited under somewhat different conditions. The ores represented by analyses 2 and 3 were deposited directly beneath sulphides, by replacement of manganosiderite, but that represented by analysis 4 was deposited directly beneath Gray porphyry, by replacement of dolomite (Blue limestone). The ore is of dark-red color and is too soft to permit the grinding of a thin section, but it contained small vugs of drusy smithsonite and calamine, and so far as could be seen, the only essential difference between it and sample 3 was the presence of a small amount of light-brown zinciferous clay. The silica and alumina in the analysis are accounted for by calamine and zinciferous clay. The ferric oxide is much greater than in analysis 3 and indicates either that the waters which introduced the zinc carried a great excess of iron or that the ore was deposited by two solutions—one, carrying the zinc and some iron, migrating along the bedding planes of the Blue limestone, and another, carrying iron but little or no zinc, working downward through the overlying porphyry. (See fig. 66.) The impossibility of learning the exact geologic conditions surrounding this deposit leaves the matter in doubt. The softness of the ore suggests that there has been a downward leaching of zinc, but hard ore directly below the soft contains no more than 30 per cent of zinc, and mere leaching of zinc is far from enough to account for the excess of iron. Another possibility is that after zinc carbonate ore had been formed ferric sulphate solutions, with excess of acid derived by decomposition of pyrite, could redissolve the zinc carbonate, and after they had become neutralized the ferric sulphate in them could become oxidized and be deposited as ferric oxide. The dissolved zinc carbonate could be transferred downward through the ore and replace the dolomite walls, thus extending the original lower limit of the ore body. This hypothesis would also explain the layers of iron oxide that are commonly found between lead carbonate and zinc carbonate stopes.

The magnesia in analysis 4, though low, is about three times as high as in analyses 2 and 3, a ratio approximately equal to that between the magnesia in dolomite and in the manganosiderite represented by analysis 1. The lime, however, is quite as low as in analyses 2 and 3, although its difference in the two rocks replaced was decidedly greater than that of magnesia. Manganous oxide is somewhat greater than in analysis 3, but little significance can be attached to the difference, owing to the irregular distribution of manganese oxide stains. The zinc oxide, though much lower than in analyses 2 and 3, is in excess over the available carbon dioxide. The excess, as shown in the calculated mineral composition (below), indicates the proportion of calamine and zinciferous clay present. The higher percentage of combined water (H_2O+) is insufficient to hydrate all the large amount of ferric oxide to the composition of limonite. The absence of phosphoric acid, in contrast to its presence in analysis 2, is again noteworthy.

The following calculation of the mineral composition of the ore is less satisfactory than those made from the other analyses, owing to the indefinite composition of the zinciferous clay and the uncertainty of the exact formula for hetaerolite:

Carbonates:		Kaolin	5.9
$ZnCO_3$	37.5	Calamine	5.0
$MgCO_3$	3.6	Excess ZnO	2.4
$CaCO_3$	.5	Excess MnO	3.3
		Limonite	15.3
		Hematite	24.2
		H_2O-	1.7
			99.4

The separation of kaolin and calamine is, of course, arbitrary. A little calamine is undoubtedly present, but how much of the calculated calamine is in reality present as zinciferous clay is not known. The excess zinc oxide is for the most part accounted for by the reasonable assumption that all the manganous oxide is present as hetaerolite, but there is a small excess (nearly 0.6 per cent) of zinc oxide over the $ZnO:Mn_2O_3$ ratio demanded by either of the proposed formulas for hetaerolite, and this excess also may be regarded as belonging to the zinciferous clay. The total absence of manganese carbonate can not be proved, but in view of the relatively low carbon dioxide any error in the assumption that all the manganese is oxidized is negligible. The iron oxide is figured so far as possible as limonite, for convenience in comparison with the other analyses, and the excess of iron oxide over water is recorded as hematite. The ratio of water to iron oxide is slightly in excess of that for turgite ($2Fe_2O_3.H_2O$). The red color indicates the presence of a considerable amount of either hematite or turgite.

BLACK ZINC ORE

The black or brownish-black zinc ore is found only in small quantity and varies considerably in composition. In part it is essentially of the same character as the brown vuggy ore, except for its greater content of a black manganese oxide, which in some specimens has the crystalline structure of hetaerolite or chalcophanite. The vugs are commonly lined with calamine, and some cellular specimens may be found consisting almost entirely of calamine and hetaerolite or chalcophanite accompanied by a small amount of iron oxide. This silicate-oxide variety of black ore is clearly derived from the carbonate ore. Other samples of black ore are composed chiefly of zinciferous clay stained black by a manganese oxide. The occurrences of this variety seen by the writer (Loughlin) were all said to be of low grade. Specimens of the black ore, especially of the silicate-oxide variety, whether of high or low grade, are likely to have a surprisingly low specific gravity, owing to their vuggy or very porous character. No chemical analyses of the black ore were made, as they would serve only to show to what extent manganese and silica had been locally concentrated and carbon dioxide eliminated.

WHITE OR "TALCY" ZINC ORE

The zinciferous clays, described on pages 160-162, may occur in masses large enough to be considered ore bodies. It is questionable whether they could be smelted at a profit.

ANALYSES

In the following table are given chemical analyses of the principal varieties of zinc ore discussed above:

Analyses of zinc carbonate ores [a]

	1	2	3	4
SiO_2	10.08	1.5	4.1	4.0
Al_2O_3	3.16	.3	1.0	2.3
Fe_2O_3	None.		13.4	36.9
FeO	26.80	9.0		
MgO	4.04	.5	.6	1.7
CaO	.08	.3	.4	.3
MnO	19.71	2.2	3.0	3.3
ZnO	Undet.	49.6	46.2	30.2
PbO	Undet.			
Ag	Undet.			
CO_2	33.14	34.4	27.2	15.3
P_2O_5	.47	.3		
SO_3	Undet.			
Cl	Undet.			
H_2O+	.89	1.0	2.5	3.8
H_2O-	.22	.5	.9	1.7
Na_2O	.57	Undet.	Undet.	Undet.
K_2O	.08	Undet.	Undet.	Undet.
BaO	Trace.	Undet.	Undet.	Undet.
TiO_2	Trace.	Undet.	Undet.	Undet.
FeS_2	.84	Undet.	Undet.	Undet.
	100.008	99.6	99.3	99.6
Metallic zinc		39.9	37.1	24.2

[a] U. S. Geol. Survey Bull. 591, p. 240, 1915.

1. Manganosiderite, seventh level, Tucson mine (collected by J. D. Irving). J. G. Fairchild, analyst.
2. Gray zinc carbonate ore, Maid of Erin mine, first intermediate above second level. R. C. Wells, analyst.
3. Brown zinc carbonate ore, Maid of Erin mine, "high line" level. R. C. Wells, analyst.
4. Red zinc carbonate ore, New Dome mine, first level (at No. 2 shaft). R. C. Wells, analyst.

RANGE IN METAL CONTENT

ZINC

The zinc content of the ores varies greatly from place to place. In some stopes bodies running over 40 per cent of zinc have been mined, and many others, especially in the Carbonate Hill workings, have yielded much ore averaging 30 per cent of zinc. In fact, up to the end of 1913 none of the Western Mining Co.'s great shipments ran below 28 per cent. These high-grade bodies, however, are bordered and separated by large quantities of lower-grade ore, averaging about 30 per cent of zinc, and these in turn may grade into iron ore or altered dolomite, in which the percentage of zinc drops to practically nothing. In some places the transition from ore into low-grade material is gradual; in others ore is rather sharply bounded by unaltered rock, an altered zone a few inches or a foot or two in thickness separating the two.

In some places it is a rather easy matter to distinguish between ore and waste, but in others distinction is possible only after frequent and careful sampling. Two of the most influential factors causing this difficulty are the varying degree of porosity and the varying though usually considerable percentage of iron in the ore. Some high-grade ore closely resembles altered manganosiderite or dolomite in color and texture, but its lightness, due to microscopic porosity, would lead to an underestimate of its zinc content. Another sample of similar appearance and approximately equal specific gravity may prove on analysis to contain a large amount of iron, either as ferrous carbonate or as ferric oxide. Some brown zinc ores of moderate to high grade may be practically identical in appearance with very low grade zinc ore, or even with iron and iron-manganese ores. High-grade brown vuggy ore with calamine druses may have the same appearance as leached brown earthy material with similar druses. Considerable experience may give the ability to detect inconspicuous though critical differences between ore and waste, but the principal result of experience tends rather to make one more cautious than ever and to depend on frequent sampling and assaying as the only reliable means of distinguishing ore from waste.

This question of the grade of the ores was experimentally investigated by Butler,[32] who analyzed and determined the specific gravity of nearly 50 specimens and found that they all absorbed water slowly, but at varying rates, for many hours. In order to procure

[32] Butler, G. M., Econ. Geology, vol. 8, pp. 14-15, 1913.

comparable data, he allowed particles weighing about 1 gram to soak 15 minutes before weighing, his determinations thus representing the specific gravity of the samples with their pores nearly filled with air. The following table gives the results of Butler's determinations, together with calculated specific gravity of seven of the samples based on chemical analyses:

Data on oxidized zinc ore of various grades from Leadville

Ore	Per cent of zinc	Observed specific gravity	Calculated specific gravity	Effervescence in dilute hydrochloric acid
1. Light gray, granular, with cavities; considerable pyrite and other sulphides visible.	17.7	3.5	3.8	Very slight.
2. Reddish brown, earthy.	20.9	2.7	3.6	Vigorous.
3. Reddish brown, earthy, with cavities.	22.4	2.7	------	Do.
4. White, finely granular compact to earthy.	23.7	2.9	3.6	Considerable.
5. Brown, cryptocrystalline; many cavities lined with druses of smithsonite crystals, some of them underlain with psilomelane.	30.4	3.8		Do.
6. Light gray, very finely granular, cavernous, a few druses of scalenohedral calcite.	31.4	3.9	------	None.
7. Dark brownish red, cryptocrystalline; many cavities with druses of smithsonite crystals; some psilomelane and calamine.	31.5	3.9	------	Considerable.
8. White, with a brownish tint, very finely granular, with a spongy appearance; microscopic drusy cavities.	32.4	3.9	------	None.
9. Same as No. 7 but contains no calamine or psilomelane.	32.7	3.9	4.0	Considerable.
10. Same as No. 5	38.4	4.0	4.1	Very slight.
11. Yellowish brown, microscopically spongy to very finely granular and compact.	41.6	3.9	4.1	Considerable.
12. Brown and white, cryptocrystalline to earthy, with a cavernous appearance; cavities wholly or partly filled with calamine.	45.4	3.7	------	Do.
13. Same as No. 12 except that some hydrozincite is recognizable.	45.4	3.9		Do.
14. Yellowish brown, very cavernous, with thin, plane walls.	46.0	3.9	------	Very slight.
15. Light yellowish brown, finely granular, cavernous.	46.4	4.0	4.2	Considerable.

Butler's analyses of seven of these samples are given in the following table:

Analyses of oxidized zinc ores from Leadville

	1	2	4	9	10	11	15
Zinc	17.7	20.9	23.7	32.7	38.4	41.6	46.4
Lime	.8	.3	.6	.3	.4	.3	.9
Magnesia	.8	1.1	.7	2.2	2.0	.4	.5
Silica	4.0	22.4	33.6	3.3	3.8	8.7	.9
Iron	17.0	14.7	5.4	12.2	5.1	3.5	2.2
Sulphur	.6	------	------	------	------	------	------
Alumina	.4	2.2	2.8	.4	.2	.2	.2
Manganese	11.2	2.1	2.0	------	6.0	2.8	------
Insoluble	4.4	24.8	34.6	3.8	4.2	9.0	2.2

Sample 1 is evidently a partly replaced manganosiderite and has a specific gravity nearly as high as those of the high-grade samples. The other low-grade specimens show a much greater discrepancy between observed and calculated specific gravities than the high-grade ores and evidently possess a much higher degree of porosity. The relation between specific gravity and zinc percentage in the high-grade samples, however, shows that specific gravity is not a closely accurate indication of the grade of ore.

The degree of effervescence of fragments in dilute hydrochloric acid (3 parts water to 1 of acid), as determined by Butler, is given in the first table on this page and, as he states, is not of much avail as an indication of the grade of ore. Similar tests by Loughlin confirm those of Butler. Gray zinc carbonate ores, which contain considerable amounts of iron carbonate, and also the manganosiderite yield little or no effervescence, as shown by samples 1, 6, and 8. Even when partly stained by oxidation, they effervesce very slightly. In the more thoroughly oxidized samples, where fine drusy or second-stage smithsonite is abundant, effervescence is more pronounced.

Blowpipe tests by Butler on all grades of the material yielded similar results, regardless of the percentage of zinc, low-grade as well as high-grade ores giving the characteristic sublimate of zinc oxide.

In concluding his discussion of the grades of the ores, Butler[33] outlined the following method for quick determination of the grade:

> Probably the simplest method for quickly ascertaining the approximate grade of oxidized zinc ore is to place about a teaspoonful of the finely powdered material to be tested upon a piece of iron or steel barrel hoop, 1½ to 2 inches in width. This charge should be introduced into the incandescent coals of a blacksmith forge which has been blown until little black smoke is evident. The iron should be sunk into a depression in the glowing coals so that they stand a half inch or so above the sample on all sides. Then the draft should be increased until the iron is heated white hot. Oxidized zinc ore will take fire at this point, burning with a bluish flame and emitting white fumes of zinc oxide. The density of these fumes varies with the grade of the ore. Experience enables one to judge within 5 per cent of the zinc content by this method, which, although

[33] Op. cit., p. 17

long known and practiced in some places, is unfamiliar to those in other localities. The scheme can be applied to ore of any grade, as material assaying 5 per cent zinc will yield visible fumes.

OTHER METALS

If the percentages of zinc oxide and carbon dioxide are subtracted from analyses 2, 3, and 4 on page 236, and the remainder recalculated to 100 per cent, the iron oxides will range from 50 to over 65 per cent. The residues, therefore, after extraction of the zinc become possible iron or manganiferous iron ores. The content of silver in each of the ores analyzed is less than 0.001 per cent. As 1 ounce per ton of 2,000 pounds equals 0.0034 per cent, the residues from ores corresponding to these analyses do not contain enough silver to pay for its extraction. Although the samples analyzed are believed to represent typical oxidized zinc ores of the district, there may be exceptions, for it has been stated that early shippers of rich silver ore appear to have purposely broken the zinc ore in some places.[34]

DISTRIBUTION AND MODE OF OCCURRENCE

GEOGRAPHIC DISTRIBUTION

Oxidized zinc ores have been found in practically all the hills of the district, as far east as the Resurrection mine, near the head of Evans Gulch, and as far south as the Continental Chief mine, at Weston Pass, 9 miles south of Leadville. Thus far, however, although extensive low-grade bodies have been reported from several places, all the high-grade deposits in the other hills have proved very small in comparison with the immense bodies in Carbonate Hill.

DISTRIBUTION WITH RESPECT TO KIND OF COUNTRY ROCK

The oxidized zinc ore bodies thus far found are limited to the horizons of the two limestones. The small bunches of red siliceous zinc material found in fissures cutting a porphyry sill in the Belgian mine are the only deposits noted that were not within or along a contact of one of the limestones. Porphyry and quartzite in different places form rather sharply defined roofs or floors to ore bodies of considerable size.

RELATIONS TO LEAD CARBONATE AND MIXED SULPHIDE ORE BODIES

The ore bodies thus far worked are all closely associated with blanket bodies of lead carbonate ore. For the most part the zinc bodies underlie the lead bodies, but in some places they have replaced the same strata, either down the dip or even along the strike. Those in the Ibex No. 1 (Little Jonny), although they are in the vicinity of veins and magnetite-pyrite bodies, are immediately associated with old blanket stopes. The Luema vein contains a considerable quantity of zinc blende, and as its upper part is oxidized, a corresponding quantity of oxidized zinc ore could be expected somewhere along the vein, below the level of oxidation. None, however, has been found, and the only apparent explanation is that the strong kaolin ("talc") selvages along the vein have prevented any considerable quantity of zinc solutions from penetrating into the limestone walls. It is also possible that the great amount of kaolin has absorbed the meager amount of zinc from the solutions, giving rise to zinciferous clay; but this point has not been tested.

One feature that is of great annoyance to miners and prospectors and is difficult to explain satisfactorily is the lack of uniformity in the relations between the oxidized zinc bodies and the associated blanket lead bodies. At the north end of Carbonate Hill large bodies of both have been mined, but in Fryer and Iron hills, where large blanket deposits of lead ore have been mined, only small bodies of zinc ore have thus far been found among a great amount of iron-stained "contact matter," and some of these bodies have not been of very high grade. In some places, although blanket lead stopes are of considerable size, associated zinc ore has been found only in small bunches from a few inches to 3 or 4 feet in diameter.

The causes of this variation are probably several and can be best discussed in connection with the genesis of the ores. (See pp. 264–267.) It may be stated here, however, that the size of a zinc body depends on the amount of zinc in the original ore body, the kind and distribution of openings through which the waters transferring the zinc had to pass, the composition and texture of the rocks through which the waters passed, and the materials that accompanied the zinc in solution. Consideration of these factors, in places where the zinc ores have been mined or searched for, may yield a satisfactory explanation; but without a knowledge of them it is impossible to make a definite prediction as to the size and position of oxidized zinc bodies that may be associated with old blanket bodies of lead carbonate.

As none of the old blanket stopes were accessible to the writer (Loughlin), predictions regarding the location and extent of undiscovered bodies are not warranted here. It may be said that the amounts of "vein matter" shown in the cross sections by Emmons[35] suggest the probable presence of good oxidized zinc bodies in the northern part of Carbonate Hill other than the bodies already worked and of good-sized bodies on other hills; but experience in Fryer and Iron hills proves that the thickness and extent of "vein matter" shown in Emmons's sections are far from being good indicators of the amount of zinc ore present.

[34] Eng. and Min. Jour., Feb. 14, 1914, p. 396.

[35] U. S. Geol. Survey Mon. 12, atlas, 1886.

In two places bodies of oxidized zinc ore of rather low grade are not closely associated with old lead-silver stopes. In the Cord Mining Co.'s workings (Page lease, 1913) a small body of red zinc carbonate ore has been mined, which is 150 to 200 feet away (down the dip) from the nearest known lead-silver stope of any considerable size. The ground in the immediate vicinity, up the dip, has not been prospected, and it can not be stated whether the zinc was carried in very low grade red siliceous zinc material pass through the porphyry, and some of them certainly connect zinc bodies with lead-silver bodies, although the largest of the zinc ore exposures appears to have the most remote connection. There seems, however, no reason to doubt that the zinc-bearing solutions were able to travel for considerable distances through unfavorable porphyry to a more favorable rock before depositing any considerable quantity of zinc.

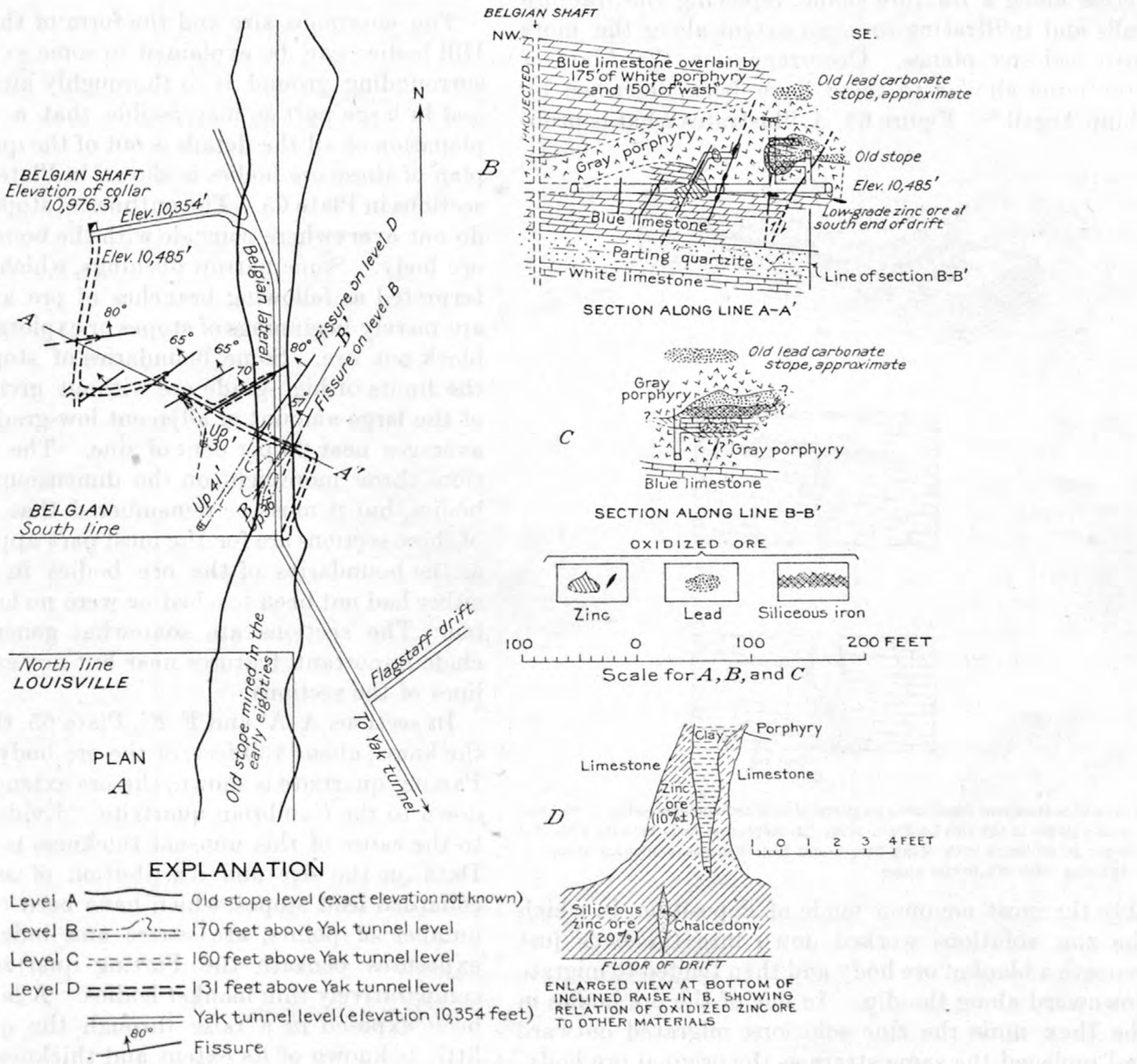


FIGURE 64.—Plan and sections of lead-silver stopes in Belgian mine. Oxidized zinc ore occurs chiefly along the three fissures nearest to these stopes. Section *A–A'* shows relation of zinc ore to lead-silver stopes. Section *B–B'* shows siliceous iron oxide immediately below lead-silver stopes and small deposit of low-grade zinc material in the angle between converging bodies of Gray porphyry. Fissures in the lower body of porphyry contain small bunches of siliceous zinc material. The sketch (*D*) shows relations of siliceous zinc ore, clay, and chalcedony in fissure just below porphyry contact, 170 feet east-southeast of Belgian shaft

solution for an unusually long distance before being deposited, or whether there may be an undiscovered lead-silver body nearer the zinc carbonate body.

In the Belgian mine (Fenton lease, 1913) small bodies of low-grade siliceous oxidized zinc ore were formed by the replacement of limestone at the base of a complex Gray porphyry sheet, which separated the zinc ore below from silver-lead bodies above, as shown in Figure 64. Fissures containing small amounts of

SHAPE AND SIZE OF ORE BODIES

GENERAL FEATURES

The ore bodies, as shown in several plans and sections (figs. 64–67 and pls. 64 and 65), are for the most part very irregular. Nevertheless, they show in several places structural features that go far toward indicating their origin. The simplest examples are represented in the sketches in Figure 65, illustrating the mode of occurrence in the Oro La Plata mine. Figure 65, *C*, represents zinc carbonate ore of shipping grade forming borders or casings to a body of lead ore that had replaced the wall rock along a fissure. The zinc on oxidation of the primary (sulphide) ore evidently moved downward, at the same time permeating the limestone for 2 feet or more. Figure 65, *B*, illustrates a place where the zinc solutions, descending from a blanket sulphide body, found the easiest course along a fracture plane, replacing the fracture walls and infiltrating to some extent along the more open bedding planes. Occurrences in the Maid of Erin mine similar to these have been described by Philip Argall.[36] Figure 65, *A*, illustrates what is probably the most common mode of deposition, in which the zinc solutions worked down into the beds just beneath a blanket ore body and then tended to migrate downward along the dip. In one of the ore bodies in the Ibex mine the zinc solutions migrated outward and replaced the same strata as the original ore body, the silver-lead and the zinc stope lying side by side.

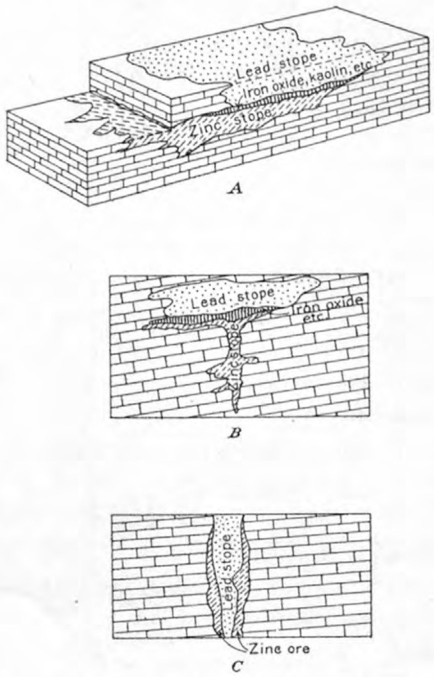


FIGURE 65.—Diagrams illustrating relations of oxidized zinc ore bodies to lead carbonate stopes in the Oro La Plata mine: *A*, Replacing beds beneath a blanket stope; *B*, replacing rock along fissure and beds beneath a blanket stope; *C*, replacing walls of a fissure stope

Other ore bodies represent some combination of the conditions just described. The New Dome deposit, represented by Figure 66, illustrates the downward migration of the zinc solutions along bedding planes just beneath a Gray porphyry sill as far as a fissured zone, which then afforded the readiest channel. The shattering of the rock along the fissure zone permitted the replacement to extend over a rather great width in proportion to length and depth.

The plan and section of the Tucson first level (fig. 67) also illustrate the development of the oxidized zinc ore bodies along fissures, with local spreading along bedding planes and minor fractures. The scattered distribution of these small bodies beneath a large continuous old silver-lead stope is in marked contrast to the continuity of the extensive bodies in the northern part of Carbonate Hill.

CARBONATE HILL ORE BODIES

The enormous size and the form of the Carbonate Hill bodies can be explained to some extent, but the surrounding ground is so thoroughly altered and soft and in large part so inaccessible that a complete explanation of all the details is out of the question. The plan of these ore bodies is shown in Plate 64 and cross sections in Plate 65. The outlines of stopes in the plan do not everywhere coincide with the boundaries of the ore body. Some narrow openings, which might be interpreted as following branches of ore along fissures, are merely beginnings of stopes or exploration drifts to block out ore. Some boundaries of stopes represent the limits of high-grade ore without giving any idea of the large amount of adjacent low-grade ore, which averages near 20 per cent of zinc. The vertical sections throw more light on the dimensions of the ore bodies, but it must be remembered that the outlines of these sections are for the most part approximations, as the boundaries of the ore bodies in most places either had not been reached or were no longer accessible. The sections are somewhat generalized to include important features near but not exactly on the lines of the sections.

In sections A–A′ and F–F′, Plate 65, the maximum thickness, about 130 feet, of the ore body beneath the Parting quartzite is shown, the ore extending in places down to the Cambrian quartzite. Evidence pointing to the cause of this unusual thickness is very scanty. Data on the size and distribution of associated old collapsed lead stopes, which have been reopened at a number of points, are scarce and indefinite. Such exposures beneath the Parting quartzite represent comparatively thin blanket bodies. A large stope has been exposed in a raise through the quartzite, but little is known of its extent and thickness. Comparison with the stopes shown in Plate 19 will show that these old stopes lie close to the area of extreme metallization, but although this fact indicates that there was an abundance of oxidized lead-silver ore in the immediate vicinity, there is no means of knowing whether the bulk of the zinc migrated vertically downward through the Parting quartzite or down along the dip beneath the Parting quartzite. Both processes no doubt took place, but it can not be said which predominated.

Although the immediate sources of the zinc ore are thus very obscure, there is evidence that the great

[36] Argall, Philip, The zinc carbonate ores of Leadville: Min. Mag., vol. 10, p. 284, 1914.

thickness of some of the ore bodies may be due to the presence of faults and the open structure of the rocks. The southeastward dip of the strata is interrupted by a fault of west-northwesterly trend (section F–F′), with relative down-slip on its south side. This fault was side; but the Parting quartzite does not appear to have been displaced to the east, along the "high line" drifts connecting with the Deener raise, and it is therefore concluded that the fault stops against one of north-northeasterly trend, as suggested in Plate 64.

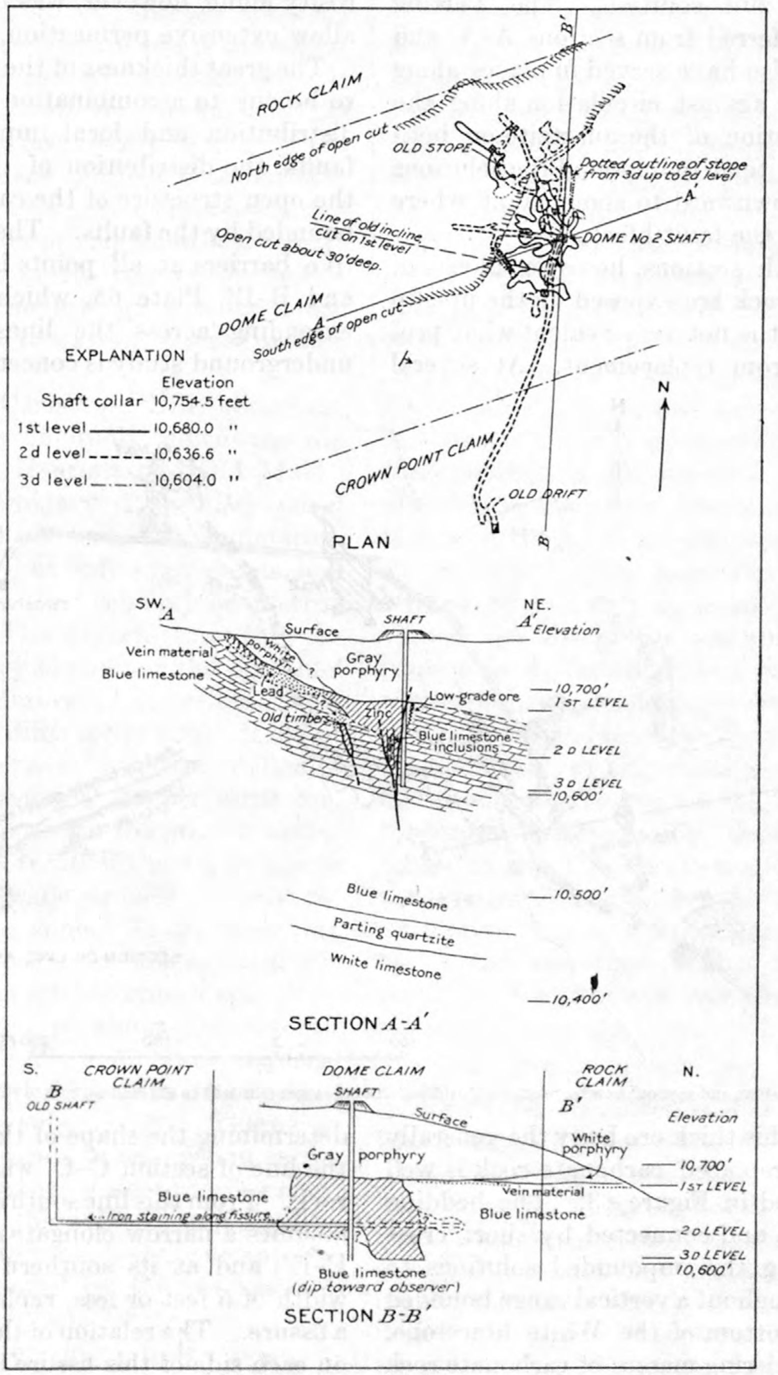


FIGURE 66.—Plan and sections showing relation of oxidized zinc ore body on the Dome claim to old lead carbonate stope. Section *A–A′*, an east-west section through the Dome No. 2 shaft, shows concentration of ore in shattered ground along fissures; section *B–B′* shows northward pitch of ore body

exposed at only one place, on the first Wolftone level, and its length and exact course are not known. The amount of displacement where the fault is exposed must be at least 25 or 30 feet, according to the positions of exposures of the Parting quartzite on either

A strong clay-filled fissure, corresponding in position to the suggested north-northeasterly fault, was exposed on the "high line" 90 feet east of the McKean raise. The ground on both sides of it consisted of ore or thoroughly altered carbonate rock, and no idea of the amount of displacement could be gained. It is significant, however, that ore of shipping grade was not being mined on the east side of this fissure.

This fissure with its heavy clay filling evidently served as an effective barrier, at least locally, against the spreading of the zinc solution. The Parting quartzite, as may be inferred from sections A–A′ and F–F′, Plate 65, could also have served in places along both faults as a barrier against circulation along the bedding. The distribution of the quartzite on both sides of the fault would tend to impound the solutions and to deflect them downward to some point where they could escape from the fault block.

In the planes of both sections, however, blocks of unreplaced carbonate rock are exposed on the up-slip sides of the fault, and it is not very evident what protected these masses from replacement. At several places in the stopes of this thick ore body the generally open structure of the replaced carbonate rock is well preserved, as illustrated in Figure 63. The bedding planes are mostly open and connected by short cross fractures, thus allowing the impounded solutions to permeate the rock throughout a vertical range bounded only by the top and bottom of the White limestone. The inclusions and bordering masses of carbonate rock found here and there, including those represented in sections A–A′ and F–F′, Plate 65, owe their preservation, to judge from their small exposures, to the local absence of this characteristic open structure. Most of these inclusions and masses are now stained by oxidation, and no tests of their composition were made, but the inclusion represented in section A–A′ proved to be typical manganosiderite. A specimen of this inclusion proved to be surprisingly porous for a crystalline rock, a character which, if common to the rock as a whole, would permit very complete permeation when once the zinc solutions had gained access along the numerous bedding and fracture planes. The porosity alone, however, was evidently not sufficient to allow extensive permeation.

The great thickness of the ore body therefore appears to be due to a combination of three conditions—the distribution and local impounding influence of two faults, the distribution of the Parting quartzite, and the open structure of the carbonate rock in the block bounded by the faults. That the faults were not effective barriers at all points is shown in sections F–F′ and B–B′, Plate 65, which represent the ore body extending across the lines of faulting. So far as underground study is concerned the principal factor in determining the shape of the ore body as far south as the line of section C–C′ was the open structure of the rock. From this line southward the ore body gradually assumes a narrow elongate outline (sections D–D′ and E–E′) and at its southern extremity is limited to a width of 5 feet or less, replacing the dolomite walls of a fissure. The relation of the preserved bedding planes on each side of this fissure indicates faulting but gives no idea of the amount of displacement. The occurrence in the fissure of a small amount of dense white quartz inclosing microscopic grains of a decomposed ferruginous carbonate and perhaps also of pyrite indicates a presulphide age for this fissure. The zinc ore along this fissure, as along those in other mines already described, tends to spread for short distances along the bedding and in one place was found to inclose a small

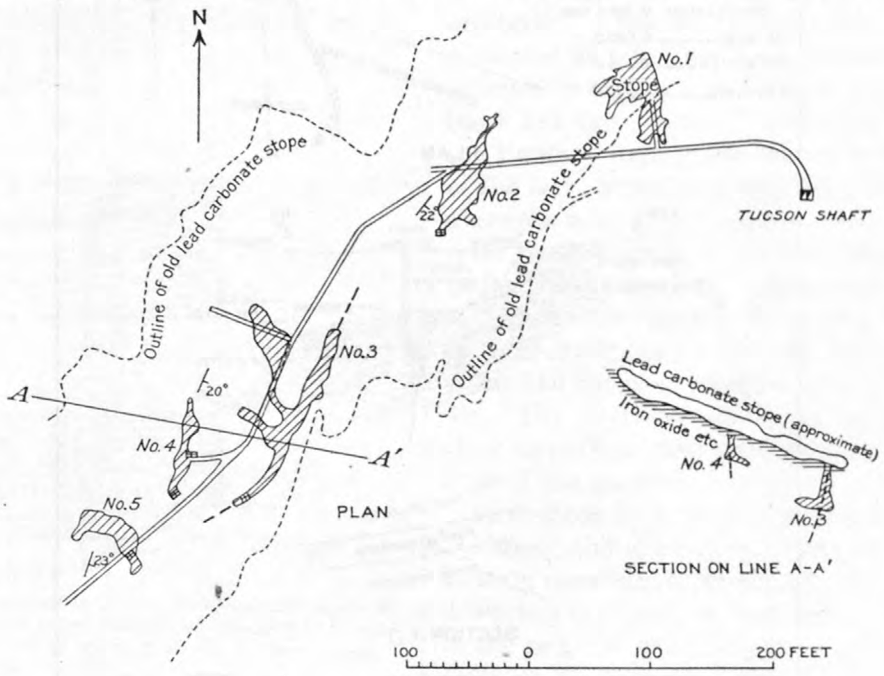


FIGURE 67.—Plan and section showing relations of oxidized zinc ore stopes (shaded) to old lead carbonate stopes, Tucson mine

bedded layer of sulphide ore, consisting chiefly of galena with cavities partly filled with calamine to mark the probable former presence of zinc blende.

The narrow stope extending northeastward from the east side of the lower ore body between the lines of sections B-B′ and A-A′, Plate 65, has no apparent connection with a pronounced fissure and is not necessarily a close indication of the limits of the ore. It deserves special mention, however, because it has yielded gray zinc carbonate ore, clearly formed by the replacement of manganosiderite, directly underneath a mass of sulphides. The existence of this ore is evidently due to the migration of zinc solutions chiefly along bedding planes east of the line of the fissure described on page 242. The geology was too much obscured by timbering here to warrant a more definite statement.

The upper ore body of Carbonate Hill, above the Parting quartzite, extends obliquely down the dip from a point near the old Henriett or "Old Maid" shaft to the southwest boundary of the Big Chief claim, a distance of about 1,050 feet. Its boundaries, however, are sharply defined at only a few points, and the factors influencing its outline can only be inferred rather than determined. The branch stope that extends a little west of south, just crossing the Big Chief northeastern boundary, underlies old silver-lead stopes that have been exposed at different points. It has at one place on its west side a nearly vertical dolomite wall opposite a wall of low-grade (10 per cent) ore. No strong fissures were exposed in the ground accessible to the writer, but the trend of the higher-grade ore and the position of its walls strongly indicate replacement along a fractured zone. At one place just south of the Big Chief line the ore narrowed downward to a fissure filling only a few inches wide.

Northeast of this branch stope, about 50 feet south of the line of section C-C′, Plate 65, the zinc ore, with an inclusion of manganosiderite, was seen directly underlying a mass of pyritic sulphide ore. There was no indication of distinct fissuring in the ground accessible. The inclusion of manganosiderite, however, would, from analogy with the evidence obtained in the thick portion of the lower ore body, warrant the inference that the rock replaced by the ore was rendered unusually permeable by shattering.

About 100 feet south of this point, in the Banquet Hall stope, the ore body attained a thickness said to be 50 feet, and still farther south, a short distance beyond the line of section E-E′, it was as thick or thicker. The ore was worked out in the former place, but in the latter it was seen to preserve the open structure of the original rock. This thick body underlay old silver-lead stopes, but nothing is known of their dimensions. The body diminished rapidly in thickness eastward and on the east side of the main third level drift, along the line of section E-E′, had dwindled to a bedded replacement deposit only 2 or 3 feet thick.

The most reasonable inference to account for the shape of the upper ore body, based on the scanty evidence presented, is that the rock had become more or less shattered along certain zones characterized by anastomosing fractures rather than pronounced fissures. The zinc solutions, descending from the oxidizing blanket bodies (now the old silver-lead stopes), found the easiest courses along these zones, with the result that bodies of relatively great thickness in proportion to their width were formed by replacement of the carbonate rock. The width of the ore body was limited by the extent of the openings in the rock; the depth, as shown in sections D-D′ and E-E′, was limited by the Parting quartzite, which in places has been exposed as the approximate floor of the stopes Whether or not these zinc solutions found their way in any considerable amount downward along fractures through the Parting quartzite has not been demonstrated by mining. It seems doubtful, however, in view of the size of the ore body and its depth with respect to oxidation, if any considerable amount of zinc carbonate or silicate ore can be expected beneath it, on the underside of the Parting quartzite.

Comparison of the position of the Carbonate Hill bodies and the slopes on the surface fails to show a concordant relation. The depths of oxidation as recorded in Emmons's notes are likewise independent of the topography, and it is evident that the depth and circulation of ground water has been governed rather by the rock structure—that is, the trends of the open portions of fissures, minor fractures, and bedding planes.

CHARACTER OF BOUNDARIES OF THE ORE BODIES

The varied character of the boundaries of the ore bodies in many places has already been mentioned and requires little additional description. It seems desirable, however, to summarize the variations and to correlate them with certain chemical data. The simplest case includes the rather sharply defined walls along nearly vertical fissure bodies. The west wall of the fissure stope near the south end of the lower Carbonate Hill body is sharply bounded by soft, sandy dolomite, a specimen of which was found by R. C. Wells to contain 1.28 per cent of zinc oxide, or 1.59 per cent of zinc carbonate. At the northwest end of the small fissure stope in the New Dome mine (fig. 66) similar but more rusted soft material bordering the stope was found by George Steiger to contain 19.22 per cent of insoluble matter, 0.36 per cent of magnesia, 0.53 per cent of lime, and 6.33 per cent of zinc oxide. The zinc here showed a stronger but still not great tendency to permeate the wall rock, which elsewhere in the mine is Blue limestone (dolomite). The insoluble material appears to be chiefly silica intimately associated with brown iron oxide and possibly combined with the zinc as zinciferous clay. This material, only a few inches thick, passed into unstained dolomite. Similar siliceous material was found along the main body of the New Dome mine on the first level. The occurrences in the Maid of Erin mine, described with assays by Argall,[37] are of similar character, though the transition from ore to country rock is more gradual.

The floors of some of the bedded zinc carbonate bodies are rather clearly defined, though not nearly so sharply defined as the fissure walls just described. Two specimens taken from the floor of a small bed stope in the Ibex mine, one at the very bottom of the stope and the other 5 inches below it, were found by R. C. Wells to contain respectively 27.4 and 14.9 per cent of zinc oxide, or 22 and 12 per cent of metallic zinc. These figures indicate a gradual change from ore into country rock within a zone between 1 and 2 feet thick. The bottom of the upper ore body of Carbonate Hill is in places abruptly bounded by the Parting quartzite, the top layers of which have been deeply stained by iron and manganese oxides, which may be accompanied by a little zinciferous clay. The lower ore body is said to be similarly floored by the Cambrian quartzite at a few places. At one place in the lower ore body, about 230 feet west-northwest of the Deener raise (pl. 64), the high-grade ore passes downward into a decomposed low-grade material consisting chiefly of silica with minor amounts of iron oxide and clay, which appears to be the residue of a siliceous rock or silicified carbonate rock. In other places the ore passes downward into unaltered carbonate rock. Such variations evidently depend on the composition of the rock replaced and on the amount of leaching that has been possible since the deposition of the zinc ore.

The sides of the bedded bodies may be rather abruptly bounded, but much more commonly they are marked by a gradual decrease in zinc content so that the high-grade ores merge into large bodies of ore averaging near 20 per cent in zinc. How extensive such low-grade bodies are has not been definitely stated, but they are said to constitute large reserves in several different places.

[37] Argall, Philip, The zinc carbonate ores of Leadville: Min. Mag. (London), vol. 10, p. 284, 1914.

The main factor determining the character of the boundary is evidently rock structure. Where permeable rock is abruptly limited, as by clear-cut fissures or by contact with impervious quartzite, shale, or porphyry, the ore also ends abruptly; where the rock bordering the main ore channels is of more open structure there is likely to be a gradation from high-grade ore through a large extent of low-grade ore into barren rock. In the latter case the degree to which zinc is concentrated in the solution may be an important factor, solutions above a certain strength readily replacing the rock, whereas solutions below that strength but otherwise under similar conditions could react only slowly and to a small extent. No experimental data are at present available to throw light on this matter.

The zinc ore bodies are for the most part separated from overlying lead-silver bodies by layers consisting of siliceous iron oxide and clay in varying proportions and ranging in thickness from a few inches to 6 feet or more. Such layers are characteristic of oxidized zinc deposits in several mining districts and are subject to more than one interpretation. They may represent the first substances deposited by the solutions that transferred material downward from the oxidizing sulphide bodies; they may represent the oxidized residue of a largely insoluble material which formed a casing to the original sulphide bodies; they may be the insoluble residue left by the leaching of the topmost part of the zinc carbonate body; or they may consist principally of material leached from the original ore bodies at a relatively late stage and deposited at the same time that the topmost part of the zinc carbonate was being leached. Partial evidence in different places suggests one or another of these processes, and it is possible that a combination of processes operated. It is also possible that one process may have been of relatively great influence in one locality and of relatively slight influence in another, owing to differences in chemical conditions. The chemical conditions are considered in the discussion of ore genesis (pp. 264–267).

Where the oxidized zinc bodies immediately underlie porphyry or shale, their upper contacts are marked by a layer of zinciferous clay that may be 2 or 3 feet in thickness. The presence of the clay is evidently due to the alumina and silica leached from or residual after the porphyry or shale. In some places it seems that the alumina must have been precipitated with the zinc; in others it seems probable that the clay, already present, has adsorbed zinc from solutions which have come into contact with it.

At a few places bodies of oxidized zinc ore have been found in contact with bodies of iron or manganiferous iron ore. These contacts are considered in the following paragraph.

RELATIONS TO OXIDIZED IRON AND MANGANIFEROUS IRON ORES

The oxidized zinc ores have been found beside and beneath oxidized iron and manganiferous iron ores and have also been reported to occur above them. The evidence obtained by the writer, while affording some explanation of these variations in distribution and occurrence, does not point to any systematic association. The lack of systematic association is not surprising when it is realized that the iron ores may have originated from the complete oxidation of either pyrite or manganosiderite masses, and that the zinc ore may have been deposited directly either beneath or beside masses of either of these materials; also that the primary shoots of zinc blende from which the oxidized zinc ores were derived were irregularly scattered through the sulphide bodies or were in places underlain by manganosiderite. The evidence as a whole indicates that if an oxidized body of either iron or zinc ore is present a body of the other may be present close by, although the relative position of the two bodies can not be predicted; but in view of the relative abundance and distribution of the primary minerals, pyrite, manganosiderite, and zinc blende, it is evident that the presence of the iron ore is not a certain indication of the presence of the zinc ore, for large bodies of almost pure pyrite bordered by manganosiderite are known to exist with no noteworthy amount of zinc blende in the immediate vicinity. Oxidation of such a body would yield a large deposit of iron and manganiferous iron ore, with no associated body of zinc ore.

VERTICAL DISTRIBUTION AND RELATION TO DEPTHS OF OXIDATION AND GROUND-WATER LEVEL

Oxidized zinc ores have been found in a few places close to and even at the surface and at varying depths down to 750 feet. The depth depends as a rule on the depth of the contact of the White porphyry and Blue limestone, as most of the zinc bodies have been found in association with the "first contact" ore bodies of this horizon. The deepest deposit in the northern part of the Maid of Erin mine is associated with a series of ore bodies including "second contact" bodies (below Gray porphyry) and with bodies just above and just below the Parting quartzite. It is in the White limestone and extends in places from the base of the Parting quartzite even down to the top of the Cambrian quartzite. This is the thickest and one of the two largest oxidized zinc ore bodies thus far worked in the Leadville district. It is associated with the thickest as well as one of the most continuous bodies, or series of bodies, of lead-silver ore in the district, and general conditions appear to have been favorable to concentration rather than dispersion of the zinc.

All the zinc carbonate and silicate thus far mined have been found in the zone of complete oxidation, except the lowest parts of the great Carbonate Hill bodies. These, as indicated in sections A–A′ to F–F′, Plate 65, in places underlie sulphide ore. In some of these places the zinc ore is practically in immediate contact with the sulphides and may even inclose small amounts of them and of associated manganosiderite. Here the zinc ore has been deposited below the local depths of oxidation.

These exposures of sulphides over or within the zinc ore have been made at depths of about 640 to 700 feet and more below the collar of the Wolftone shaft. Old lead carbonate stopes were noted as far down as about 650 to 660 feet below the shaft collar. These figures based on observations at several places in the Western Mining Co.'s ground, place the average local depth of complete oxidation about 640 to 650 feet below the collar of the Wolftone shaft, or at an altitude of about 9,950 feet. They correspond closely with figures in Emmons's notes, for he found the depths of oxidation to be at an altitude of 9,936 feet (660 feet below the surface) in the Wolftone mine, 9,941 feet (639 feet below the surface) in the Brookland, and 9,981 feet (667 feet below the surface) in the Upper Henriett. Emmons's notes, however, show that the depth of oxidation fluctuates considerably in the northern part of Carbonate Hill.

The relation of the oxidized zinc ores to the ground-water surface can not be definitely shown, because the water levels, as they stood before mining began, have been altered in many places by mining operations. So far as can be learned, all the ore bodies that have been studied are well above the natural ground-water surface except those in the northern part of Carbonate Hill. It is said that if pumping were discontinued in the Wolftone mine at the north end of this hill, the water would rise within about 300 feet of the collar of the shaft. This is more than 300 feet above the average depth of complete oxidation and well above all the oxidized zinc bodies thus far found in the mine; the ground-water level at the time these ore bodies were formed must therefore have been considerably lower. Not even the depth of complete oxidation, however, gives a precise indication of the natural ground-water surface; for oxidation is known to extend somewhat below that surface in some places and considerably below it in excessively fractured zones. On the other hand, sulphide bodies of small to considerable size are found, in more protected ground, above ground-water level. The depths at which the zinc carbonate and silicate are found are also unreliable indications, for these minerals may be deposited by the replacement of limestone below as well as above ground-water level. The composition of the zinc carbonate ores is such as to indicate that they were deposited in the absence of free oxygen, a condition that may exist in the lower part of the ground above the water level as well as below it. Large portions of the carbonate ores also have undergone considerable oxidation and leaching, a fact which proves the downward migration of the oxidized zone since the bulk of the carbonate ores were deposited. The ground-water surface also doubtless migrated downward, keeping pace with surface erosion. It is obvious, therefore, that no exact relations can be determined between the distribution of the oxidized zinc ores and the ground-water surface. The evidence as a whole, however, indicates that the zinc carbonate ores were deposited close to if not in part below the water level that existed at the time of their deposition, and it is possible that their lower portions were still below the water surface as it stood just prior to the disturbances caused by mining.

LACK OF ASSOCIATION WITH SECONDARY SULPHIDES

No sulphides known to be secondary have been found in association with the oxidized zinc ores, and no zinc sulphide known to be secondary has been found anywhere in the district. The sulphide ore exposed in contact with the zinc carbonate ores has all the characteristics of primary ore. Even small grains of pyrite, zinc blende, and galena found inclosed in the ore proved under the microscope to be intimately associated with veinlets and patches of quartz and sericite, the typical gangue minerals of primary sulphide ore. The three sulphides, as well as the quartz and sericite, were evidently unaffected by the zinc-bearing solutions that replaced the carbonate rock.

The sulphide masses adjacent to the zinc carbonate ore are all composed largely, if not entirely, of pyrite, but no sign of zinc sulphide, either sphalerite or wurtzite, upon pyrite was found. This is a point of some significance in view of the conclusions by Blow[38] and Emmons[39] that the zinc removed from the oxidized zone had been precipitated as sulphide just below water level and had thus migrated downward at equal pace with the limits of oxidation. The only available agents for the precipitation of zinc as a sulphide, on the assumption that the zinc was in solution as sulphate, were a very small quantity of organic matter and a large quantity of pyrite.

It has been assumed by some writers that pyrite or marcasite has precipitated secondary zinc sulphide, especially in deposits of the Mississippi Valley; but experiments with the two minerals have not confirmed this assumption, at least in a convincing way. The experiments of Schuermann[40] and Weigel[41] lead to the conclusion that under certain conditions zinc sulphide is slightly more insoluble than iron sulphide but that the two metals are so very nearly equal in solubility that any precipitation of zinc sulphide at the expense of an iron sulphide would not be nearly so rapid as the precipitation of silver or copper sulphide by the same agent. The conditions of these experiments by no means duplicate the conditions governing the secondary deposition of zinc minerals at Leadville, but so far as they go they suggest that if pyrite can precipitate zinc sulphide from the ground waters in question it does so very slowly and can hardly precipitate large quantities of zinc blende just below the zone of oxidation.

The only experiment known to the writer in which zinc sulphide has been precipitated by pyrite or marcasite was performed by Stokes,[42] who treated pyrite and marcasite each with a solution of zinc carbonate and potassium bicarbonate, in sealed tubes which contained an excess of both carbonates and were filled with carbon dioxide, for 24 hours at 180° C. Stokes also found that under similar conditions pyrite and marcasite were decomposed by alkaline solutions, including potassium bicarbonate. It therefore seems probable that the potassium bicarbonate made the precipitation of zinc sulphide possible. In the Leadville deposits the secondary zinc solutions, whether sulphates or carbonates, evidently found the surrounding carbonate rock to be

[38] Blow, A. A., The geology and ore deposits of Iron Hill, Leadville, Colo.: Am. Inst. Min. Eng. Trans., vol. 18, pp. 168-172, 1890.

[39] Emmons, S. F., and Irving, J. D., The Downtown district of Leadville, Colo.: U. S. Geol. Survey Bull. 320, pp. 32-33, 1907.

[40] Schuermann, Ernest, Ueber die Verwandtschaft der Schwermetalle zum Schwefel: Liebig's Annalen, vol. 249, p. 326, 1888.

[41] Weigel, Oskar, Die Löslichkeit von Schwermetallsulphide in reinem Wasser: Zeitschr. physikal. Chemie, vol. 58, pp. 293-300, 1907.

[42] Stokes, H. N., Experiments on the action of various solutions on pyrite and marcasite: Econ. Geology, vol. 2, p. 17, 1907.

more readily replaceable than the pyrite, and for this reason the zinc was precipitated as carbonate. The conditions, including low temperature as well perhaps as absence of a sufficient amount of alkali in solution, apparently were not right to convert it to secondary sulphide at the expense of pyrite.

Experimental evidence is thus negative, and local field evidence shows that conditions were not favorable for the precipitation of secondary zinc sulphide. Local evidence furthermore accords with general evidence, which has been discussed by W. H. Emmons,[43] who says:

It has frequently been stated that zinc sulphide has been precipitated at the expense of iron sulphide and that zinc has driven iron out of its sulphide combination, but no examples of the pseudomorphous replacement of pyrite or marcasite by zinc blende are available. On the other hand, Hintze [44] notes a pseudomorph of marcasite after zinc blende.

Lindgren[45] states that "zinc is not, as a rule, deposited as a secondary sulphide, and no authentic case has been recorded where it replaces pyrite, as chalcocite so often does." In his discussion of Bain's conclusion that secondary sulphides of zinc and other metals have been deposited at Joplin, Mo., below the zone of oxidation, he remarks[46] that "possibly this has taken place on a small scale, but most of the ore immediately below the oxidized zone appears to be of primary origin."

In a few places, notably the San Francisco district, Utah, described by B. S. Butler,[47] wurtzite, the hexagonal form of zinc sulphide, probably occurs as a secondary mineral. Butler, while suggesting that the replacement of pyrite by zinc sulphide may be possible, remarks that

in none of the ore examined can the zinc sulphide be seen replacing the iron, but there are abundant specimens that show wurtzite surrounding sphalerite, apparently as a later growth on it. This suggests that the precipitation has been effected by agents other than the pyrite, and that the attraction of the sphalerite had caused the secondary sulphide to be added to it. * * * E. T. Allen and J. L. Crenshaw have suggested that acid solutions containing zinc sulphate and hydrogen sulphide in solution on having their acidity reduced would precipitate zinc sulphide. That such solutions are formed in the zone of oxidation there can be little doubt, and as they pass to lower levels their acidity may be reduced either by solutions from the adjacent limestone or by reaction with alkali silicates that form a part of the gangue of the ore.

From this evidence it would seem possible that wurtzite could have crystallized upon zinc blende in some of the Leadville deposits at or below the downward limit of oxidation, but no such occurrence has been reported. So far as positive evidence is concerned, no bodies of secondary zinc sulphide have been formed. The bodies of zinc blende just below the zone of oxidation, referred to by Blow and Emmons, can doubtless be interpreted as primary and can be shown to differ in no essential way from other segregated deposits of zinc blende lying well below the zone of oxidation, such as have been found in the Cord mine below the level of the Yak tunnel.

[43] Emmons, W. H., The enrichment of ore deposits: U. S. Geol. Survey Bull. 625, p. 140, 1917.
[44] Hintze, Carl, Handbuch der Mineralogie, vol. 1, p. 481, 1904.
[45] Lindgren, Waldemar, Mineral deposits, p. 811, 1913.
[46] Idem, p. 834.
[47] Butler, B. S., Geology and ore deposits of the San Francisco and adjacent districts, Utah: U. S. Geol. Survey Prof. Paper 80, p. 154, 1913.

CHAPTER 12. ALTERATION AND ENRICHMENT OF THE ORES

When Emmons made his first survey of the district only oxidized ores were being mined in considerable quantity, although isolated bunches of galena were found in them here and there. Sulphides had been reached in one or two mines but not developed, and although the oxidized ores were thought to have been derived from sulphides and were expected to give way to sulphides with increasing depth, the evidence then available was insufficient to afford full insight into the processes involved in their formation. Subsequent developments in the sulphide zone, together with increased understanding of the alteration effected by descending surface waters in general, now permit a more comprehensive discussion of the subject.

ZONES OF ALTERATION

The ores and inclosing rocks that lie above the preglacial ground-water surface have been partly or completely altered by processes of oxidation. The bottom of the oxidized zone is in general sharply defined in the blanket ore bodies, as the action of descending waters, which permeated them largely along the bedding planes, has affected them over a large horizontal but a comparatively small vertical extent; but where downward circulation was confined to the steeply dipping lodes the bottom of the zone is less sharply defined and some effects of oxidation are found considerably below the zone of thorough oxidation.

Where considerable quantities of metals have been dissolved in the zone of oxidation and redeposited below it by reaction with sulphide minerals a zone of sulphide enrichment has been developed between the zones of oxidation and primary sulphides; but this zone of sulphide enrichment, in contrast to that of oxidation, is poorly defined and can rarely be separated from the zones above and below it. In several places it is absent entirely.

The zinc carbonate ores, classed as oxidized ores, have to a great extent been formed at or below the ground-water surface and locally are found beneath sulphide ore. For this reason they are considered separately. Copper carbonate occurs in the same manner, but only in very small quantity.

OXIDIZED ZONE

DEPTH

Although the inaccessibility of the oxidized parts of many of the ore bodies has prevented study of them or their transitions into the sulphide ores, much information has been drawn from the scattered records of Emmons and his assistants during the first survey and from the later studies by Blow and others. In many mines, notably in Fryer Hill, Yankee Hill, the Downtown area, southern Carbonate Hill, southern Iron Hill, and Rock Hill, all the workings are in the oxidized zone, and the data procured from them are presented in Figures 68–78. It is shown on page 272 that oxidation of the ores took place mainly before the last stage of glaciation. The depth to which the process of oxidation extended should therefore be measured from the bottom of the glacial moraines.

Many shafts represented in the diagrams are entirely in the oxidized zone but furnish the best local information available. All the shafts are arranged as nearly as possible in groups determined by a similarity of geologic structure and presumably by a uniformity of hydrostatic conditions.

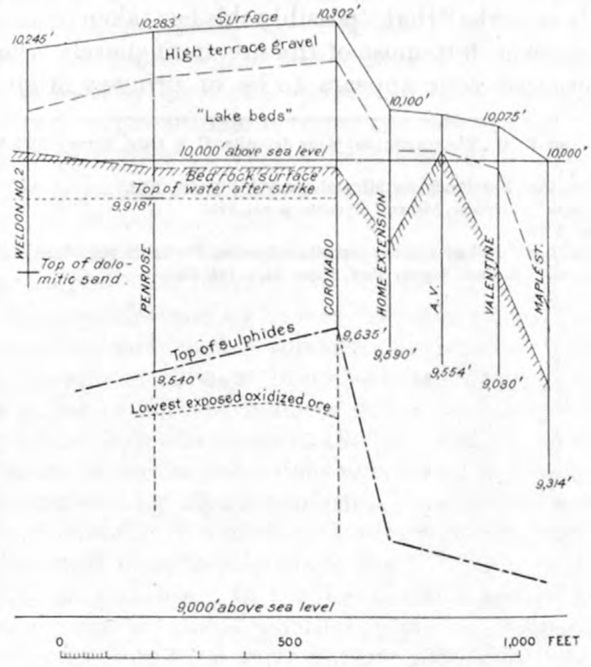


FIGURE 68.—Top of sulphides in Downtown district

According to these diagrams, the depth of oxidation from the ground surface ranges from 75 to 940 feet, and an average for the district is about 525 feet. In most parts of the district, however, it is between 400 and 600 feet. Depths of less than 200 feet and more than 800 feet are uncommon and limited to small areas. Within any area bounded by major faults the depth of complete oxidation approaches uniformity but is very different from that in adjacent areas or that within the fault zones along its borders. In some of these areas the change from oxidized to sulphide ore is sharp;

in others it is gradual, and the depths indicated refer to the highest point at which sulphides are found in appreciable quantity rather than the lowest point to which local oxidation happened to reach.

DOWNTOWN AREA

Extensive workings in the Downtown district disclosed only oxidized ore to a depth between 600 and 700 feet. Drill holes in the Coronado and Penrose mines cut loosely compacted sulphides at depths of 667 and 740 feet, respectively, and in 1919–1923 the Downtown Mines Co. mined oxidized lead, zinc, and manganese-iron ores as well as partly leached sulphide ore above and below the eighth level of these mines, 800 feet below the collar of the Penrose shaft. No other sulphides are known west of the Pendery fault zone. West of the Penrose and Coronado mines the depth of oxidation is even greater, the Home Extension, Cloud City, and Maple Street shafts disclosing nothing but oxides, and there seems every reason to believe that near the Arkansas Valley the depth of oxidation is nearly 1,000 feet below the surface. The altitude and depth of oxidation are graphically represented in Figure 68. The depths of the bedrock surface beneath the "lake beds," high terrace gravel, and glacial moraines are also shown. It will be seen that depths of oxidation measuring 667 and 743 feet from the land surface are only 339 and 443 feet, respectively, as measured from the bedrock surface. If oxidation was mainly earlier than the "lake beds" and high terrace gravel, its depth thus agrees fairly well with the average depth for the entire district. If the oxidation in this area was mainly later than the high terrace gravel, the cover of glacial material must have afforded little if any protection against oxidation, which has conformed to the bedrock topography only.

FRYER HILL AND EAST FRYER HILL

All the bonanzas in Fryer Hill were oxidized ores. So far as could be learned no sulphides have ever been found in the main part of Fryer Hill, except in a drill hole sunk in the bottom of the Roberts shaft, and the record of this hole is not available; but a drill hole in the Day shaft, near by, disclosed oxidized ore on the "second contact," and the oxidation level in the Roberts must have been at least that low. It is probable that there is little difference between the level of oxidation at these shafts and that farther east in the El Paso shaft. In East Fryer Hill sulphides are found in the El Paso, Olive Branch, Bangkok, and Forepaugh mines at a uniform altitude of 10,130 feet, or at depths between 431 and 450 feet. In the Hayden mine, which lies at a lower altitude, the sulphide is reached at 9,958 feet, or at a depth of 510 feet. These figures show that the oxidation bore a slight relation to the topography, although the increase in depth beneath the gulch is the reverse of what might be expected. The sulphide levels and depths are shown graphically in Figure 69.

These levels may be compared with the bedrock surface that lies deep below the terminal moraine of the Evans Gulch glacier. If this moraine is of later origin than the oxidation, the depth of oxidation is only between 310 and 400 feet. The existence here of oxides below the present ground-water level indicates that since the period of oxidation the water level has been raised owing to the water-containing capacity of the moraine.

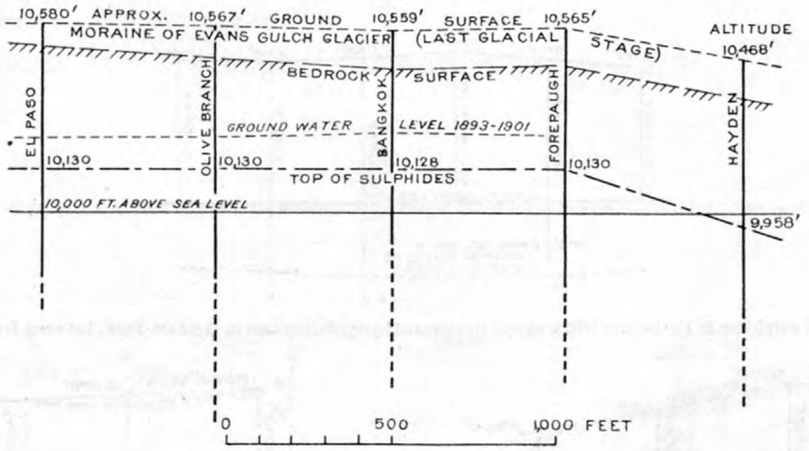


FIGURE 69.—Top of sulphides in East Fryer Hill area

CARBONATE HILL AND GRAHAM PARK

In the northern part of Carbonate Hill the depths to sulphides are known with considerable certainty. In the Pendery fault zone itself no dragged-in sulphides remained unoxidized, for the granite is relatively near the surface, and all the ore bodies in the sedimentary rocks are in the oxidized zone. Immediately east of the fault the same statement holds true, and no sulphides are found until the blanket bodies have been followed eastward down the dip beneath the crest of Carbonate Hill. Here sulphides have been found beneath the Parting quartzite in the Upper Henriett and Maid-Combination mines, and their top maintains a fairly constant altitude, extending obliquely across the blanket bodies, which dip eastward with the inclosing rocks. At the Pendery fault the top of the sulphides is well down in the Lower quartzite. It crosses the edge of the eastward-dipping series in a nearly horizontal direction, but between the Wolftone and Gonabrod shafts it has a marked eastward slope, as shown in Figure 70. The depth of oxidation in northern Carbonate Hill therefore appears to conform more to geologic structure than to topography. Beneath the broad summit of the hill the depth of oxidation

MIKADO WEDGE

Within the narrow wedge-shaped block between the Mikado and Iron faults the lower limit of oxidation lies from 10,310 to 10,408 feet above sea level, and its depth below the land surface is surprisingly shallow—310 to 398 feet. (See fig. 70.) In the Mikado fault itself the altitude of oxidation on dragged-in ore between the selvages of the fault is 10,109 feet and the depth 560 feet. The reasons for the sharp rise in the oxidation level in this wedge are given on pages 255–256.

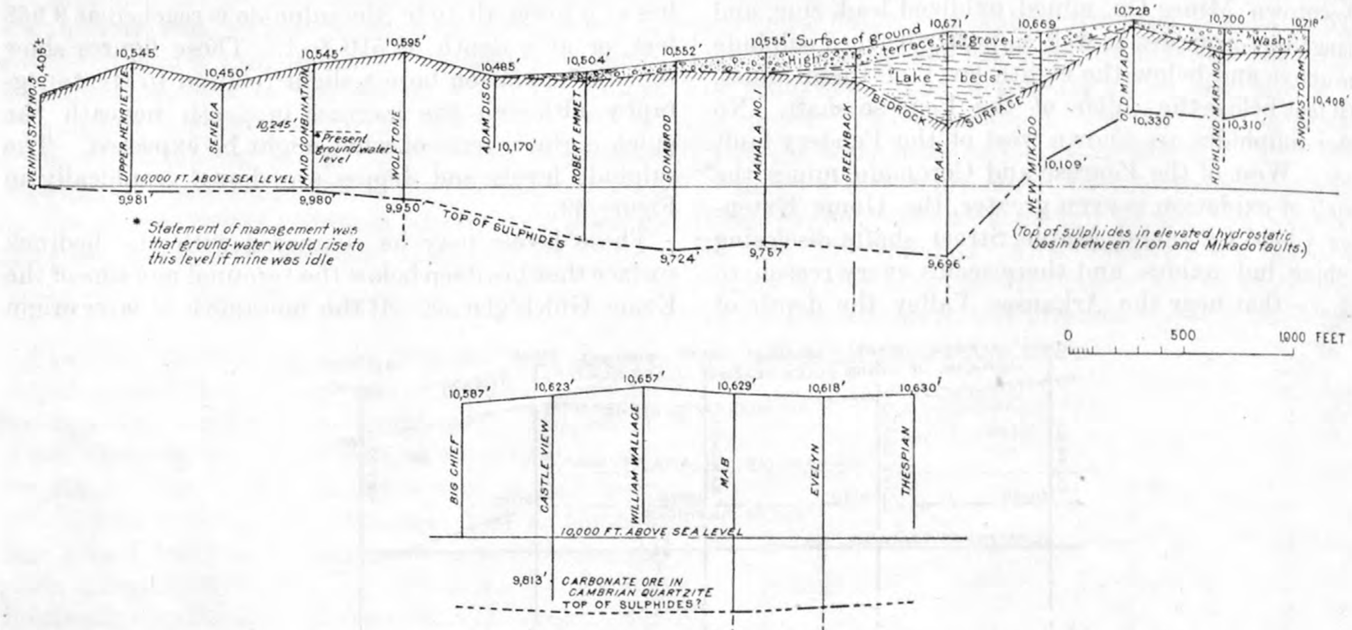


FIGURE 70.—Top of sulphides in Carbonate Hill area and in elevated hydrostatic basin in Graham Park, between Iron and Mikado faults

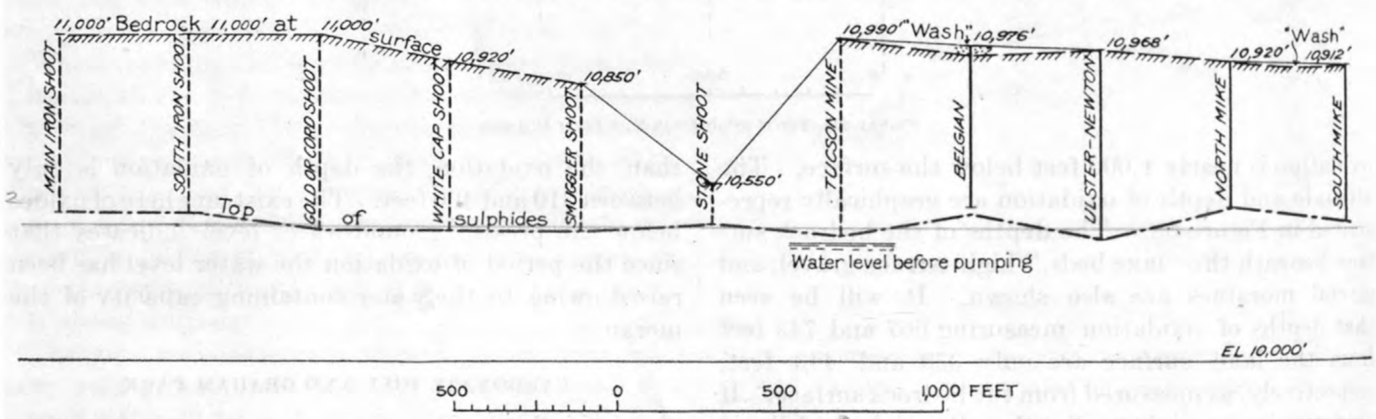


FIGURE 71.—Top of sulphide ores at constant altitude irrespective of topographic relief, Iron Hill east of Iron fault

below the bedrock surface is greater than elsewhere, although its depth below the land surface is exceeded in the R. A. M. mine. There is very little difference in altitude between the tops of sulphides in the Evelyn, at the summit of the hill, and the R. A. M. No shafts south or southeast of the Evelyn have reached sulphides, although the Satellite No. 2 and the Star of the West were 684 and 530 feet deep, respectively. In this synclinal basin (sections E–E′ and F–F′, pl. 15) the depth of oxidation is certainly very great and nearly reaches the maximum for the district.

IRON HILL EAST OF IRON FAULT

The top of the sulphide zone appears to be more nearly level in Iron Hill than in any other equally extensive portion of the Leadville district, although locally some fissure or local feature has carried oxidation below the prevailing level, and some protected sulphide bodies have remained unoxidized above that level.

The upper limit of sulphides in the Iron Hill mines is about 10,400 feet above sea level, though it ranges from 10,368 feet in the Ulster Newton to 10,470 feet in the North Mike. Depths below the bedrock surface vary much more widely—from 130 to 615 feet. In other words, a nearly constant level is maintained, alike independent of topographic relief and of the eastward dip of the geologic formations. These features are illustrated graphically in Figures 71 and 72.

DOME HILL

The data regarding oxidation on Dome Hill are scanty, and no average depth can be given (fig. 73). downward on the west side of the Iron fault, though how far is not known. South of the latitude of the Oro La Plata shaft on both sides of the fault the deep gorge, now filled with glacial deposits, has caused a depression of the depth of oxidation.

ADELAIDE PARK EAST OF ADELAIDE FAULT

None of the shafts in Adelaide Park east of the Adelaide fault that were accessible during the visits of Emmons and Irving showed sulphides except the Flagstaff, Lady Alice, and Badger State; and in these

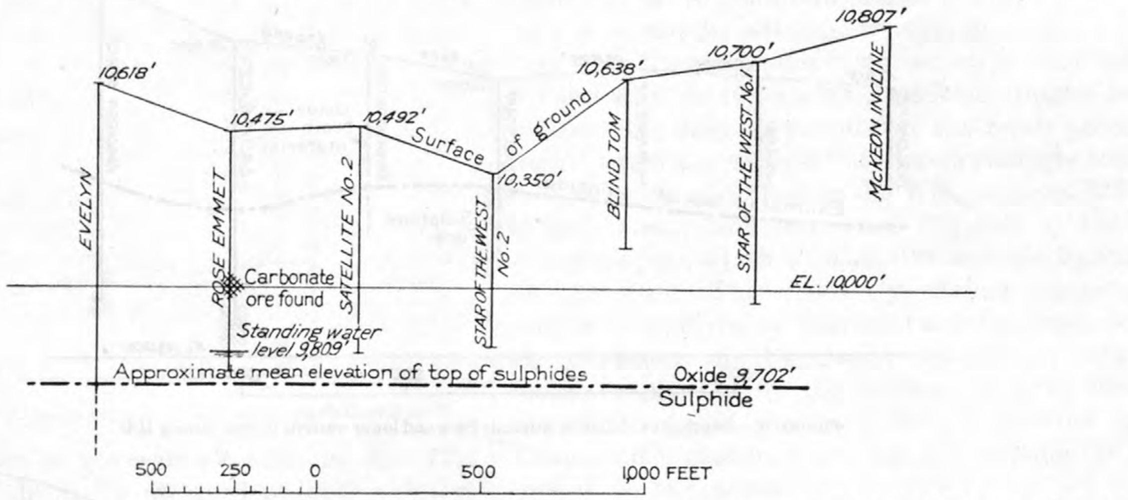


FIGURE 72.—Depth of oxidized zone in synclinal hydrostatic basin west of Iron fault, West Iron Hill. Compare altitude with that shown in Figure 71

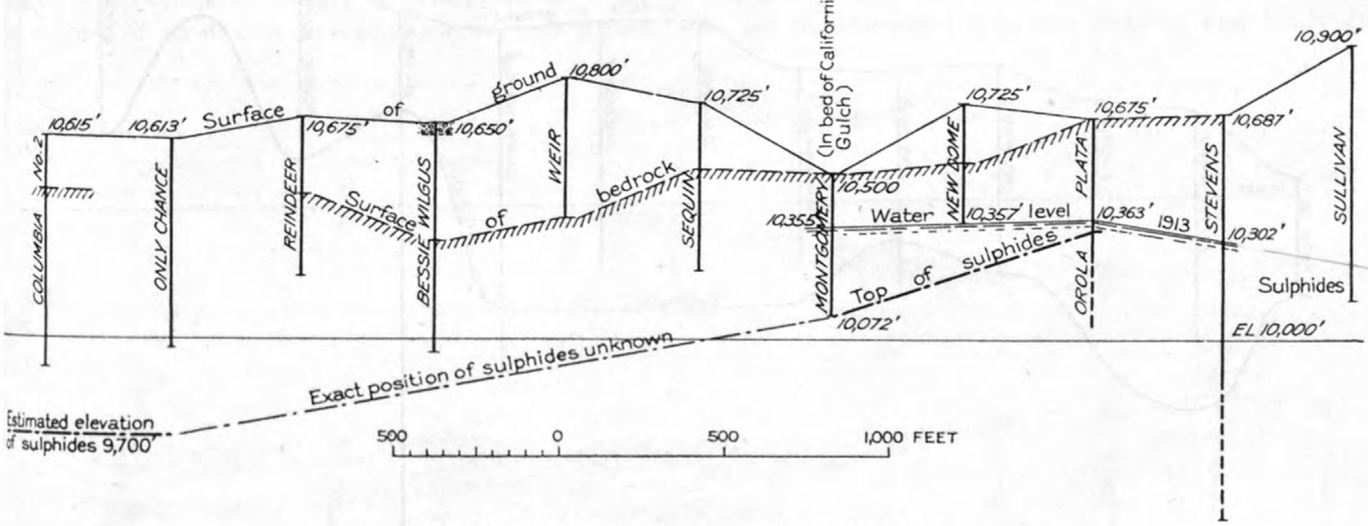


FIGURE 73.—Top of sulphide ores in Dome Hill east of Iron fault

In the Oro La Plata mine sulphides were reached at a depth of 344 feet. In the Stevens shaft their depth is not known. All the other mines, including a long list on both sides of the Iron and Dome faults, were entirely in oxidized ore so far as known. The greatest depth attained by any shaft in the oxidized zone, 650 feet, was in the Coon Valley mine, west of the Iron fault. As shown on sections F–F′ and G–G′, Plate 15, the top of the sulphides pitches abruptly the actual depth of oxidation could not be seen. The Badger State and Lady Alice each showed sulphides in porphyry at a depth of 860 feet, and the Flagstaff at 400 feet; the Park Benton, 325 feet deep, was all in oxidized matter. As fairly uniform conditions may be assumed, it is probable that in this area as a whole the transition from oxide to sulphide occurred at depths ranging from 400 to 550 feet. The shafts are shown graphically in Figure 74.

BREECE HILL WEST OF WESTON FAULT

Breece Hill, west of the Weston fault, shows only Gray porphyry at the surface. In the workings of the Penn, Robert Burns, and Hunter mines this porphyry is underlain by sedimentary rocks, but south of the Penn mine it extends to great depth.

In the southern and eastern portions of this area oxidation appears to be relatively shallow (fig. 75), for pyrite appears a short distance from the portal in the Agwalt tunnel, at about 200 feet from the surface in the Antioch quarry, and at 200 feet also in the Banker shaft. The depth of oxidation is considerably greater in the Robert Burns and Forest Queen mines, which are near the Weston fault, but is still considerably less than in the mines to the northwest. Its greatest depth in the Penn mine, 350 feet, is in a vein. Pyritiferous porphyry forming the wall rock of the veins in this area is relatively unoxidized in many places, whereas the veins, which have afforded easier passage to descending waters, are oxidized to considerable depth. Oxidation as a whole, however, is much shallower in this area than in the others.

EVANS GULCH WEST OF WESTON FAULT

The Mammoth Placer and Pawnolos shafts, northeast of Yankee Hill, are the only ones that have reached sulphides in Evans Gulch west of the Weston fault. (See fig. 76.) The transition in the Mammoth Placer is sharp at a depth of 570 feet from the ground surface, or a little less than 500 feet below bedrock surface. This considerable depth beneath a glaciated valley is explained by the fact that glacial erosion has been relatively slight near the terminal moraine.

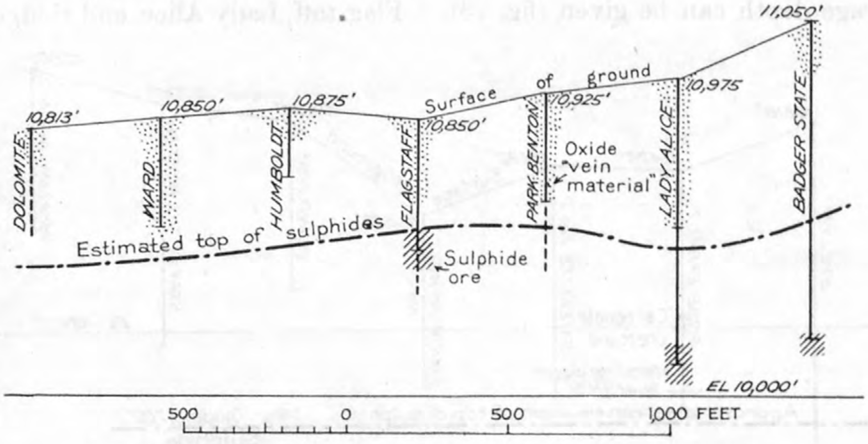


FIGURE 74.—Depth of oxidation in Adelaide Park and lower western slope of Breece Hill

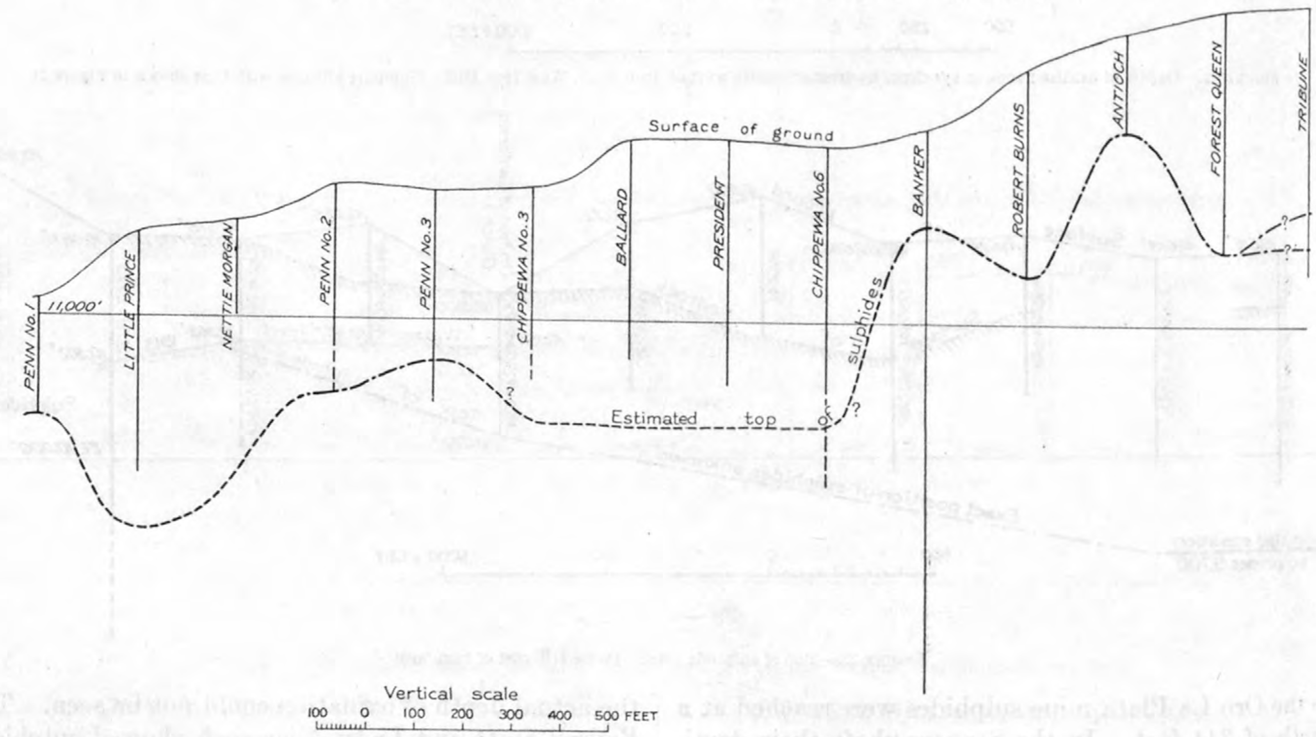


FIGURE 75.—Depth of oxidation in Breece Hill west of Weston fault

EVANS AND SOUTH EVANS GULCHES EAST OF WESTON FAULT

The depth of oxidation in the large area including Evans and South Evans gulches east of the Weston fault shows a wide variation, which expresses a cor-

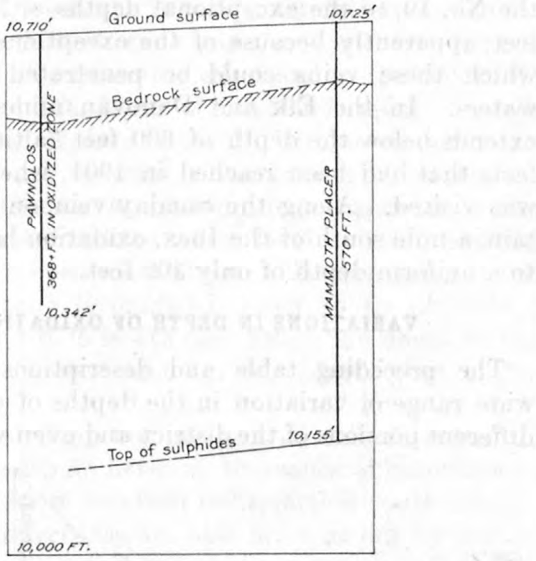


FIGURE 76.—Depth of oxidation beneath Evans Gulch west of Weston fault

responding variety in governing conditions (fig. 77). The greatest uniformity is attained on both sides of South Evans Gulch, along and opposite the base of Breece Hill, where according to available data the lower limit of oxidation averages about 11,000 feet

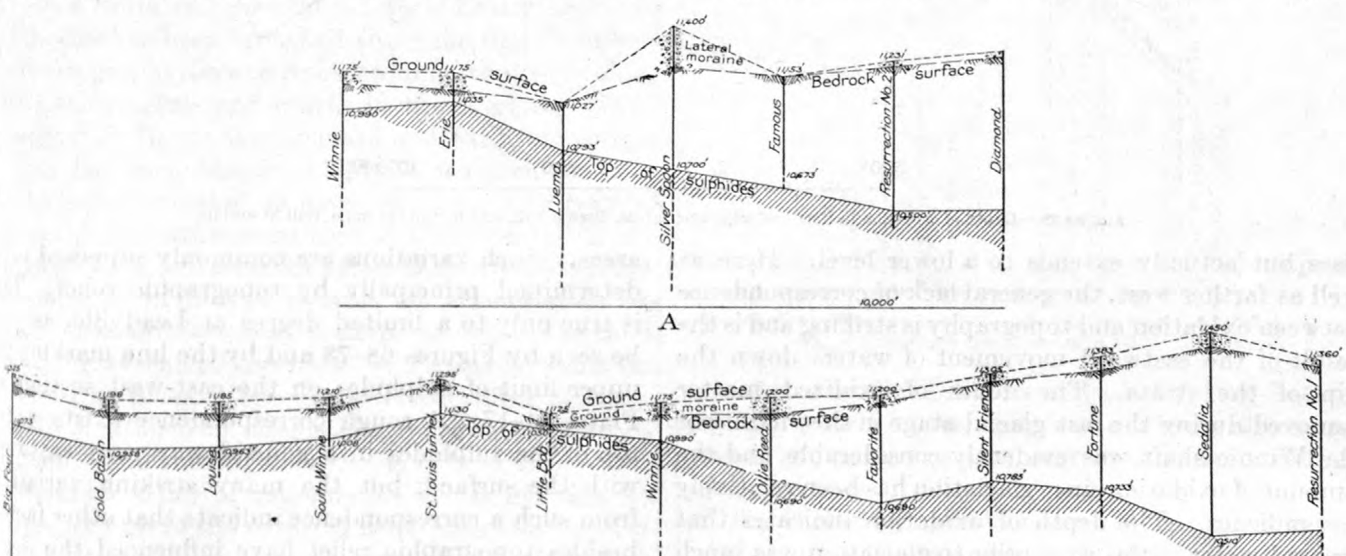


FIGURE 77.—Depth of oxidation beneath Evans and South Evans gulches east of Weston fault as shown by a northern east-west row of shafts (A) and a roughly parallel southern row (B)

above sea level. It ranges from 10,958 feet in the Gold Basin to 11,130 feet in the St. Louis tunnel at a point 400 feet south of the portal. This is the area of shallowest oxidation in the Leadville district, and the shallowness is probably due to a combination of causes, among which the steepness of slope, relatively high water level, predominance of siliceous or quartzitic rock, and intensity of glacial scouring are the most potent. The nearest approach of sulphides to the surface in the entire district, 75 feet, is found in a small vein near the Little Bob shaft. The greatest depth of their top below the surface in this area, 275 feet, occurs in the Big Four mine, but its altitude here is somewhat above the average, in conformity with the local contour of the bedrock surface. On the whole, however, the bottom of the oxidized zone tends rather to maintain uniform altitude than to vary in sympathy with the topographic relief.

In the Winnie-Luema vein, which is vertical and connected with the surface, oxidation might be expected to be deep on account of the ready access afforded to surface waters; but it is surprisingly shallow, its depth being 185 feet in the Winnie mine, 325 feet in the Luema, and less than 140 feet in the Erie (Chautauqua), which is on blanket ore close by and not on the vein. This relatively shallow oxidation is unquestionably due to the removal of the upper part of the oxidized zone by glacial erosion, an inference further supported by the increase in depth beneath the south edge of the north lateral moraine of the Evans Gulch glacier, which lies just outside the tract eroded by the glacier.

East of the Silver Spoon mine the lower limit of oxidation decreases in altitude, whereas the surface of the ground increases. At the Famous and Dolly B mines, in Evans Gulch, the ore was oxidized in the old workings to a depth of 480 to 500 feet, and the depth to the sulphides was almost as great as in the Diamond and Resurrection No. 2 mines. Only sulphide ore was found at the "first contact" in these mines, and the depth of oxidation is inferred to be from 750 to 800 feet (altitude about 10,500 feet.)

A similar though less regular increase in the depth of oxidation takes place east of the Winnie shaft. In the Ollie Reed, Favorite, and Silent Friend the average depth of oxidation is about 500 feet. In the Fortune mine a little sulphide ore was found at a depth of 650 feet (altitude, 10,733 feet), and in the Sedalia and Resurrection No. 1 at an average depth of about 900 feet (altitude, 10,530 feet). The altitude in the last two mines is very near that in the Resurrection No. 2 and Diamond mines, but exact data have not been obtained. In the Resurrection No. 1 the fifth level of the Little Ellen incline showed only oxidized ore, and the seventh level only sulphide ore. The sixth level, which should be near the transition, was inaccessible; its vertical depth below the surface was 890 feet and its altitude 10,560 feet.

Eastward from the Silver Spoon, Erie, and Winnie shafts oxidation not only becomes deeper as the surface rises, but actually extends to a lower level. Here, as well as farther west, the general lack of correspondence between oxidation and topography is striking and is the result of the eastward movement of waters down the dip of the strata. The depth of oxidized matter removed during the last glacial stage in the vicinity of the Winnie shaft was evidently considerable, and the amount of oxidation since glaciation has been relatively insignificant. The depth of oxidation indicates that ground water in this area prior to glaciation was much lower than at present.

BREECE HILL IN VICINITY OF IBEX MINE

In the Ibex and adjoining mines the top of the sulphides stands at a uniform altitude of about 11,125 feet (fig. 78). This means a depth of about 450 feet and applies equally to the blanket ore bodies and the veins connected with them where they are inclosed in walls of porphyry or sedimentary rock other than "Weber shales" and "Weber grits." Ores in the Weber (?) formation are oxidized only to depths of 160 feet (altitude 11,465 feet). The causes for this variation are explained on page 256.

Northwest of the Ibex No. 4 shaft oxidation has extended downward in two of the veins, the No. 4 and the No. 10, to the exceptional depths of 700 and 900 feet, apparently because of the exceptional ease with which these veins could be penetrated by surface waters. In the Elk and Donovan mines oxidation extends below the depth of 600 feet (altitude 10,900 feet) that had been reached in 1901, when the mine was visited. Along the Sunday vein, on Ball Mountain, a mile south of the Ibex, oxidation has extended to a uniform depth of only 300 feet.

VARIATIONS IN DEPTH OF OXIDATION

The preceding table and descriptions indicate a wide range of variation in the depths of oxidation in different portions of the district and even within small areas. Such variations are commonly supposed to be determined principally by topographic relief. This is true only to a limited degree at Leadville, as may be seen by Figures 68–78 and by the line marking the upper limit of sulphides on the east-west sections in Plates 14–17. A rough correspondence exists, as the top of the sulphides in a general way rises eastward with the surface; but the many striking variations from such a correspondence indicate that other factors besides topographic relief have influenced the depth of oxidation.

The causes of variation are geologic structure, the lithologic character of the country rock, the form and position of the ore body, and glacial erosion and deposition. The first three of these are considered in the following paragraphs. The fourth requires a preliminary understanding of the relation of oxidation to the geologic events of Tertiary and Pleistocene time and is discussed under the heading "Age of supergene alteration" (p. 272).

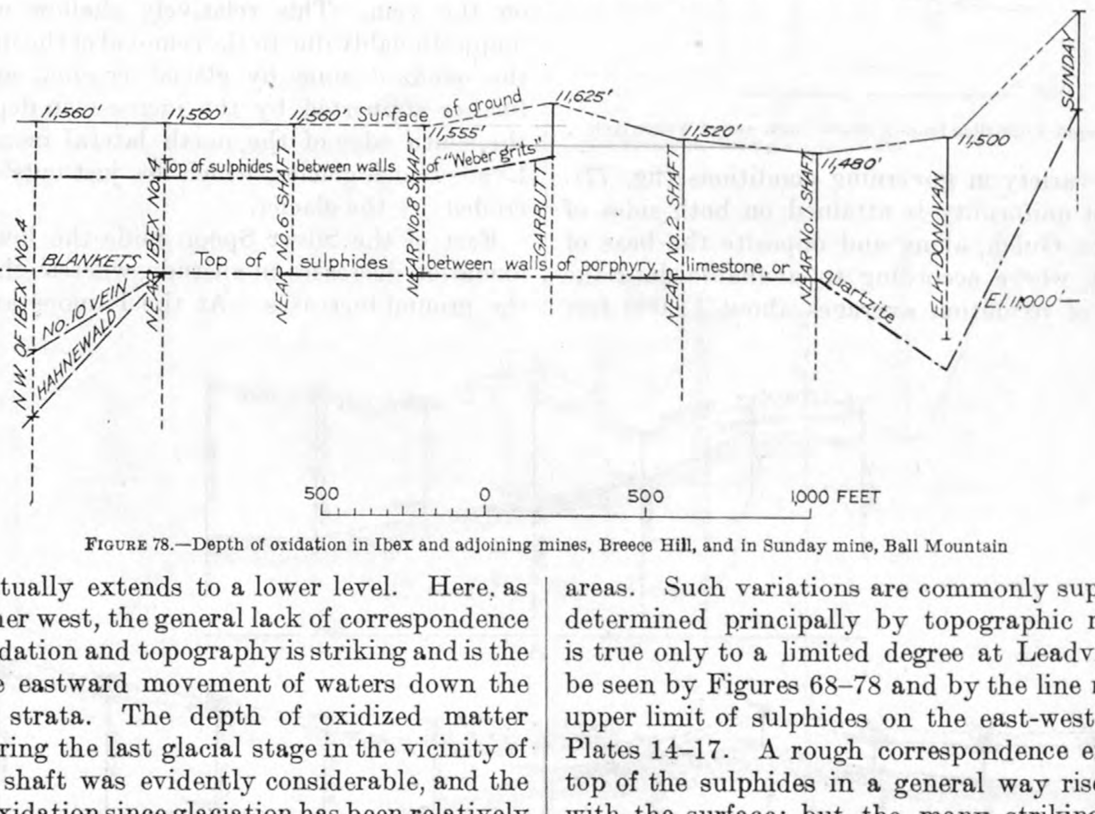


FIGURE 78.—Depth of oxidation in Ibex and adjoining mines, Breece Hill, and in Sunday mine, Ball Mountain

EFFECTS OF GEOLOGIC STRUCTURE

Faults.—The major faults with their impervious linings have served as dams between adjacent blocks of ground or hydrostatic basins, within each of which the water level, and therefore the depth of oxidation, has remained fairly uniform. The difference in altitude, 634 feet, between the depths of oxidation on the two sides of the Mikado fault (fig. 70) is probably the best evidence of this damming effect and of the lack of dependence of the depth of oxidation upon the local configuration of the surface. There as elsewhere the fault zone with its impervious borders of selvage has itself constituted an independent reservoir within which an intermediate water level and depth of oxidation have been maintained. The ore dragged into the fault zone is oxidized down to an altitude of 10,109 feet, which is 413 feet below the depth of oxidation on the east and 221 feet above that on the west.

Equally striking but not so well defined is the difference in altitude between the zones of oxidation on opposite sides of the Iron fault, farther south.

Similar differences are also brought out by Figures 79 and 80, which epitomize the data along two general east-west lines through northern Carbonate Hill and southern Iron Hill. The altitude of the lower limit of oxidation immediately east of the Pendery fault zone has not been closely determined because of the much higher altitude of the lowest ore zones, but it is well within the underlying granite.

Tilted strata and porphyry sheets.—Easier access to ore bodies has been furnished along the tilted contacts between porphyries and fractured limestone than along the smaller joints and cracks in the overlying White porphyry. Hence the circulation of oxidizing surface waters has been especially active along such contacts, and where downward progress was unusually easy, as beneath the northeastern part of Carbonate Hill and Graham Park and beneath Little Ellen Hill, oxidation extended to an unusual depth. Its accentuation beneath Graham Park may perhaps be due to the thick body of gravel and "lake beds" which there overlies the ore-bearing rocks. The characteristic effect of structural conditions on circulation, however, is scarcely perceptible in the large ore shoots of Iron Hill.

Isolated bodies of sulphide ore are found in a few places well up in the oxidized zone, where an impervious cap of porphyry or shale unusually free from fracturing has prevented access of oxidizing waters directly from above and where waters guided downward along the dip of the limestones have passed below.

EFFECTS OF PHYSICAL CHARACTER OF COUNTRY ROCK

The impermeability of porphyry and shale has just been cited as a factor preventing or retarding oxidation. The quartzites also are impervious, though evidently to a less degree than the porphyry and shale. Sulphides are found in these three kinds of rock comparatively near the surface—for example, in the stock at Breece Hill, where disseminated pyrite is found at very shallow depths in the less fractured porphyry, although it has been oxidized to a considerable depth along veins or fissure zones. In the Forest Queen and Chippewa shafts oxidation extends to a depth of 500 feet. The presence of oxidized ore replacing limestone beneath or within thick masses of pyritic porphyry is further

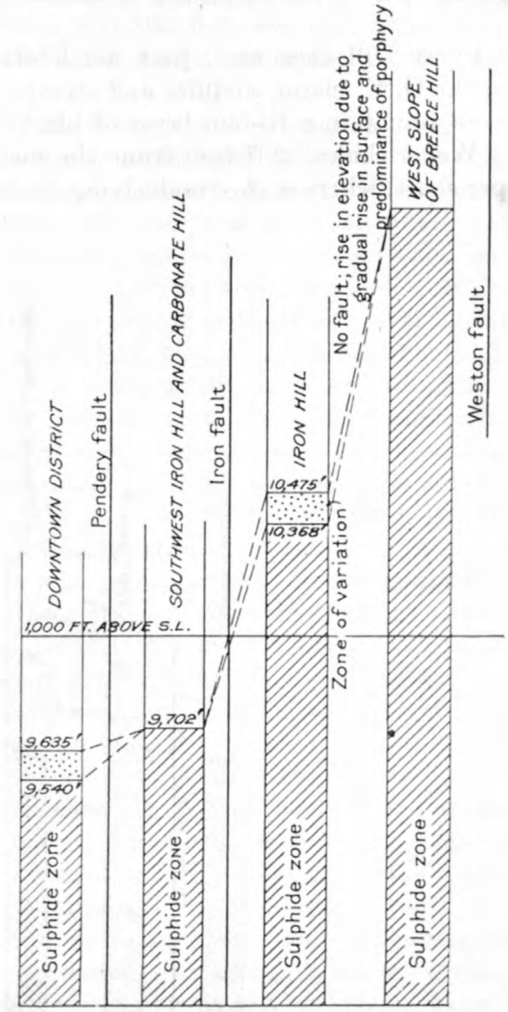


FIGURE 79.—Abrupt rise in altitude of sulphide zone due to faults and rise of ground surface from Downtown district to Antioch quarry

proof that oxidizing waters may pass for long distances along fractures in porphyry without being able to permeate the porphyry itself and to oxidize the disseminated pyrite.

The Weber (?) formation contains much black, coaly shale, which is not only impervious but apparently has a reducing effect on surface waters. Where veins pass through this shale, or blanket bodies are found replacing beds of grit between beds of shale, they have been protected from oxidation even though ores included in other rocks have, in the same locality, been thoroughly oxidized. In the Ibex mine near the No. 3 shaft the vein in the Weber (?) formation contains sulphide within 160 feet of the surface, whereas through the rest of the mine oxidation extends to a fairly uniform depth of 450 feet. In the Garbutt shaft, near the Ibex No. 3 shaft, veins of sulphide in the Weber (?) formation were found at 162 feet from the surface, and in the Negro Infant claim at about 65 feet from the surface, with small isolated patches even higher. So striking is this effect that on the first level of the Ibex mine, 200 feet below the surface, many veins may be followed across small faults separating the Weber (?) formation from the intrusive porphyries and observed to change abruptly from sulphides to oxides at the contact.

In the Fryer Hill area also, just north of Evans Gulch, on the O. K. claim, nodules and streaks of sulphides were found in a 10-foot layer of black carbonaceous "Weber shales" 207 feet from the surface in the Cooper shaft, whereas the underlying formations were all oxidized down to and beyond the bottom of the shaft, which was 294 feet deep.

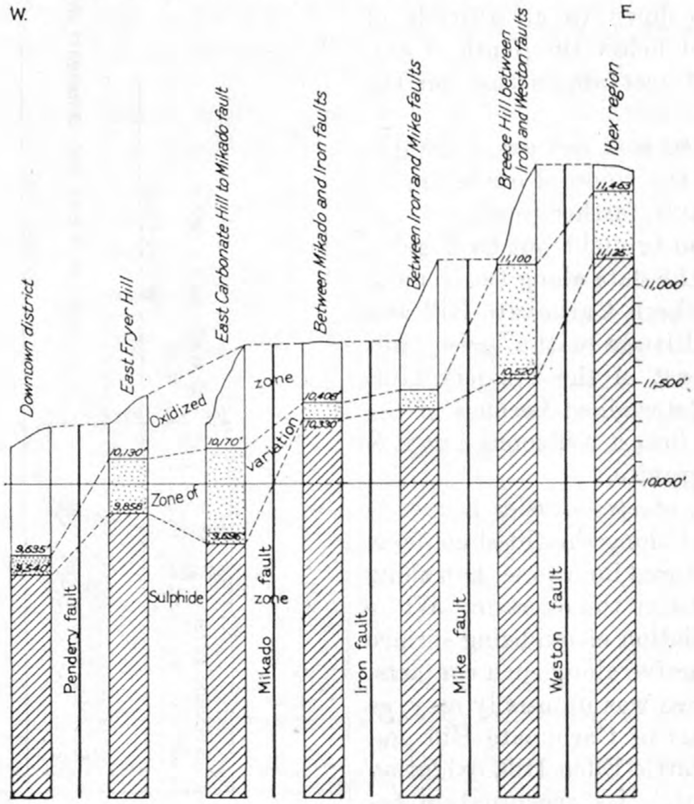


FIGURE 80.—Abrupt rise in altitude of oxidized zone on the upthrown side of each successive fault to a new hydrostatic basin

EFFECTS OF FORM AND POSITION OF ORE BODIES

In many places oxidation extends deeper along the lodes than along the blanket ores in their immediate vicinity, and the deepest traces of oxidation known are in some of the lodes of the Ibex mine on the 1,300-foot (Yak tunnel) level. In the same mine some of the larger veins are completely oxidized to depths of 700 to 900 feet, but general oxidation of blanket ore bodies extends to a depth of only 450 feet. In the Penn mine complete oxidation extends down into a vein to a depth of 350 feet or more, as against 235 feet in the associated blanket bodies, and traces of oxidation extend much deeper. Similar conditions exist in the Tucson mine. There are many places, however, where the depth of complete oxidation in both veins and blankets is at a common level.

In the veins that crop out complete oxidation is surprisingly shallow, as is illustrated by the Winnie-Luema, Little Bob-Louise, South Winnie, and Colorado Prince. Glaciation may be the cause of some of this shallowness but can hardly account for it all. In all such veins, however, oxides are mingled with the sulphides well below the depth of complete oxidation.

The reason for the ready penetration of some veins by surface water is easily found in the highly inclined channels of easy circulation which they afford. Where gouge or selvage is well developed the waters are confined to the veins and extend their chemical activity lower than where they mingle with the deoxidized ground water of the surrounding area. In areas like the upper Ibex, however, and in South Evans Gulch, the general permeability of the rocks as a whole has brought both veins and blankets under the governing influence of local ground-water conditions.

RELATION OF OXIDATION TO PRESENT GROUND-WATER LEVEL

Although ground-water levels originally differed in different hydrostatic basins, these differences were largely destroyed, very early in the history of the district, by the driving of drifts across the major fault zones. Reliable data regarding the original ground-water level are therefore limited to a few parts of the district and are particularly scarce in the areas drained by the Yak tunnel. The most significant data relate to the Downtown, East Fryer Hill, and Graham Park areas.

In the Downtown area the different mines were so completely connected both by natural watercourses and by workings that the vast amount of water was handled by an association supported by member companies in proportion to their output. Operations of nonmember companies were dependent on those of the association. After operations had been suspended for 25 months during the strike of 1896, water level stood at an altitude of 9,918 feet—a depth of 365 feet below the surface and 400 feet above the top of the sulphides.[48] Loose, stratified dolomite sand, deposited at the time the mines were flooded, was found filling the drifts at about the 9,725-foot level in the Weldon mine.

In the East Fryer Hill area the following accurate data were obtained by Emmons. The mines of this area were closed for a time in 1893, and again in June, 1896, at the time of the strike. Although pumping was resumed in the Downtown, Carbonate Hill, and Fryer Hill areas, the East Fryer Hill area was not materially affected, and the water stood for a long time at a fairly constant altitude, averaging 10,231 feet, or 330 feet below the surface, as shown in the following table:

Depth to water in shafts in East Fryer Hill area, 1893–1901

Shaft	Approximate altitude at ground surface (feet)	Date	Depth to water (feet)	
Bangkok-Cora Bell.	10, 559	April, 1893	327. 20	Av. 328. 00
		July, 1899	327. 80	
		June, 1901	329. 01	
El Paso	10, 580	April, 1893	346. 33	Av. 352. 88
		February, 1897	370. 00	
		July, 1899	347. 20	
		June, 1901	348. 00	
Joe Davis	10, 560	April, 1893		324. 80
Forepaugh	10, 565	do		335. 25
Olive Branch	10, 567	do		336. 20
Tip Top	10, 535	do		301. 20
				Av. 329. 72

Slight variations were noted in different years, the most noticeable in 1897, when the water level in the El Paso shaft for some unknown reason fell to a depth of 370 feet. With this exception the level was fairly constant. The range of about 50 feet in the distance from the surface to ground-water level is due mainly to the different altitude of the shafts. The upper limit of sulphides is about 100 feet below the average water level.

In the Maid mine the bottom of the oxidized zone is at an altitude of 9,980 feet, or 564 feet below the surface. The management states from past experience that if pumping in all the mines in the vicinity were discontinued the water would rise to an altitude of about 10,245 feet, or 265 feet above the bottom of the oxidized zone. This level appears abnormally high, compared with that in the Mikado mine. Here the pumps had kept the water down to an altitude of 9,295 feet until April, 1919, when pumping was suspended owing to a strike; by March, 1922, the water had risen to an altitude of 10,085 feet, and it remained approximately at that level until pumping was resumed in 1923.[49]

The differences in altitude of the water level in the three areas and its practically uniform altitude in East Fryer Hill in 1893 and 1896 show that these three areas are still practically independent of one another. The fact that the water levels are well above the bottoms of the respective oxidized zones can not, therefore, be attributed to the raising of the water level by tapping adjacent hydrostatic basins. It is possible that some workings in and east of the Pendery fault may have lowered the original water level of Carbonate Hill and raised that of the Downtown area to a minor degree, and in that case the difference between water level and depth of oxidation at Carbonate Hill before mining began was greater than that indicated above. There is no reason for suspecting connections between the East Fryer Hill and other hydrostatic basins, and the water level of 1893 and 1896 is regarded as the same as that existing prior to mining operations.

It therefore appears that the water level has risen since the major part of the oxidation was completed. The thick covering of glacial débris in the East Fryer Hill, Graham Park, and Downtown areas appears to be the cause of this rise in water level, both within these three areas and in the adjacent part of Carbonate Hill. The implication that oxidation took place before the last stage of glaciation is supported by the evidence presented on page 272, which shows that by far the greater part of the oxidation occurred in late Tertiary or early Pleistocene time.

If the water surface were lowered at every point in these western areas by an amount equal to the thickness of the overlying glacial débris, it would nearly coincide with the base of the oxidized zone. The great depths of oxidation beneath Little Ellen Hill and upper Evans Gulch, however, reach far below the water level that existed before the driving of the Yak tunnel, and that level must have been very shallow because of the abundance of rain and snow and the thickness of the White porphyry and Weber (?) formation, both of which tend to retain water. The difference between this shallow water level and the depth of oxidation can not be attributed to glacial deposits, as glacial erosion here exceeded deposition. Similar

[48] Eng. and Min. Jour., Oct. 22, 1898.

[49] Written communication from G. O. Argall, June 20, 1923.

though less striking differences occur in other parts of the district.

The prevailing lack of relation between water level and topography is due largely to the presence of limestone and dolomite, in which the development of open watercourses along fractures permits rapid descent of water to a common level within a hydrostatic basin, in contrast to the slow circulation along kaolinized fractures in impervious siliceous rocks. Had the limestones extended to great depth throughout the region, a nearly level ground-water surface would have been established beneath the whole area at an altitude near that of Arkansas and South Platte rivers, the principal lines of drainage. Such a condition exists in the Tintic district, Utah.[50] There, in spite of great topographic relief, water in the extensive limestone area stands approximately at the level of Utah Lake, in the main drainage basin 20 miles to the northeast; in the stock of igneous rock adjacent to the limestone it is much shallower, and in the area of volcanic flows which overlie the limestone there is a shallow water table well above the deep water table in the limestone. In the Leadville district the depth to which water could circulate rapidly within a hydrostatic basin was evidently limited by the positions of Cambrian quartzite and basal granite, and the fairly uniform water table was established in the limestones or overlying White porphyry at a level where the rate of slow escape through the bounding faults equaled the rate of supply. The supply of water before the last stage of glaciation was evidently much less than at present, and the local water table in each basin was correspondingly lower.

ZONE OF SULPHIDE ENRICHMENT

The zone of sulphide enrichment in the Leadville district is nearly everywhere poorly defined. At most places where oxidized ore passes gradually into sulphide ore oxides, primary sulphides, and secondary sulphides occur together. The only conspicuous secondary sulphide is sooty chalcocite. This mineral forms coatings around chalcopyrite, which it may partly or completely replace; it also coats pyrite, and thin films of chalcocite or covellite are found on zinc blende. The chalcocite is accompanied by considerable quantities of invisible silver and is regarded as a good indication of silver. It may also be accompanied by gold, although the most striking occurrences of gold are fracture fillings in zinc blende. Where chalcocite is absent the presence of white claylike gangue accompanying sulphides is an indication of alteration and perhaps enrichment by descending waters.

Enriched sulphide ore is far more common in the veins than in the blanket ore bodies, because, as already stated, downward circulation along the veins is confined between their gouge walls, and practically all the metals carried downward in solution have an opportunity to be redeposited by reaction with the primary sulphides; furthermore, owing to the nearly vertical position of the veins the metals originally above the present erosion surface were largely preserved by transfer and redeposition at lower levels. Downward circulation in the nearly horizontal deposits, however, has carried much of the soluble metal compounds into the siliceous or carbonate rock below, where there is little or no opportunity to react with appreciable quantities of primary sulphides, and in this way metals formerly above the present erosion surface have in large part been lost. Downward circulation in sulphide blanket ore bodies is likely to follow local fractures, where any enrichment, though appreciable in itself, may add but a negligible proportion to the value of the ore body as a whole.

In the Greenback mine the lower blanket ore body consists of low-grade pyrite, which is locally enriched in silver. Below this blanket and above the vein exposed on the seventh level several stringers rich in silver were reported. The vein in the seventh level was also enriched and contained some chalcocite staining and claylike gangue. Similar evidence of enrichment was found on the ninth level of the Cord mine in the vein and stockworks beneath the blanket ore bodies, but some of the rich ore there showed no visible evidence of enrichment. These two occurrences, however, prove that where structural conditions are favorable sulphide enrichment has taken place in or below blanket ore bodies.

It has sometimes been supposed that the primary ores in the Blue limestone are more valuable than those in the White limestone; but the only evidence in support of this opinion is the greater amount of siliceous impurity in the White limestone, which commonly has escaped replacement. Bodies of low-grade pyrite in the Greenback and Mahala mines have replaced White limestone, whereas similar material in the Diamond mine has replaced Blue limestone. Bodies of zinc sulphide ore in each limestone are essentially identical in metal contents. It is true that in the western part of the district the ores in the Blue limestone, largely because of oxidation, have been more valuable than those in the White limestone, but sulphide enrichment, though comparatively scarce, is more marked below the Blue limestone. In the eastern part of the district sulphide enrichment is evident in both limestones as well as in the siliceous rocks.

TRANSITION BETWEEN OXIDIZED AND SULPHIDE ZONES

The bottom of the oxidized zone is very irregular in detail, and even in those localities, such as Iron and East Fryer hills, where it exhibits the nearest approach to uniformity, depressions and irregularities are common. Locally the transition from oxides to sulphides takes place within a very few feet, but for the most

[50] Lindgren, Waldemar, and Loughlin, G.F., Geology and ore deposits of the Tintic mining district, Utah: U. S. Geol. Survey Prof. Paper 107, pp. 19, 123, 1919.

part it is gradual. In nearly all the mines remnants of sulphides wholly surrounded by oxidizing material occur far up in the oxidized zone. Galena, protected from complete oxidation by comparatively insoluble coatings of lead carbonate and sulphate, is especially likely to occur in this manner and was frequently found in the highest ore bodies of the Fryer Hill mines. Pyrite, chalcocite, and rarely the bismuth-silver intergrowth "lillianite," occur in the same manner; but zinc blende is never found so isolated, as the sulphate to which it oxidizes is very soluble and readily removed, leaving the blende subject to continuous attack. For this reason the blende has been entirely removed from certain mixed sulphide bodies in which the other minerals have been little affected.

Here and there sulphide masses of considerable size survive because of local protection, although the ores below them are completely oxidized. For example, an ore shoot mined on the fourth level of the A. Y. and Minnie mine, in Iron Hill, consisted of porous carbonate ores, although sulphides remained above, where the locally impervious cap of porphyry and selvage had protected them.

On the other hand, oxidation extends down along marginal cracks and fissures and even on the under sides of blanket bodies for considerable distances below the general level of oxidation—for example, traces of oxidation have been found in some of the veins of the Ibex mine as far down as the 1,300-foot or Yak tunnel level; but these downward extensions do not usually extend more than 200 feet below the point at which the sulphides first appear.

In this transition zone ore bodies that contain nearly equal amounts of oxides and sulphides are common. Such an ore body, wholly inclosed in White porphyry and composed of mixed sulphides through which completely oxidized material intricately ramified, was found in the Moyer mine. Some of the oxidized matter was high in iron and some high in lead, but nearly all the zinc had been removed and carried below.

Some veins are partly oxidized along the walls but contain streaks of sulphides in the middle; others, seen in the Penn, Ibex, and other mines, contain oxides in the center and sulphides along the walls.

The blanket ore bodies are usually attacked first at the top, even where protected by overlying porphyry, but numerous exceptions to this rule are found. Thus in the Gonabrod mine a shell of oxidized ore surrounded a mass of sulphide ore which was quite free from alteration.

In many places oxidation extends down to some particular stratum of shale or quartzite, where it ceases abruptly. Thus in the Ulster Newton mine the ore is all carbonate and oxide down to the Parting quartzite, but beneath this quartzite and its shaly and impermeable transition beds there is an abrupt change to sulphides. Similar abrupt changes take place at certain sheets of Gray and White porphyry. In general, however, oxidation appears to be more nearly related to height above sea level than to the structure of the inclosing rock. Thus in the Maid, Wolftone, Evening Star, and adjacent mines region it transgresses the eastward-dipping sediments from the White porphyry on the east to and into the Lower or Cambrian quartzite on the west.

At some places thoroughly oxidized ore with no residual nuclei of partly oxidized sulphides passes unexpectedly into sulphide ore that shows no trace of oxidation. The transition in several places is marked by open caves partly filled with carbonates and oxides, which are underlain by loose pyrite sand. Native silver is likely to appear in considerable quantity just before the sulphides are reached and continues into the partly disintegrated sulphides, as in the El Paso, Olive Branch, and Cora Bell mines, at East Fryer Hill, and the Oro La Plata mine, at Rock Hill.

The most noteworthy example of sudden transition from oxides to sulphides occurs at Iron Hill and is described by Blow[51] as follows (see also fig. 81):

On Iron Hill the change from carbonates to sulphides occurs so rapidly that the miner is suddenly surprised by finding himself out of a body of fine oxidized smelting ore and in a close-grained refractory sulphide, consisting principally of zinc and iron sulphides, with sulphide of lead in small quantities. By close observation, however, this point of transition of the ore shoots can be accurately predicted. With the ore under consideration these indications are identical with those in numerous other instances observed in other mining districts. It is first noted that the carbonates become more "patchy" or occur in vugs and caves. Among the iron oxides sulphide of iron next makes its appearance in similar pockets and vugs, and open caves are of frequent occurrence. The iron pyrites first appear in a soft friable ore in a semioxidized condition, or generally as a clean pyrite sand with quartz crystals, which is always found in the bottom of the chute under heavy lead carbonates. The carbonate ore, though showing no change which can be detected by the eye, is here found to contain from 2 to 8 per cent of zinc but with no increase of sulphur, the zinc occurring mostly as a silicate.

In the immediate vicinity of the sulphides the ores are distributed in a loose, porous mass of iron oxides, in which open caves are invariably found. These caves, which are caused partly by the shrinking of the original ore body in oxidation and more largely by the removal and partial redeposition of the zinc, are surrounded on all sides by cerusite crystals of different sizes and varying in color from perfectly white to nearly black, the latter being colored by oxides of iron. In the bottom of the caves heavy lead ores are found, and, underlying them, the pyritiferous sand, resembling carefully sized concentrates, occurs and can be spaded out like sea sand. Beyond these regions of change and alteration in physical condition the ore shoots pass suddenly, as before stated, into the unaltered sulphides.

Where the transition zone is more gradual, bodies of loose pyrite sand may continue far below the level of the recognized oxidized zone. In the two main veins of the Ibex mine great quantities of pyrite sand

[51] Blow, A. A., Am. Inst. Min. Eng. Trans., vol. 18, p. 145, 1890.

were found, and much of it was mingled with loose particles of iron sulphate and copper sulphate, the latter often serving to raise the copper content materially. Crumbly masses of zinc blende have also been noted and evidently mark the very beginning of oxidation where water had penetrated among the grains and had begun to corrode their surfaces.

PROCESSES OF ALTERATION

COMPOSITION OF DESCENDING WATERS

The soils of the Leadville district, as of other districts in the West, doubtless contained appreciable quantities of alkali chlorides, bromides, and iodides, deposited by winds. These compounds were readily dissolved by rain water, which had already dissolved considerable oxygen and carbon dioxide from the air. The amount of these alkali salts in solution at any one time was never large, but continual additions to the supply in the soil made the aggregate amount considerable. Organic compounds in the soil were doubtless dissolved by the water and may have increased its ability to attack the minerals of the soil and underlying rocks, but none of the alteration products in the ores or wall rock can be attributed to organic compounds.

When the water descended through the soil into pyritized porphyry or "Weber grits," it oxidized the pyrite to ferrous and ferric sulphates and sulphuric acid. The sulphuric acid thus derived was partly consumed by reaction with feldspars, sericite, chlorite, and calcite, the last increasing the amount of carbon dioxide in the water. The other minerals were in part removed as soluble sulphates of alumina, alkalies and alkaline earths, and soluble silica and in part remained along the watercourses as kaolin or similar hydrous silicates of alumina. While the descending solutions were still dilute the iron sulphates in the presence of the dissolved oxygen tended to decompose into hydrous oxides, which were deposited with kaolin along the watercourses, and sulphuric acid, which further increased the power of the water to attack the rock. So long as sulphuric acid was available the carbon dioxide did not attack the rock minerals appreciably, but by combining to a certain degree with the dissolved constituents to form bicarbonates it released a corresponding amount of sulphuric acid for renewed attack on the rock minerals.

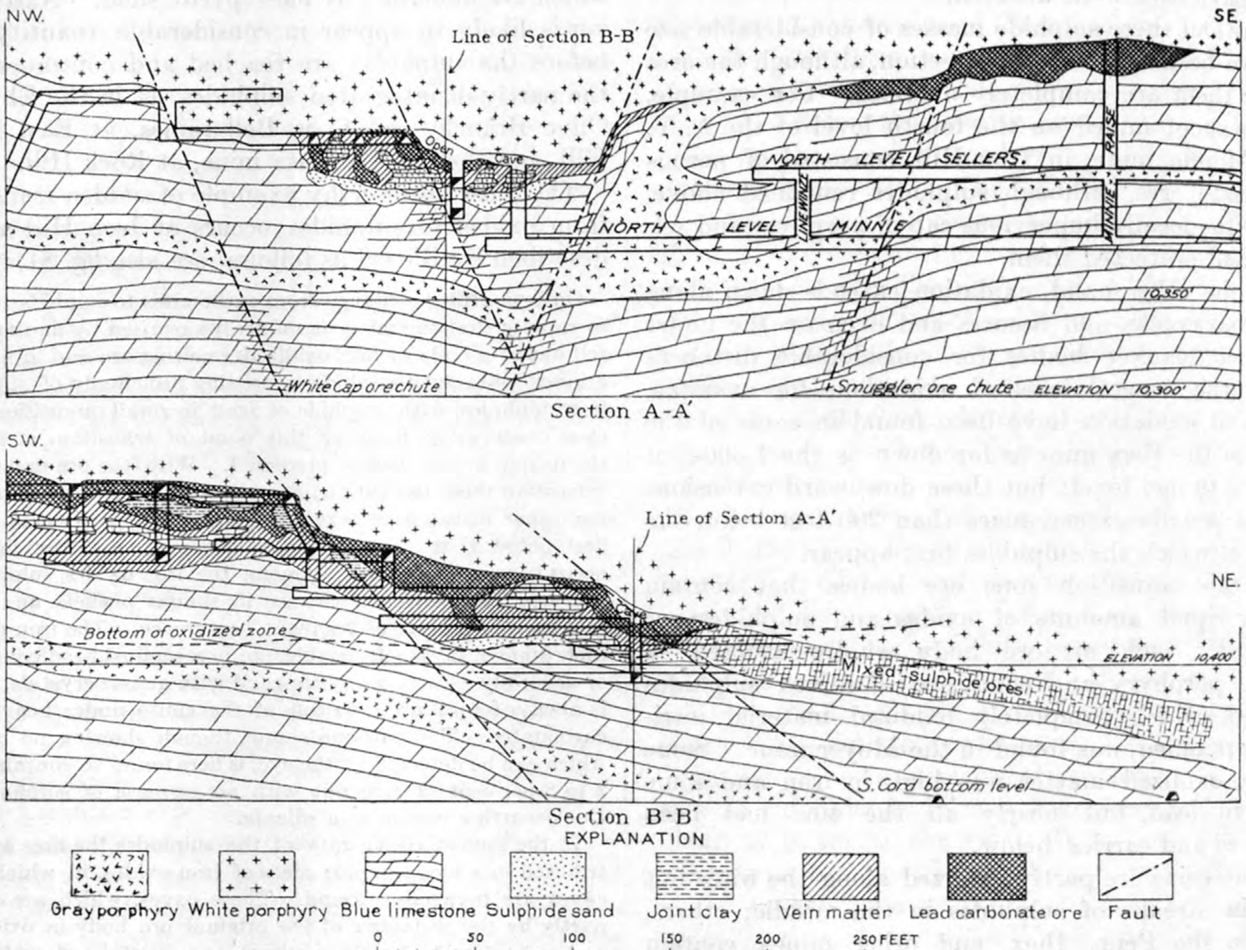


FIGURE 81.—Cross section and longitudinal section of White Cap ore shoot, showing transition from oxidized to sulphide ore. (After A. A. Blow, op. cit., pl. 5)

ALTERATION OF LIMESTONE AND MANGANOSIDERITE BY DESCENDING WATERS

During the early stages of the process above outlined free oxygen and sulphuric acid may have become exhausted before the descending solutions reached the limestone or ore beneath the porphyry or Weber (?) formation. Eventually, however, the rocks near the surface became thoroughly oxidized along the watercourses, and free oxygen was carried down to take part in reactions that produced new supplies of sulphuric acid. The solutions at this stage probably contained considerable quantities of alkalies, alkaline earths, carbon dioxide, and oxygen, together with larger quantities of the two iron sulphates and sulphuric acid. The presence of alkalies and alkaline earths may have exerted some influence in accelerating the processes of solution and deposition, as suggested by Nishihara.[52] Minor quantities of alumina and silica also were doubtless present in solution, as indicated by the composition of many mine waters that have percolated through pyritized siliceous rocks.[53] Where the solution descended into carbonate rock, this acid was quickly neutralized by the formation of soluble sulphates and a corresponding amount of carbon dioxide.

When the reaction was completed ferric sulphate (or ferrous sulphate plus oxygen) reacted with the carbonate rock, forming limonite and further increasing the supply of carbon dioxide and of dissolved sulphates of lime, magnesia, and manganese. This reaction was followed by a similar reaction between the carbonate rock and aluminum sulphates and silica, which resulted in replacement of the rock by kaolin or similar hydrous aluminum silicates and dense flinty silica; but this supergene silica is readily confused with original or hypogene silica. Under some conditions, presumably where the amount of silica was deficient or where the concentration of alkali and aluminum sulphates was high, the carbonate rock was replaced by alunite. Higher concentration of alkali and iron sulphates caused replacement of carbonate rock by jarosite.

Owing to the similarity in appearance between the hydrous aluminum silicates and alunite and between the paler varieties of limonite and jarosite, they could be distinguished with certainty only by chemical analysis, and their relative abundance and relations to each other were not determined. Limonite was evidently the most stable of these minerals, and as new supplies of solution arrived the other minerals were veined, impregnated, or even considerably replaced by limonite. They also were veined in places by black manganese oxides derived in small part from the porphyry and in part formed by reaction between the solution and manganosiderite. This combination of hydrous iron oxides and aluminum silicates, free silica, and minor quantities of jarosite, alunite, and manganese oxide constitutes most of the "vein material" or "contact matter" found between the Blue limestone and the overlying siliceous rocks in the oxidized zone.

This "contact matter," though abundant near "first contact" ore bodies, is also abundant at considerable distances from them. It is obviously independent of ore bodies and is roughly coextensive with the pyritized siliceous rocks above it. It has a very small, variable content of silver, which was evidently derived from disseminated pyrite grains and small veinlets in the overlying siliceous rocks and deposited as chloride. In some places, as in the Evening Star mine, the silver chloride was deposited in the porphyry before the solution carrying it reached the limestone contact. "Contact matter" or "vein material" found beneath oxidized ore bodies has been derived wholly or in part from those ore bodies and will be referred to later.

The descending waters, after having completed the reactions whereby they deposited "contact matter" and increased their content of carbon dioxide or of other acid radicles, were able to permeate and corrode the Blue limestone and reduce it to dolomite sand until the dissolved carbon dioxide was consumed in the formation of soluble bicarbonates. The White limestone was similarly reduced by these acid waters, but less extensively because of its low position.

ALTERATION OF ORES BY DESCENDING WATERS

SOLUTION OF PRIMARY SULPHIDES

Study of the sulphide ores in the Leadville district and of similar ores in other districts shows that the sulphides most readily removed are destroyed first. Zinc blende is the first of the ore minerals to be removed by oxidation and may be nearly or quite all removed before the other sulphides are attacked to any considerable extent, although the rapidity and thoroughness of removal would obviously depend on the degree to which oxidizing solutions could permeate the ore.

Of the other sulphides galena is the most protected from oxidation, owing to the insolubility of the sulphate that forms around it. Owing to the scarcity of chalcopyrite at Leadville, there are no definite data at hand regarding its relative liability to oxidation. Observations of ores in other districts favor the view that chalcopyrite underwent oxidation before the pyrite and after the zinc blende—a view that accords with the occurrence of copper in the oxidized zinc ores at Leadville and with the interpretation of their genesis but does not harmonize with the results of certain

[52] Nishihara, G. S., Geology and ore depcsits of the Tetiuxe district, Russia: Econ. Geology, vol. 12, pp. 277-278, 1917.

[53] Analyses of 37 such waters are tabulated and discussed by W. H. Emmons in U. S. Geol. Survey Bull. 529, pp. 60-74, 1913.

experiments,[54] which, however, were made under conditions differing considerably from those governing the oxidation of the Leadville ores.

These experiments have been described and discussed by W. H. Emmons,[55] who makes the following concluding statement: "All these experiments and observations seem to indicate that in the zone of oxidation in many deposits the sulphides are dissolved in the following order: Sphalerite (?), chalcocite, pyrrhotite, chalcopyrite, pyrite, galena, enargite." The positions of sphalerite, chalcopyrite, pyrite, and galena in this order accord with observations made by the writer (Loughlin).

Where a solution containing free sulphuric acid descended from the overlying siliceous rocks directly into an ore body the acid was neutralized by reaction with zinc blende or carbonate gangue. Structural conditions, however, were such that most ore bodies, even at the top of the Blue limestone, were attacked by a combination of solutions coming in part direct from the overlying porphyry or the Weber (?) formation and in part from the limestone. After any free sulphuric acid was neutralized the zinc blende reacted with ferric sulphate and formed soluble zinc sulphate and ferrous sulphate and free sulphuric acid, the last continuing the attack on zinc blende. It is doubtful if carbon dioxide exerted much solvent action upon zinc blende so long as sulphuric acid, ferric sulphate, and oxygen were present in excess, for zinc sulphate is much more soluble than zinc carbonate. Where descending waters have evaporated in the Leadville mines deposits of the zinc sulphate, goslarite, have been found, but none of zinc carbonate. Carbon dioxide, however, may have aided solution indirectly by combining with a certain amount of dissolved zinc to form the soluble bicarbonate and releasing an equivalent amount of the sulphate radicle for further removal of zinc blende.

Experiments by Gottschalk and Buehler[56] have shown that although zinc blende alone when leached by water is oxidized very slowly, the process is hastened if the water has first descended through pyrite or marcasite—that is, if it has first become charged with sulphuric acid and ferric sulphate. They have shown also that oxidation is much more rapid if the blende is in contact with the galena or—still better—with pyrite, the oxidation being accelerated by electrolytic action. The water used in these experiments is not strictly analogous in composition to the ground waters that had descended through the pyritized porphyries of Leadville, but the results of the experiments accord with those of the natural process. Whatever the exact reactions were, the zinc blende was oxidized before the other two sulphides, and there is little doubt that the zinc and iron of the zinc blende were removed as sulphate.

The supply of free oxygen in these solutions probably became exhausted at an early stage of the process, and it may be that more or less sulphuric acid and ferric sulphate were still available for further reactions. Experiments by R. C. Wells[57] have shown that sulphuric acid out of contact with air dissolves zinc blende more readily than it dissolves galena, pyrite, or chalcopyrite, converting the zinc to sulphate and liberating hydrogen sulphide. The hydrogen sulphide, if free to escape upward, could finally reach the zone of free oxygen, oxidize, and thus tend to renew the supply of sulphuric acid; if not free to escape it could, after the sulphuric acid had become exhausted, possibly succeed in reprecipitating some of the zinc as the hexagonal sulphide, wurtzite, but no evidence has been found to show that this reaction has taken place in the Leadville deposits. Ferric sulphate, out of contact with air, could also convert the zinc and iron in zinc blende to sulphates, setting free sulphur and itself changing to ferrous sulphate. The disposition of the free sulphur under these conditions is questionable, but there is nothing to indicate that it played a conspicuous part in the supergene processes at Leadville. If these reactions took place after the free oxygen in the descending waters had become exhausted, they must have served to supplement the reactions which had taken place before, by increasing the amount of zinc sulphate and ferrous sulphate already in solution.

This removal of zinc blende was illustrated at the transition from oxidized to sulphide ore below the fourth level of the Tucson mine. There the original sulphide ore contained considerable blende, but the leached ore, which extended downward for some distance below the oxidized ore, had lost its blende without appreciable solution of the other sulphides, which remained as a porous, crumbly mass. The loose pyritic sand mentioned in Blow's description, quoted on page 259, is doubtless due to the removal of zinc blende. Another striking illustration of this process was noted in a large body of mixed sulphide ore surrounded by White porphyry 50 feet above the second level of the Moyer mine. The upper 2 feet of the ore body is completely oxidized and connects downward with small to large irregular branches of oxidized ore, one

[54] Emmons, W. H., The enrichment of sulphide ores: U. S. Geol. Survey Bull. 529, pp. 76–78, 1913.

[55] Idem, p. 78.

[56] Gottschalk, V. H., and Buehler, H. A., Oxidation of sulphides: Econ. Geology, vol. 5, pp. 28–36, 1910; vol. 7, pp. 15–34, 1912.

[57] Emmons, W. H., op. cit., pp. 59, 76.

of which is represented in Figure 82. These consist of brown to red iron oxide locally darkened by manganese oxide and accompanied by varying quantities of lead carbonate. Zinc in the surrounding sulphide ore amounts to about 30 per cent, but in the oxidized ore it usually runs not over 3 per cent, though rarely 7 per cent. Similar evidence could be cited throughout the district, and the absence of zinc in the oxidized ore was commented on by Emmons.[58]

Chalcopyrite, so far as scanty evidence shows, behaved similarly to zinc blende. It was converted into a soluble sulphate and carried downward.

The large quantities of pyrite in pyritic and mixed sulphide ores underwent the same changes as the disseminated pyrite in the overlying siliceous rocks and increased or renewed the quantity of ferric sulphate and sulphuric acid available for attack on ore, gangue, and country rock below it. A certain amount of its iron was converted into hydrous oxide and remained

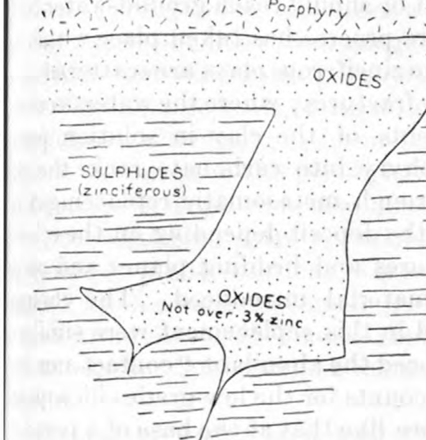


FIGURE 82.—Section of irregular oxidized part of a mixed sulphide ore body, 50 feet above second level of Moyer mine. Illustrates removal of zinc during oxidation

practically in place, staining lead carbonate or siliceous gangue, or forming comparatively pure masses. The proportion of iron that remained as oxide depended upon the supply of oxygen and the concentration of iron and sulphate radicles in the water.[59] The remainder of the iron was carried downward as ferric and ferrous sulphates.

Galena alone begins to oxidize more readily than either zinc blende or pyrite, but it is surrounded almost immediately by a relatively insoluble coating of lead sulphate and carbonate, which so retards its further decomposition that it is the last of the conspicuous sulphides to be destroyed; it therefore commonly occurs as residual nodules in otherwise completely oxidized ore. The ease with which it begins to oxidize may account for the small quantities of cerusite and anglesite that line vugs and fractures at some distance from oxidized ore bodies, and also for the large masses of the lead-iron sulphate plumbojarosite that are found below the shoots of lead carbonate.

By far the greater part of the lead in the original galena was converted to sulphate by reaction with sulphuric acid or ferric sulphate and deposited without appreciable change in position. The sulphate, however, was readily attacked by the excess carbon dioxide in the descending water and converted into the even more insoluble carbonate. The behavior of lead and of zinc during oxidation was thus extremely different, the one remaining almost wholly in place and the other being entirely removed.

Bismuthinite, present in the intergrowth "lillianite," behaved like galena, inasmuch as it soon became coated with the insoluble carbonate, bismutite, and oxide, bismite, which protected it from further rapid oxidation. Scattered residual nodules of "lillianite" are present, therefore, in otherwise thoroughly oxidized ore. These oxidation products contain little or no silver, which must have been removed in solution from the argentite of the "lillianite," presumably as sulphate. Argentite elsewhere was oxidized to sulphate and carried downward to some extent, but the alkali chlorides, bromides, and iodides in the descending water promptly reacted with part of it and caused its deposition as horn silver.

Gold also was dissolved and carried downward to a considerable extent, particularly in the veins, where concentration of primary gold was greatest. The best-known agent for the solution of gold in nature is chlorine, generated by reaction between hydrochloric acid (or alkali chlorides?) and manganese dioxide, as explained by W. H. Emmons.[60] Manganese is present throughout the district in the porphyries and in manganosiderite, and it is converted to one of its black oxides in the same general way that ferric oxides are formed in the oxidized zone. As water containing chlorides descends from the surface and comes into contact with the manganese oxides chlorine is generated and readily takes gold into solution. The removal of gold from the oxidized zone therefore takes place after the processes of oxidation are rather well advanced, and the amount removed depends upon the opportunity for free chlorine to form. Gold may also have been dissolved and removed by other processes that are not yet understood. Where the supply of chlorine or other dissolving agents was deficient the gold remained as residual specks in the thoroughly oxidized ore, and by partial removal of other metals and gangue the content of gold remaining

[58] U. S. Geol. Survey Mon. 12, pp. 376, 389, 398, 547, 550, 556, 557, 560, 1886.

[59] Posnjak, Eugen, and Merwin, H. E., The system Fe_2O_3-SO_3-H_2O: Am. Chem. Soc. Jour., vol. 44(2), p. 1992, 1922.

[60] Emmons, W. H., The agency of manganese in the superficial alteration and secondary enrichment of gold deposits in the United States: Am. Inst. Min. Eng. Bull. 46, pp. 789-791, 1910.

may have been raised to commercial grade. The character of the richer gold ores, however, indicates that most of it is the result of concentration by leaching and redeposition.

REDEPOSITION AS PRODUCTS OF OXIDATION

Redeposition in the oxidized zone may take place by hydration and oxidation of the solutions, desiccation or evaporation, replacement of the wall rock, and reaction between different solutions. The first process as already stated, has been important in the deposition of lead carbonate, of iron oxide in the place of original pyrite, and, along watercourses, of iron-manganese oxides in place of manganosiderite, and it accounts for certain minor minerals; the second accounts for the exceptional deposits of copper sulphate in the Ibex mine, for crusts of calcite along cavities in oxidized ore, and for accumulations of such soluble sulphates as melanterite, goslarite, and epsomite in mine workings; the third accounts for the principal deposits of zinc carbonate and to some extent for deposits of iron and manganese oxides, as well as for "contact matter"; the fourth accounts for native silver and gold and may have contributed to the deposition of zinc-bearing clays.

As the oxidation of the sulphides took place in stages, the redeposition of materials may be conveniently considered in corresponding stages.

ZINC CARBONATE STAGE

Where the water, after taking zinc sulphate into solution, became locally supersaturated through desiccation, while still in the sulphide body or in a porphyry sill beneath the sulphide body, goslarite was formed (and is being formed) as a lining of fissures and other openings. Such deposits are only temporary, being redissolved sooner or later by unsaturated waters.

Where the waters pass through the sulphide bodies into underlying rocks two sets of conditions may be considered, according as this rock is siliceous or carbonate. Each of these sets of conditions may be subdivided into two phases—one in which the free sulphuric acid and ferric sulphate have not been exhausted and one in which they have been exhausted. If the underlying rock is sericitized porphyry, and sulphuric acid and ferric sulphate are present, either or both of these reagents will tend to decompose the sericite and any unaltered feldspar in the porphyry, taking into solution silica and sulphates of alumina and alkalies. The alumina and silica will tend to be precipitated again, perhaps without having traveled for any considerable distance, as kaolin or material of similar composition and appearance. This process will also cause the deposition of an indefinite amount of zinc and result in the formation of zinciferous clay. Whether the zinc is deposited simultaneously with the other materials as a primary constituent of the clay or through the replacement of aluminum in clay previously deposited is an open question. It seems probable that where the zinc in such clay is abundant it is a primary constituent, and that where it is sparingly present it is either the result of replacement or a primary constituent of clay deposited from a solution poor in zinc. The origin of the iron and manganese oxides locally present in these clays is obscured by their segregation, since their deposition, into patches and streaks. They, like the zinc, may have been original or secondary (adsorbed) constituents of the clay. Under all these suppositions the precipitation of aluminum and zinc compounds from solution may imply the liberation of a corresponding amount of sulphate radicle and the renewal of sulphuric acid capable of dissolving new portions of the rock and tending to repeat the process until the water itself should become exhausted or should reach ground-water level.

Where the entire process has taken place within the porphyry mass, the zinciferous clays are scattered along fissures and minor fractures; where the waters containing the constituents of the clay in solution passed through the porphyry into carbonate rock, the clay was deposited through metasomatic replacement, the size and shape of the deposit depending on the relative openness of fractures and bedding planes and on the amount of clay material introduced. The chemical reactions involved in this replacement were similar to those which produced the abundant "contact matter."

This process accounts for the low-grade siliceous and argillaceous zinc ore like that at the base of a porphyry sill in the Belgian mine. (See fig. 268.) This ore contains veinlets and vugs lined or filled with calamine, which was deposited with and just after the clay and appears to represent the excess of zinc over that which could be contained by the clay. The opal and chalcedony closely associated with the calamine represent a further excess of silica. The presence of calamine appears also to indicate that sulphuric acid and ferric sulphate had become exhausted, and that zinc sulphate in the neutralized solution, concentrated by depletion of the water, could not remain in solution in the presence of an excess of silica. The absence of any conspicuous amount of smithsonite in this deposit is noteworthy as an indication that carbon dioxide was a very minor constituent of the solution that introduced the zinc. The presence of a few microscopic needles of aurichalcite associated with the calamine and chalcedony also points to the scarcity of carbon dioxide, as it is probable that the basic carbonates of zinc are deposited when there is no excess of carbon dioxide.

It is known that sodium carbonate produces a basic carbonate of zinc when added to zinc sulphate; on the other hand, sodium bicarbonate yields a normal carbonate. Raikow [61] showed that an excess of carbon dioxide transforms the hydroxide of zinc into the normal carbonate.

If the descending waters on passing from the sulphide body into underlying porphyry have been depleted of their free sulphuric acid and ferric sulphate, it is doubtful if any considerable replacement of the wall rock can occur, at least until the waters become concentrated through depletion or adsorption by wall rock material. It seems unlikely that the difficultly soluble minerals of the porphyry can be readily replaced by interchange with the easily soluble sulphate of zinc, and no indication of such a process has been noted. It seems probable, on the other hand, that such a solution will pass through the porphyry until ground-water level is reached, or until concentration by the above-mentioned factors causes the deposition of goslarite, or of calamine in the presence of sufficient silica, or of zinciferous clay in the presence of alumina and silica. The alumina and silica would presumably have been derived chiefly from gangue material within the sulphide body and from porphyry above the ore body. Workable deposits of calamine with more or less zinciferous clay could be formed in this way where excessive fracturing of the porphyry would afford an opportunity. It is possible also that in such places some of the shattered porphyry could be replaced by these minerals if the solutions were sufficiently concentrated, but no such deposits in porphyry have been noted at Leadville. The same comments apply to solutions passing through thick masses of jasperoid or quartzite.

If the solution with a high content of zinc should pass through the porphyry or other siliceous rock into carbonate rock, deposition of the zinc as carbonate by replacement would be possible, and the process would be analogous to that described below.

Where the solution passed directly from the sulphide body into carbonate rock, either manganosiderite or dolomite, and contained an excess of sulphuric acid and ferric sulphate, the sulphuric acid would at once be neutralized by reaction with the carbonates. If free oxygen were also present in solution, a corresponding amount of ferrous sulphate formed by the reaction would be oxidized to ferric sulphate, and this together with ferric sulphate already in solution would react further with the carbonate rock and be precipitated as ferric hydrate, according to the following equation: [62]

$$Fe_2(SO_4)_3+3(Fe, Mn, Mg, Ca)CO_3+3H_2O=$$
$$2Fe(OH_3)+3(Fe, Mn, Mg, Ca)SO_4+3CO_2.$$

[61] Raikow, P. N., Weitere Untersuchungen über die Einwirkung der Kohlensäure auf die Hydrate der Metalle: Chem. Zeitung, vol. 31, p. 55, 1907.

[62] Meigen, W., Beiträge zur Kenntnis des Kohlensauren Kalkes: Naturforsch. Gesell. Freiburg im Breisgau Ber., vol. 13, p. 76, 1903. The equation given above is adapted from one given by Meigen, in which $CaCO_3$ is the only carbonate represented.

The ferric hydrate thus formed would, by gradual loss of a part of its water, be gradually transformed into one of the hydrous oxides and thus account for a part of the iron oxide in the layers that separate the lead carbonate stopes above from the zinc carbonate stopes below. If the supply of oxygen were sufficient, manganese hydroxide also would deposit along with that of iron. The carbon dioxide formed by this reaction would augment the small amount already present in solution.

If aluminum sulphate were present in considerable amount it may have reacted in the same manner as the ferric sulphate and have been precipitated in the presence of sufficient silica to form kaolin or similar compounds. The greatest argument for this reaction is the intimate association of kaolin with iron oxide in the layers just mentioned. There is also evidence that small amounts of alumina, now present as pockets of zinciferous clay in zinc carbonate ore, were formed at a later stage. The precipitation of the silica in the kaolin may be attributed to the mutual absorptive tendencies of colloidal silica and ferric and aluminum hydroxides. More or less zinc may have been removed from solution by the same influence at this time. The solution, after being depleted of free sulphuric acid and ferric sulphate, would meet the same conditions as those considered in the next paragraph.

Where the solutions had become depleted of free sulphuric acid and ferric sulphate before reaching the carbonate rock, no layer of ferric oxide and kaolin would be formed at first, but replacement of the carbonate rock by zinc carbonate would occur. This reaction has usually been explained by the simple equation

$$ZnSO_4+CaCO_3=ZnCO_3+CaSO_4,$$

zinc carbonate being precipitated as smithsonite and calcium sulphate passing off in solution. This reaction, however, although it plays an important part in the process, is not sufficient to explain the entire metasomatic process involved in the deposition of the Leadville zinc carbonate ores. Direct replacement of calcium, magnesium, and manganese carbonates by zinc carbonate involves a large amount of shrinkage; similar replacement of iron carbonate involves less but still considerable shrinkage. Some of the Leadville zinc carbonate ore of the first stage (see p. 231) presents some indications of shrinkage, but this is so much obscured by later processes of leaching and cavity filling that its amount can not be even approximately measured. Other specimens of the gray ore which show little or no evidence of leaching contain no pore spaces large enough to be detected with the high powers of the microscope, and the only evidence of shrinkage is the presence of microscopic fractures containing veinlets of smithsonite. The metasomatic process in this material, as shown on page 232, evidently proceeded by infiltration of the solution along the boundaries of the original carbonate grains and replacement of them from the boundaries inward, leaving a very small amount of indeterminable material (unreplaced carbonate?) in the center of each grain. The only conclusion warranted by such inconsistent evidence is that some shrinkage may have occurred during replacement but was not everywhere so great as that which would result from direct molecular replacement of dolomite or manganosiderite by zinc carbonate.

This problem in metasomatism has been discussed by Lindgren,[63] who states:

> Replacements of limestone by smithsonite within the rigid rocks are quite common, and in this case the mineral often reproduces exactly the texture of the original rock, even to the most minute details; the resulting secondary zinc mineral is compact and at least not more porous than the original limestone. If this replacement were effected according to a chemical equation, be it by substitution of zinc for calcium in carbonate or by interchange of zinc sulphate and calcium carbonate, a reduction in volume should necessarily be expected. It does not take place provided the metasomatic action goes on within the mass of the rock itself.

It is therefore necessary to look to the mineralogic evidence in the ores for suggestions as to the metasomatic processes that took place. This evidence, presented in the ore descriptions, shows that both manganosiderite and dolomite were replaced by the gray zinc ore, also that after replacement of manganosiderite by ferruginous smithsonite had ceased fractures and other openings were partly or completely filled by smithsonite relatively free from iron.

The descending zinc solutions, depleted of free sulphuric acid and ferric sulphate and most or all of their alumina, contained principally zinc and ferrous iron, with minor amounts of manganese, alkalies, and alkaline earths, chiefly as sulphates and to a minor extent as bicarbonates. Silica was also present. The conditions of chemical equilibrium that exist when so complex a solution attacks the complex carbonate rock manganosiderite can be only roughly inferred from experimental data on relatively simple solutions and compounds. Lack of solubility is the predominating factor in determining the order of separation of the products of such a reaction.[64] The composition of the gray ore is proof that under the conditions here discussed zinc carbonate was the least soluble product. It is therefore concluded that the zinc in solution as sulphate replaced the bases of the manganosiderite, and that the zinc in solution as bicarbonate was also precipitated. Precipitation of zinc as smithsonite thus proceeded either until the manganosiderite was completely replaced or until the zinc in solution became exhausted.

Any shrinkage due to replacement by reaction between zinc sulphate and manganosiderite is believed to have been compensated by simultaneous precipitation of the zinc carbonate from solution, as long as the supply of zinc and the carbonate radicle remained. If the supply was insufficient to compensate fully for shrinkage, a corresponding amount of shrinkage space in the gray ore must have resulted. This space may later have been filled by precipitation from a new supply of solution, or modified, if not obliterated, by the effects of oxidation.

The constituents removed from the manganosiderite thus became, with the sulphate radicle, the principal constituents in solution and were presumably removed from the manganosiderite zone. Whether or not they could have reacted with and replaced dolomite (Blue or White limestone) is a question on which there is no definite evidence. The manganese and magnesium in the manganosiderite were evidently more soluble, or replaceable, than the iron, as shown by comparison of the analyses on page 236.

Certain experimental data seem to indicate that iron carbonate is not replaceable by zinc carbonate; Knopf,[65] in his description of zinc carbonate deposits at Cerro Gordo, in the Inyo Mountains of California, cites experiments by R. C. Wells that showed ferrous carbonate to be less soluble than zinc carbonate. More recent experiments by Mr. Wells[66] have shown that the relative solubility or precipitability of the two carbonates differs according to the precipitant used. Thus if sodium carbonate is added to a sulphate solution of the two metals, zinc carbonate is precipitated before iron carbonate; if sodium bicarbonate is used, the order is reversed. The precipitants, or replaced compounds, of the Leadville zinc ores were carbonates, not bicarbonates, and this fact may be of some significance in the light of Wells's experiments.

That both zinc and iron and possibly manganese are similarly precipitated by magnesium and calcium carbonates is shown by the composition of the zinc carbonate ores which have replaced dolomite.[67] In this case zinc, iron, and manganese carbonates were precipitated together, in varying proportions, which depended, no doubt, on their proportions in the solution.

This isomorphous character of the carbonate ore is of interest. The fact that the gray carbonate ore, although free from visible microscopic inclusions of

[63] Lindgren, Waldemar, The nature of replacement: Econ. Geology, vol. 7, p. 530, 1912.

[64] Johnston, John, and Niggli, Paul, The general principles underlying metamorphic processes: Jour. Geology, vol. 21, p. 506, 1913.

[65] Knopf, Adolph, Mineral resources of the Inyo and White mountains, Calif.: U. S. Geol. Survey Bull. 540, p. 107, 1914.

[66] Personal communication.

[67] No unoxidized carbonate ore replacing dolomite was seen by the writer at Leadville, but the ferric and manganese oxides in the brown ore are mostly or wholly the result of oxidation in place of gray (ferrous) zinc carbonate. In the Tintic district, Utah, gray zinc-iron carbonate ore replaces practically pure limestone (Loughlin, G. F., Econ. Geology, vol. 9, pp. 2-3, 1914).

manganosiderite, contains about 14 per cent of ferrous carbonate and smaller amounts of manganese, magnesium, and lime carbonates suggests that replacement of these carbonates by zinc carbonates can extend up to a certain limit but not to their complete elimination. The same feature may have been shown by the ore that replaced dolomite or limestone, but oxidation has obscured the evidence. The ratio of calcium carbonate to other carbonates in these ores is misleading, owing to the presence of calcite as fillings of fractures and vugs of later origin than the replacement ore.

The progress and behavior of the solutions after deposition of the zinc carbonate could not be adequately studied underground, as the mine workings do not generally follow watercourses beyond the limits of ore bodies. The few such watercourses seen were stained by iron and manganese oxides, but these could hardly have been deposited directly from the waters that deposited the gray zinc ore. The waters after the replacement of manganosiderite must have contained principally ferrous and manganous sulphates with some magnesium and small amounts of several other elements. It is possible that they could cause a replacement of dolomite by manganosiderite, but no such replacement is known, and it is doubtful if they could cause any other chemical action. They would presumably pass on to ground-water level, if they had not already reached it, and enrich the ground water in sulphates. The relation of ore deposition to ground-water level is discussed on page 245, where it is concluded that the gray zinc carbonate ore was deposited close to if not below water level. In this connection the following statement by Lindgren[68] is of interest:

> Replacement by equal volume demands the nicest balance between solution and precipitation and takes place when the rock is permeated by stagnant or slowly moving solutions.

These conditions are satisfied below ground-water level and probably in the zone just above it. In arid regions similar replacement deposits are found well above the present ground-water level and are to be attributed either to the existence of a higher water level when replacement occurred, to local impounding of water above an impervious stratum, or to gradual absorption of the descending waters by the rock, with resulting slow movement and supersaturation, thus producing conditions of chemical equilibrium essentially the same as those already considered. The abundant precipitation at Leadville and the presence of sulphide bodies above gray zinc carbonate ore favor the conclusion that deposition of the zinc carbonate bodies on Carbonate Hill below the surface of ground water was quite possible. The ground-water level, in fact, may have aided the geologic structure in the concentration of these great bodies. In other places—for example, in Iron and Rock hills—deposition took place above the water level, the concentration and the size of the ore bodies being determined by the amount of zinc and other elements in solution and by the rock structure which influenced the rate at which the solutions descended and the degree to which they could permeate the rock.

IRON-MANGANESE OXIDE STAGE

The second stage of oxidation was primarily characterized by oxidation of the pyrite in the pyritic and mixed sulphide ores. This generated new supplies of sulphuric acid and of ferric sulphate, which was in large part immediately converted into limonite (brown iron ore) and deposited in the place of the pyrite. The porous character of the ore and the open character of the watercourses developed during the first stage had given oxygen much readier access to the ore bodies than was possible at the beginning of that stage. The free sulphuric acid and the ferric sulphate that remained in solution were carried downward into zinc carbonate ore or carbonate rock, either directly or through siliceous rock, and reacted as in the first stage. The jasperoid floors of ore bodies and the underlying quartzite or porphyry became stained with brown or red iron oxide. Where the waters reached the top of zinc carbonate ore bodies the acid was neutralized and the ferric sulphate reacted in the manner explained above (p. 265), replacing zinc carbonate with ferric oxide, which supplemented the layer formed during the first stage. The dissolved zinc was carried farther along until it could be redeposited by replacing carbonate rock.

Where the sulphuric acid and ferric sulphate descended into manganosiderite, the acid reacted to form ferrous and manganous sulphates, which in the presence of oxygen were promptly converted into additional ferric and manganic sulphates. These together with the ferric sulphate already present reacted with the remaining manganosiderite, which was replaced by iron and manganese oxides, or "black iron."[69] Where the manganosiderite was entirely replaced before the supply of ferric and manganic sulphates became exhausted the adjacent Blue or White limestone was similarly replaced. Although manganese oxide is not so insoluble as iron oxide, the abundance of carbonate rock generally caused the two to deposit before the manganese could be carried appreciably onward; but in a few places a partial separation took place and resulted in the deposition of manganese ore relatively free from iron. None of these high-grade manganese deposits were accessible to the writers, and no further

[68] Lindgren, Waldemar, The nature of replacement: Econ. Geology, vol. 7, p. 531, 1912.

[69] Since this statement was written, interesting data have been published by G. A. Thiel (The precipitation of manganese from meteoric solutions: Am. Jour. Sci., 5th ser., vol. 7, pp. 457–472, 1924).

discussion of the separation of manganese from iron is therefore attempted.

Chalcopyrite, though probably more readily oxidized than pyrite, was in part protected for a time by inclosing pyrite, but when once oxidized into soluble sulphate it was carried downward about as readily as zinc. Where copper was unusually abundant, as in some of the Ibex deposits, the descending water became supersaturated and deposited copper sulphate in commercial quantity in the lower part of the oxidized zone; but where silica taken into solution from porphyry was also abundant, small amounts of chrysocolla were formed, and where the solution reached limestone or zinc carbonates one or more of the copper carbonates could be formed either through replacement or as a cavity filling.

LEAD CARBONATE STAGE

Oxidation of galena for the most part followed that of pyrite. The waters by this time were bringing comparatively little sulphuric acid from the overlying siliceous rocks, and the proportion of carbon dioxide in water from these rocks, especially in water that had passed through limestone before reaching the ore, was relatively high. Under these conditions most of the lead sulphate derived by oxidation of galena was quickly changed to carbonate and deposited without appreciable displacement. For this reason shoots of lead carbonate are commonly found at the top of oxidized ore zones. Occasional deposits of white cerusite free from iron were derived either from pure masses of galena or from mixed sulphides from which iron was entirely leached; but for the most part the oxidation of pyrite inclosed in galena and the iron oxide left by pyrite that had already been oxidized caused the cerusite to contain appreciable quantities of iron.

The changing of lead sulphate to carbonate added an equivalent amount of sulphuric acid to the waters, and this water retained some lead and iron sulphates in solution. If the concentration of lead was sufficient the basic lead-iron sulphate, plumbojarosite, was formed as soon as the acid became neutralized by reaction. This mineral and other minerals of the jarosite group and their relations to one another have been too seldom seen by the writers to warrant a positive statement regarding their origin. As they have been found mainly between the shoots of lead carbonate and underlying masses of iron oxide, they may have been deposited in part before the iron oxide and in part as a replacement of iron oxide. According to Posnjak and Merwin,[70] a basic ferric sulphate ($3Fe_2O_3.4SO_3.9H_2O$) close to jarosite in composition is deposited from the more concentrated solutions and ferric oxide from the more dilute solutions. It may be, therefore, that basic ferric sulphate and jarosite were deposited before ferric oxide. It is also possible that the waters after depositing lead carbonate were able to react with ferric oxide and replace it with plumbojarosite, and they may also have replaced other minerals of the jarosite group by plumbojarosite. These reactions would account for the irregular lead content of this material.

[70] Posnjak, Eugen, and Merwin, H. E., op. cit., pp. 1992–1993.

PRECIOUS-METAL STAGE

The oxidation of argentite evidently took place at a late stage, probably because this mineral was so well protected by galena and pyrite. Its first oxidation product, the sulphate, was soluble to a considerable degree, but where it came into contact with dissolved chlorides, bromides, or iodides, the silver was precipitated as the highly insoluble horn silver (principally cerargyrite and embolite), as coatings on lead carbonate, jasperoid, iron oxide, and other oxidation products, or more commonly as microscopic particles disseminated among them. The position of much of the richest ore indicates that a little downward concentration took place before deposition of the horn silver.

Silver sulphate that did not react with chlorides was carried downward to the lower part of the oxidized zone and redeposited as native silver, or into the sulphide zone and deposited as native silver and secondary argentite. The chief precipitating agent in the lower oxidized zone, where free oxygen was scarce or absent, was evidently ferrous sulphate in solution, which was changed to ferric sulphate while the silver was reduced to native metal.[71] Cuprous sulphate produced similar results where it was present in noteworthy amount. Some native silver formed in this way may have been later converted to chloride as the process of oxidation continued, and that which escaped such change is near the bottom of the oxidized zone. The same reaction best accounts for the native silver on pyrite, galena, and blende, described by Blow (p. 259). The probable reactions involved were as follows:

(1) $4Ag_2SO_4 + 8FeSO_4 = 8Ag + 4Fe_2(SO_4)_3$

(2) $4Fe_2(SO_4)_3 + ZnS + 4H_2O = ZnSO_4 + 8FeSO_4 + 4H_2SO_4$

(3) $4[H_2SO_4 + ZnS = ZnSO_4 + H_2S]$

(4) $4[H_2S + Ag_2SO_4 = Ag_2S + H_2SO_4]$

and the net result

(5) $8Ag_2SO_4 + 5ZnS + 4H_2O = 8Ag + 4Ag_2S + 5ZnSO_4 + 4H_2SO_4$

According to these equations, native silver is deposited nearly twice as rapidly as the zinc blende (or other sulphide) is removed; furthermore, the supply of ferrous sulphate is renewed as fast as it is consumed,

[71] Stokes, H. N., Experiments on the solution, transportation, and deposition of copper, silver, and gold: Econ. Geology, vol. 1, p. 649, 1906.

and the sulphuric acid generated may in the absence of carbonate gangue react with zinc blende or galena and produce hydrogen sulphide, which can reduce additional silver sulphate to the sulphide, argentite, and renew the sulphuric acid. Although similar reduction by direct reaction with zinc blende or galena is theoretically possible and would agree with the net result of the above reactions (equation 5), Palmer and Bastin found little or no evidence of it, and convincing indications of it in nature are surprisingly few.[72]

Direct reaction between silver sulphate and chalcocite, however, readily produces native silver and argentite, as shown by Palmer's experiment, and the high content of silver in some of the ores that contain considerable chalcocite is most probably due to this reaction. Similar direct reaction with chalcopyrite takes place less readily. These reactions, which cause deposition of secondary argentite as well as native silver, are features of the zone of sulphide enrichment but are discussed here in order that the oxidation and redeposition of silver may be concisely presented.

Where native silver is found at the tops of ore bodies close by black shales, its reduction from sulphate may have been caused by carbon in the shales.[73]

Precipitation of gold from acid chloride solutions by neutralization of the acid or by reaction with ferrous sulphate at or below the bottom of the oxidized zone has been shown by W. H. Emmons[74] to be a probable cause of gold enrichment in many ore deposits. Palmer's experiments[75] have shown that gold is rapidly and completely precipitated from the chloride solution by chalcocite; also by chalcopyrite and galena, on which the gold is deposited as a plating and tends to protect the mineral from further reaction. Similar deposition took place more slowly on pyrite, and still more slowly on zinc blende. Cleavage surfaces of blende were particularly resistant to deposition of gold. The association of gold and copper in some of the deposits at Leadville is thus explained, as is the association of gold with pyrite or galena in others. The presence of gold plating crystals of zinc blende in specimens from the Ibex mine (p. 168) is less in accord with the results of Palmer's experiments, and it may be that the deposition of gold was there due to reaction with ferrous sulphate, which was changed to ferric chloride and ferric sulphate. The ferric sulphate could attack zinc blende according to equation 2 on page 268.

The process of gold enrichment in the Leadville district may therefore be summarized as follows: Wherever the reaction between alkali chlorides and manganese dioxide in the oxidizing zone liberated chlorine, the chlorine dissolved any gold present, and the resulting gold chloride was carried downward in solution. Wherever gold chloride came into contact with undecomposed sulphides above ground-water level, gold was deposited—most rapidly and completely by chalcocite and to the least degree by zinc blende. Where the gold chloride reached ground-water level gold was precipitated by both ferrous sulphate and the sulphides. Gold that escaped attack by chlorine remained essentially in its original position, and the ore became enriched by removal of sulphide and certain gangue matter by processes of oxidation. Gold enrichment has thus taken place throughout and below the oxidized zone, although as processes in the oxidized zone approach completion the zone of greatest gold enrichment descends lower and lower; but some of the rich bunches of gold, concentrated by reaction with sulphides or ferrous sulphate at an early stage, have evidently escaped re-solution and remain in thoroughly oxidized ore as flake and wire gold.

FINAL STAGES

After processes involving sulphuric acid and ferric sulphate had come to an end, processes involving oxygen and carbon dioxide became conspicuous and produced minor modifications and additions to the oxidized ores already formed.

Oxygen on reaching the gray zinc carbonate ore oxidized the iron and manganese, causing the formation of red or brown ferric oxide and the zinc-manganese oxide, hetaerolite; the zinc carbonate recrystallized in a relatively pure state. The iron oxide, to judge from the many specimens of brown ore studied, tended to remain in place, while the new smithsonite and hetaerolite migrated short distances to fractures and other openings to form druses or complete fillings.

This process shows that the smithsonite and hetaerolite were to some extent soluble in the solutions and that, although they were for the most part quickly redeposited, small amounts of them may have been carried for considerable distances. The free carbon dioxide in the water also had a tendency to dissolve the carbonate ore and carry the zinc as bicarbonate, the iron and manganese separating out as oxides. The combined effect of the oxygen and carbon dioxide was to add slightly to the slow downward migration of the zinc carbonate bodies and to thicken correspondingly the layers of iron oxide and clay at their tops. After the exhaustion of carbon dioxide to a certain degree silica became the active acid radicle, uniting with zinc to form calamine, the latest of the more abundant zinc minerals. The character of different calamine aggregates shows that the zinc and silica were for the most part carried in solution and the calamine was deposited in openings as a result of supersaturation; on the other hand, replacement of smithsonite by calamine shows that a part of the zinc was derived in place and the

[72] Emmons, W. H., op. cit., p. 121.
[73] Vogt, J. H. L., Ueber die Bildung des Gediegen Silbers, etc.: Zeitschr. prakt. Geologie, 1899, p. 117.
[74] Emmons, W. H., U. S. Geol. Survey Bull. 625, p. 321, 1917.
[75] Palmer, Chase, and Bastin, E. S., op. cit., pp. 156-160.

silica introduced in solution. The source of the silica is to be referred especially to the porphyry overlying the original sulphide bodies. Small amounts of silica may also have been derived from the gangue of these ore bodies and from the original carbonate rocks.

The conditions of equilibrium governing the deposition of calamine are not well understood. It is evident from paragenetic study that calamine can not form until smithsonite in its late drusy form, has finished crystallizing.

This statement is supported by the experimental work of Wang,[76] who found that calamine is soluble in water containing carbon dioxide and even more soluble in water containing bicarbonate of zinc as well. On the other hand, it is also evident that calamine can, under certain conditions, replace smithsonite. Why smithsonite is the less soluble in one case and the more soluble in the other is not clear. There is no reason for supposing that silica was not present while the smithsonite was being deposited. A reasonable inference is that crystallization of smithsonite, once started, continued for a time after the equilibrium point was passed, and that the smithsonite was later redissolved by the now more stable calamine. Another conjecture is that as the solution, through prolonged permeation, became more concentrated, silica superseded carbon dioxide as the stronger acid radicle—in other words, whereas smithsonite was the more insoluble mineral in the dilute solution, calamine was the more insoluble in the concentrated solution.

The occurrence of small amounts of zinciferous clay closely associated with calamine shows that the two were deposited at about the same time. These small amounts of clay may be attributed to alumina, which is commonly present with silica in mine waters of the oxidized zone and was derived from the same sources; but in this case the occurrence of the clay as one of the latest minerals is rather surprising, especially as the waters that deposited it appear to have been practically free from sulphates. Some of the clay, however, has evidently resulted from chemical precipitation and suggests that aluminum can be held in solution until the waters become concentrated by evaporation or adsorption by wall rock, when, in the presence of silica and zinc, it is precipitated as zinciferous clay.

Another interpretation is that the clay was in reality precipitated at an earlier stage and carried in suspension for indefinite distances until finally it was deposited in openings where the waters became stagnant, the zinc content being due to replacement of the aluminum in the clay. This suggestion could be applied to the clay fillings in fractures and fissures. Such fillings may have been formed during the preceding (sulphate water) stages, and if they were the chemistry of deposition could be regarded as generally similar to the processes outlined in the preceding pages. The nodules of native copper found on the fifth level of the Ibex mine were also formed by replacement of clay.

Failure to find any conspicuous occurrences of hydrozincite prevents an adequate discussion of its place and significance in the genesis of the Leadville deposits. In the Tintic zinc ores [77] hydrozincite as a rule followed the drusy smithsonite and therefore belonged to the same period of crystallization as calamine. This paragenetic relation is in accord with experimental evidence,[78] which shows that when an excess of carbon dioxide is present in solution the carbonate of zinc, smithsonite, will crystallize, but that when carbon dioxide is not in excess the basic carbonate, hydrozincite, will crystallize. This principle applied to the waters at Leadville implies that as the solutions diminished in volume, owing to their spreading along fractures or to permeation through the ore bodies, they would lose their excess of carbon dioxide. Smithsonite therefore would cease to form, and the remainder of the zinc carbonate would crystallize into hydrozincite. According to this principle, hydrozincite should be found coating druses of smithsonite and lining fractures below the limits of smithsonite deposition, as described by Argall;[79] also as a local alteration product where water containing no free carbon dioxide succeeded in causing recrystallization of smithsonite.

The aurichalcite in the Ibex mine accords with this interpretation. It was deposited at the same time as calamine, and both were formed later than drusy smithsonite. Evidently the solution, locally impounded in cavities in the ore, lost its excess of carbon dioxide. The copper and a corresponding amount of zinc then crystallized as the basic carbonate, aurichalcite, and the rest of the zinc went to form calamine. Any excess of silica over that required to form calamine was deposited as opal, chalcedony, or quartz coating or inclosing the calamine crystals.

After the waters had become depleted of zinc carbonate and silicate calcite was deposited in small amount, though only in a few places, as the final product of the third stage. As nicholsonite and aragonite were not found within the ore, they can not be assigned to a definite place in the sequence. Both minerals crystallized in openings in limonite and from

[76] Wang, Y. T., The formation of the oxidized ores of zinc from the sulphide: Am. Inst. Min. Eng. Bull. 105, pp. 1988–1991, 1915.

[77] Loughlin, G. F., Econ. Geology, vol. 9, pp. 3, 7, 1914. Where hydrozincite in the Tintic district alternated with drusy smithsonite, the later smithsonite was evidently deposited from a new supply of solution, and this was in turn followed by renewed deposition of hydrozincite.

[78] Raikow, P. N., Weitere Untersuchungen über die Einwirkung der Kohlensäure auf die Hydrate der Metalle: Chem. Zeitung, vol. 31, p. 55, 1907.

[79] Argall, Philip, Min. Mag., vol. 10, fig. 4, p. 285, 1914.

heir mode of occurrence would appear to belong to the ery latest stage of deposition—that is, to the calamine-alcite period—but their relations to calamine, hydro-incite, aurichalcite, and calcite are not known. A ittle secondary barite was also found at this stage.

Although these minerals are the latest to be depos-ited, the process of oxidation has obviously not ended. The less stable minerals are being corroded or altered to more stable forms, and the zone of oxidation continues o enroach downward upon the sulphide zones.

In this discussion no consideration has been given to uch oxidation products as pyromorphite, mimetite, and other minor ore minerals, as too small quantities of hem have been seen to serve as a reliable basis for

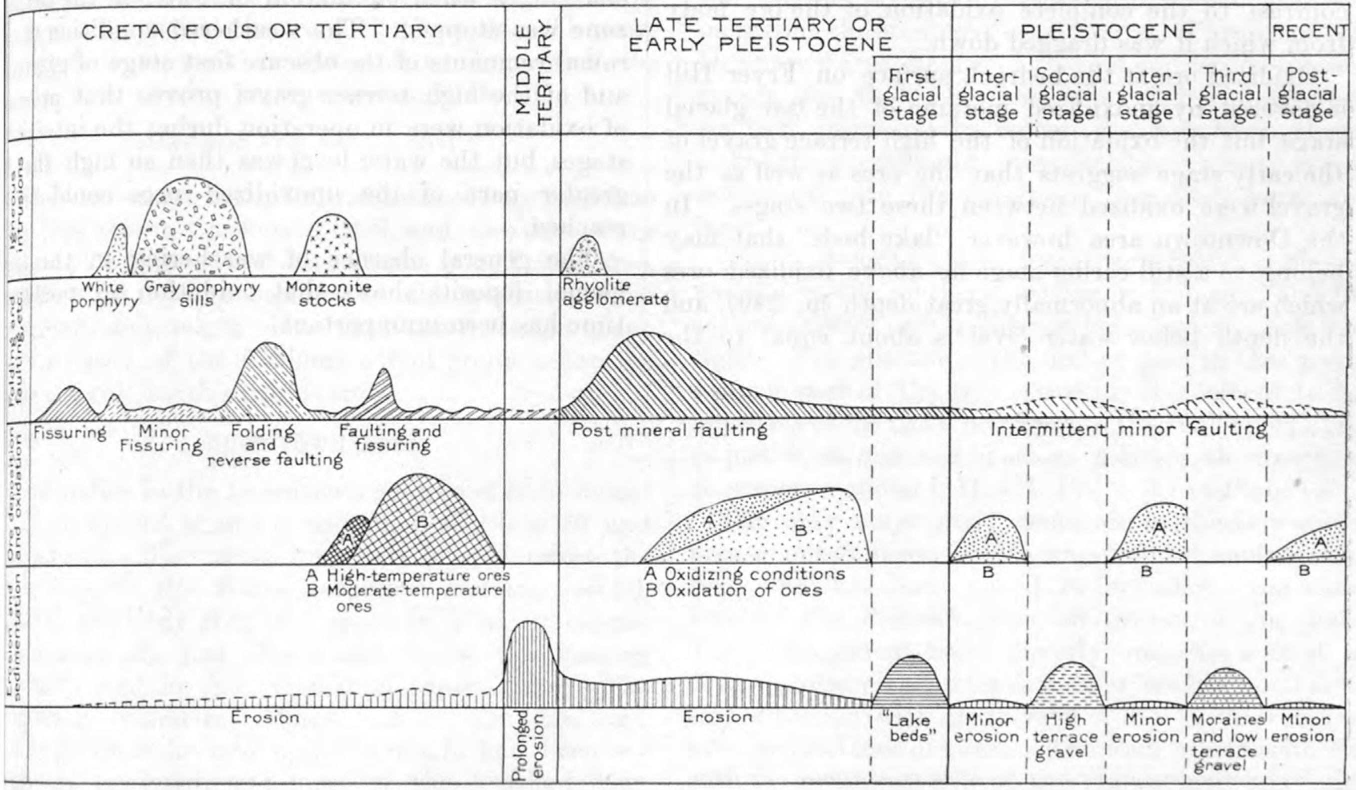


FIGURE 83.—Time relations of geologic events in the Leadville district, with special reference to the oxidation of the ores

oordinating them. Those which occur as fracture llings and vug linings in the more abundant oxidized inerals must have formed during a later stage than hese minerals, but their relations to other late minerals re not known. This lack of information, however, oes not weaken the interpretation of the principal rocesses of oxidation presented in this chapter.

REDEPOSITION AS SECONDARY SULPHIDES

Discussion of secondary sulphides has been largely nticipated in the preceding pages. The only con-icuous secondary sulphide is chalcocite. Although me of the copper derived from chalcopyrite was rede-posited as sulphate, silicate, or carbonate (p. 268), most of it was carried downward as sulphate until it came into contact with sulphides and was deposited as chalcocite. So far as noted, chalcopyrite was the strongest precipitating agent and became coated or considerably replaced by chalcocite while adjacent pyrite remained unaffected; but where chalcopyrite was inconspicuous or absent, pyrite became similarly coated. The concentration of chalcocite varied with the opportunity for permeation of the primary sulphide ore. In a few places it raised the copper content from practically nothing to several per cent, but for the most part, especially in the veins, it was deposited in thin coatings and streaks through a great distance and hardly raised the copper content to the minimum (2.5 per cent) for a copper ore. Films regarded as covellite but too thin for determination were also deposited upon the sulphides, particularly zinc blende.

The reprecipitation of silver and gold by primary sulphides, and particularly by chalcocite, has already been considered. The questionable occurrence of secondary galena as minute stalactites on sulphide ore in the Tucson mine may be noted, as well as the absence of secondary zinc sulphide, either as wurtzite or blende. Where descending zinc solutions penetrated pyrite or mixed sulphide ore no reaction with it took place, but the adjacent carbonate rock was replaced by smithsonite.

AGE OF SUPERGENE ALTERATION

Although the alteration of the ore bodies is continuing to-day, it was mainly accomplished prior to glaciation of the region. The times when processes of oxidation were most active are represented diagrammatically in Figure 83. As the ores were deposited at an approximate depth of 10,000 feet, a long time elapsed before erosion brought them within the zone of oxidation. Uplift accompanied by major postmineral faulting lowered the ground-water level and therefore hastened the beginning of oxidation of the ores. That the main part of this faulting preceded oxidation is shown by the partial oxidation of the dragged ore in the Mikado fault zone (p. 255), in contrast to the complete oxidation of the ore body from which it was dragged down.

Oxidized ore at the bedrock surface on Fryer Hill is covered by unoxidized moraine of the last glacial stage, but the oxidation of the high terrace gravel of the early stage suggests that the ores as well as the gravel were oxidized between these two stages. In the Downtown area, however, "lake beds" that may belong to a still earlier stage lie above oxidized ores which are at an abnormally great depth (p. 249), and the depth below water level is about equal to the thickness of the "lake beds" and high terrace gravel combined. This fact suggests that oxidation took place before deposition of the "lake beds," which caused the water level to rise and protect the ores from further appreciable oxidation. It has also been suggested that the abnormal depth of oxidation where glacial deposits are insignificant indicates a generally lower water level and a relatively dry climate prior to the glacial epoch. The evidence, though not absolute proof, points to the interval between the principal development of postmineral faults and the beginning of glacial conditions as the time when most of the oxidation of the ores took place.

Little or no oxidation could occur during the glacial stages when circulation of water in the oxidized zone was stopped. The weathered condition of morainal remnants of the obscure first stage of glaciation and of the high terrace gravel proves that processes of oxidation were in operation during the interglacial stages, but the water level was then so high that the greater part of the unoxidized ores could not be reached.

The general absence of weathering in the latest glacial deposits shows that oxidation in postglacial time has been unimportant.

CHAPTER 13. LOCAL DESCRIPTIONS

Data for local descriptions of ore bodies are in general incomplete, principally because of the inaccessibility of workings that were opened and closed between the earlier and later geologic surveys. Some ore bodies or groups of ore bodies can be described in considerable detail, but others can not be described at all. The following descriptions present such data as are available and will give, it is hoped, a fairly representative if only partial picture of the deposits. They are arranged from west to east and conform with the groups of ore bodies represented on Plate 45.

CARBONATE HILL GROUP

The Carbonate Hill group includes the ore bodies in the Downtown, Carbonate Hill, and Graham Park areas and is represented by columns B to I, inclusive, of Plate 59. Were records of old workings more complete, they might show that the Adelaide group is really part of the Carbonate Hill group, separated from the rest by the Iron fault.

DOWNTOWN AREA

Ore bodies in the Downtown area have been mined at five contacts, shown in column B of Plate 59 and in Plate 18. The most work has been done at the first, beneath the White porphyry, and the second, beneath the Gray porphyry sheet in Blue limestone. The others are just above and below the Parting quartzite and in the "transition shales" above the Cambrian quartzite. When seen by Emmons and Irving in 1902 the two upper contacts had been extensively explored, and most of the ore had been mined from them. After the unwatering of the Penrose shaft in 1916 a large quantity of oxidized zinc, lead, and manganese-iron ore was mined by the Downtown Mines Co. south of the Coronado shaft and west of the Midas shaft in the lower part of the Blue limestone and in the White limestone, and a small quantity in the underlying "transition shales," but in 1924 these operations were suspended. Elsewhere there has been no production from the Downtown area since 1907, except for a small tonnage of manganese-oxide ore from the first contact in 1918.

The first contact follows uniformly the upper surface of the Blue limestone, which is shown by scattered fragments of black chert to be present in its full thickness beneath the White porphyry. The contact surface is marked by many irregularities and undulations, some of which are due to irregularities in the original intrusive contact and some to the distortion to which both ore bodies and porphyries have been subjected by faulting. In a small portion of the area (see section XII) between the Penrose and Coronado shafts, the Gray porphyry rises to the under surface of the White porphyry, and there is locally no "first contact." In other places the single Gray porphyry sheet that forms the "second contact" divides into several branches, increasing the number of ore contacts. Throughout the Downtown area the ores of the first and second contacts depart less than elsewhere from their characteristic position immediately below the porphyry sheets, although exceedingly irregular protrusions extend downward into the limestone from their lower surfaces.

The first-contact ores have been found in greater amount in the southern portion of the area, and the second-contact ores in the northern and eastern portions. The absence of the first contact in the northeastern part of the area is due in some places to the approach of the Gray porphyry to the White porphyry, as just explained, and in others, perhaps, to erosion, as shown on sections I, II, III, IV, V, VI of Plate 18.

The only noteworthy vein seen in the Downtown area is one connected with an oxidized replacement body that has been mined 12 feet above the third level of the Penrose mine, southwest of the shaft. This replacement body directly underlies a sheet of Gray porphyry and extends for 280 feet in a northeasterly direction with an average width of 20 feet and average thickness of 5 feet. The vein, which connects with the northwest side of the replacement body (fig. 84), has an average thickness of 1 foot and extends to and below the fourth level but has not been followed deeper. The ore mined from the replacement body consisted chiefly of iron and manganese oxides and silica with considerable lead and 100 to 200 ounces of silver to the ton. The vein also was found to be highly siliceous and to contain considerable horn silver, but it could not be profitably worked. A few other small veins have been reported beneath replacement bodies in the Downtown area, but they are on the whole scarce and inconspicuous.

Third-contact ore, lying directly on the Parting quartzite, has been found on the bench between the Pendery and Niles faults in the Wildcat, Bison, and Catalpa mines (section IV), where the Gray porphyry approaches within 60 feet of the Parting quartzite and the second-contact and third-contact ores come together. Third-contact ore has also been mined by the Downtown Mines Co. (sections V and XII), as already stated.

The presence of a fourth contact, beneath the Parting quartzite, had been demonstrated by 1902 in the Lazy Bill, Midas, Sixth Street, and Coronado mines. In drill holes Nos. 7 and 1 of the Coronado mine and No. 2 of the Sixth Street mine (see section XII) this fourth-contact ore was found to extend completely through the White limestone down to the Cambrian quartzite. During 1918 to 1923 the fourth-contact ore of the Coronado was mined by the Downtown Mines Co. In the Hibschle and Walcott mines (section III) a large body of ore was found on a fifth contact; it lay mainly in the "transition shales" at the top of the Cambrian quartzite but extended for a short distance

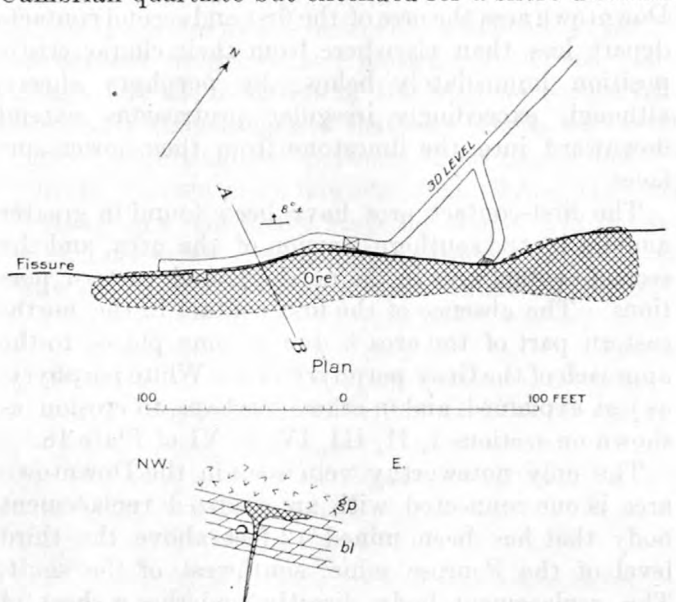


FIGURE 84.—Plan and section of oxidized ore body, with feeding fissure extending downward from it, Penrose mine. gp, Gray porphyry; bl, Blue limestone

into the quartzite itself. This ore body was in line with the northwestward projection of the Tucson-Maid reverse fault. Upthrow along the Pendery fault brought it sufficiently near the surface to permit complete oxidation.

All the ores mined on the first three contacts in the Downtown district were oxidized, and the fourth-contact ores found in drill holes and in recent workings of the Coronado mine below the Parting quartzite were partly oxidized sulphides. The first-contact ore bodies were, on the whole, the richest in silver, the ores of the second and third contacts had a slightly lower tenor in this metal, and the fourth-contact ores were prevailingly of low grade. How much of this difference was due to oxidation and how much to differences in the original silver content could not be determined from the available data.

A fairly good conception of the thicknesses of the various blanket masses may be gained from a comparison of sections I to XII, Plate 18. The ore bodies on the first contact were in general relatively thinner than those on the second. The maximum thickness for the second-contact ore, 150 feet, was attained by the Coronado-Sixth Street body immediately above the Sixth Street drill hole No. 2 (section XII). Over most of the area the ore bodies of both contacts ranged in general from 6 to 30 feet in thickness, with a thickening here and there to 60 feet and in a few places to nearly 100 feet. The disseminated ore bodies in White limestone in the Sixth Street and Coronado mines were apparently much thicker and may have occupied the entire thickness of the White limestone; but recent developments in the Coronado showed that only parts of them could be profitably worked. In the Midas and Penrose they were thinner, being, respectively, 80 and 30 feet thick. The ore bodies on all contacts were much more variable in thickness than is indicated on the generalized sections of the Downtown map.

CARBONATE HILL

The number of contacts and the position and number of intrusive bodies of Gray porphyry are the same throughout the Carbonate Hill area as in the Downtown area, but the degree to which mineralization has affected the different horizons differs. In the western part of the area, just west of the Pendery fault zone, the ore horizons are similar to those in the Downtown district, as shown in section C, Plate 59; those in and near the Maid of Erin mine, where workings have penetrated completely through the sedimentary rocks into granite, are represented by section D.

On the northern slope of the hill, from the Niles fault southeastward to the Maid of Erin mine, the principal ore bodies were found on the second, third, fourth, and fifth contacts in the vicinity of the Tucson-Maid reverse fault. A vein 4 feet in width was found on the 900-foot level, at the north end of the Maid-Combination shaft station, and was followed in the Lower quartzite for 42 feet upward from the level. It was filled with loosely compacted sulphide ore, chiefly pyrite, but showed no galena or zinc blende; it had a high silver content (300 ounces to the ton), and 15 tons of ore was mined from it. This vein was not followed far enough to connect with the ore bodies above, but there can be little question that a connection exists. On the third level of the Henriett-Maid mine another vein was found connected with the shoot that extends southeastward through the Mahala mine. This vein was reported to trend southeastward beneath the middle of the ore body. It was not followed downward. Both of these veins were near the Tucson-Maid fault, whose existence was not suspected when they were examined.

Farther north, on the 450-foot level of the Shenango mine, a pyrite vein a few inches thick was found in the Holden winze. It crosscut the Cambrian "transition shales" and connected flat replacement ore bodies along different beds within the shale horizon.

In the Halfway, Lower Henriett, New Waterloo, and Harker No. 1 mines an immense body of ore occupied the combined second and third contacts between the Gray porphyry above and the Parting quartzite below and was followed downward to the southeast by an incline from the Harker No. 1 shaft to the Maid-Combination workings. This ore extended down through the Parting quartzite and connected with the fourth contact below. Another body of ore occurred beneath the Parting quartzite in the White limestone and extended into and beyond the workings of the Henriett-Maid. None of these workings have ever been accessible to the writer (Loughlin), so that no details other than the simple statement of the horizon of occurrence and the outlines of the ore body shown on Plate 66 can be given. In the workings of the Maid of Erin mine little could be learned of the first or White porphyry contact, as the workings above the Gray porphyry were inaccessible at the time of the writer's visits. First-contact ore may therefore extend farther east than is indicated on the map.

In the Henriett, Maid of Erin, Seneca, Surprise, Vanderbilt, Clontarf, and Wolftone mines ore not only appeared at the same contacts as in the northwest Iron Hill region but more additional horizons were found than at any other mine west of the Iron fault. An immense shoot of ore extended southeast by east from a point 50 feet west of the Seneca shaft to and beyond the Wolftone shaft, a total distance of about 1,200 feet. It lay in the transition shales at the top of the Lower quartzite and at its widest point showed a width of 330 feet.

Within a roughly circular area, approximately 200 feet in diameter, just north of the Maid-Combination shaft, the ore bodies on all contacts were so thick that with the single interruption of the Gray porphyry sheet in the Blue limestone they formed a practically solid mass from the White porphyry roof to and into the Cambrian quartzite.

The ores of the first contact, long inaccessible, in the Maid of Erin mine appear to have been less extensively developed than those on the lower contacts, but this may have been due to lack of records on the older maps. One of the most extensive ore bodies of the mine lay at the fifth contact, beneath the Parting quartzite. Other less continuous bodies of great horizontal extent occur beneath the second contact. An extremely large ore body on the sixth contact, immediately above the Cambrian quartzite, extended from a point north of the Seneca shaft into the lower workings of the Wolftone mine. This ore body at several places extended for some distance into the Cambrian quartzite. The ore bodies of the Maid and adjacent mines, which lie in one of the most thoroughly mineralized and most productive areas in the Leadville district, are shown on Plate 66. Too few observations were possible in these workings to permit further description of the details of occurrence. The ore bodies in the Maid of Erin workings are oxidized down to the base of the Parting quartzite, where the lead carbonate ores pass rather abruptly into sulphides; but the zinc carbonate ores have been extensively mined in the underlying White limestone and locally beneath pyritic sulphide ore (pl. 66).

STRAY HORSE DEPRESSION

Obtainable information on the mine workings beneath Stray Horse and Little Stray Horse gulches and the intervening Stray Horse Ridge is meager and unsatisfactory. It is roughly represented in columns F and G of Plate 59.

GRAHAM PARK

General features.—The ground between Graham Park on the south and Stray Horse Gulch on the north has been remarkably productive. The ore shoots extend from the workings of the Maid mine on the west to the Mikado fault on the east, and most of them occur at great depth. Within this tract the principal shafts are the Wolftone, Standard, Mahala No. 1, Mahala No. 3, Greenback, R. A. M., Cumberland, Rialto (Pyrenees), Hunkidori, Gonabrod, Cyclops, and Agassiz. Ore is found at more horizons than in any other area in the district except Iron Hill and East Breece Hill (Ibex). In the Wolftone workings on the west there are six ore horizons, but the number increases toward the east until in the R. A. M. mine there are as many as eleven. They are represented by sections D and H, Plate 59. They are in part clearly related to the Tucson-Maid fault, and in part to a premineral fissure zone closely parallel to the Mikado fault, as shown in the descriptions on page 277.

The horizons in the Blue limestone form two series. One lies above the main White porphyry intrusion and is continuous with the upper beds which were so productive in the Small Hopes mine and adjacent territory to the north; the other lies below the main White porphyry intrusion and forms an eastward continuation of the ore horizons developed in the Maid, Big Chief, and Castle View workings.

The part of the Blue limestone above the White porphyry is in most places thin and is divided locally by minor sheets of White and Gray porphyry into two or more portions. Some of these portions are connected where the porphyry sheets wedge out; others form superposed lenses entirely inclosed in porphyry. Toward the south the amount of Blue limestone below the main White porphyry sheet increases until in the Mab, Satellite, and Blind Tom shafts the entire formation is below the White porphyry. The southern limit of the ore horizons above the main sheet of White porphyry is at the Greenback and Mahala shafts. In the basin-shaped area filled with "lake beds" just west of the Mikado fault the beds at these uppermost horizons have been removed by erosion, as shown in the Rialto and Cumberland shafts.

The ore on these upper contacts is for the most part directly beneath a porphyry roof, but in several places a layer of limestone intervenes between the ore and the porphyry. At one place in the upper workings of the R. A. M. mine the "lake beds" are in immediate contact with the ore. (See section E–E′, pl. 20.) Ore has completely replaced these limestone members only where they are very thin. Most of the ore bodies terminate downward, and some both downward and upward, against limestone. All the ore mined in the upper contacts was oxidized. The horizons below the main porphyry sheet have been the most productive.

Certain blanket bodies and veins in the Greenback mine.—In the Greenback and Mahala mines the ore bodies are in many places so thick that the entire space between the Gray porphyry and the Parting quartzite is occupied by ore. This is true of the large ore body on the second contact beneath the Gray porphyry, which extends from the southern workings of the Wolftone mine southeastward through the Mahala into the Greenback workings. (See pl. 19.) In part of the Mahala and Greenback mines, its maximum thickness is about 60 feet. For the greater portion of its length it lies in contact with the Gray porphyry roof. It is closely related to the Tucson-Maid fault, along which it extends down into the Parting quartzite. Farther east in the Greenback mine there is another blanket body of northward trend at the same horizon, equally thick but less extensive. Beneath the north end of this body some ore within the Parting quartzite was also mined, notably at the intersection of two vertical veinlets. One of these veinlets strikes east. The other strikes north and has been followed directly above a large blanket body in White limestone, and there is no doubt that this blanket is connected with that in the Blue limestone by the two veinlets. Recent work in the Greenback has shown the ore body in White limestone, mostly low-grade pyrite with marginal shoots of blende-galena ore, to be practically continuous down into the Cambrian quartzite, where it forms a vein in a probable branch of the Tucson-Maid fault.

The vein is exposed on the seventh level of the Greenback mine, 330 feet south of the shaft (pl. 40). At its junction with the main drift it is 16 to 20 feet thick. It strikes about N. 65–70° W. and dips 63° S. between a footwall of Cambrian quartzite and a hanging wall of shale. The quartzite dips at a low angle for a long distance but steepens close to the fault. The shaly beds are nearly vertical from the fault to the south end of the drift, a distance of 100 feet.

The ore in the vein consists of lenticular bands of sulphide, some rich in zinc blende and others in pyrite, dipping steeply southward and alternating irregularly with bands of clayey gangue. The pyrite bands are blackened by chalcocite. The vein has been mined for the full width of the drift and upward in raise for 52 feet. There sulphide ore is continuous to the sixth level, 50 feet above, and is said to contain streaks very rich in silver, evidently due to sulphide enrichment.

On the seventh level 110 feet west of the main drift a small stope has been opened where the same vein or one closely parallel to it has replaced White limestone at or near its contact with the underlying "transition shales." The ore is of the same banded character but contains more galena and is accompanied by considerable manganosiderite. The bands dip steeply northward and the width of the ore body is 30 feet. This stope is very near the projected position of the Tucson-Maid fault.

The workings when visited in 1919 were not sufficiently open for the exact relations between these two exposures on the seventh level to be determined. They are lens-shaped shoots in steplike arrangement and may be connected by a fault which is followed by the crosscut and which crosses the strata at a low angle. The shaly beds between the two exposures are partly replaced by pyrite.

Another veinlet is exposed in Cambrian quartzite on the seventh level and extends northward from the large vein. It is almost directly under the northward-trending veinlet above the fifth level and the major axes of the two large blanket ore bodies. Although its only exposure is 150 feet below the lower blanket, its presence adds to the evidence of a system of northward mineralized fractures parallel to the longer dimensions of the blankets in this vicinity.

Veins in the Wolftone mine.—Irving reports three closely spaced sulphide veins in Cambrian quartzite connecting upward with an ore body in the "transition shales" on the eighth level of the Wolftone mine, 15 feet from the shaft. The veins are nearly vertical, 8 to 12 inches thick, and of northerly trend. The ore body with which they connect is about 75 feet thick. They are near the Tucson-Maid fault, but their exact position was not recorded.

On the eighth level 200 feet east of the shaft a small pyritic vein with a considerable silver content trends northeast and dips 74° NW. along a crushed zone in Cambrian quartzite (fig. 26). It has been followed upward for 16 feet, but there is no record of its passage into the overlying "transition shales." About

380 feet southeast of the shaft a vein connecting with extensive replacement bodies has been followed down the Tucson-Maid fault in a 10-foot winze and is said to have contained enriched pyritic ore with a considerable copper content. A connected vein, followed upward along a northeast auxiliary fissure to the seventh level, joins a blanket ore body before reaching that level.

On the first level of the Wolftone mine 150 feet northeast of the shaft a veinlet of galena 3 to 4 inches thick has been found connecting a sulphide ore body beneath the Gray porphyry with an oxidized ore body beneath the White porphyry. The difference in composition between this minor connecting veinlet and the pyritic veinlets at lower levels in or close by the Tucson-Maid fault below is noteworthy. A search in the limestone beneath the large ore body on the second level east and north of the shaft has failed to disclose any veins, and their absence implies that at that place the ore-forming solutions had moved along the base of the porphyry for a long distance from the fissures through which they rose.

Veinlets in the Mikado mine.—In the new Mikado workings, on the fifth and sixth levels, small sulphide veins in Gray porphyry have been found close to and about parallel to the Mikado fault. They doubtless connect upward with the large shoots of zinc sulphide and mixed sulphide in Blue limestone and indicate a premineral fissure zone that served as a feeder for the large replacement bodies. This fissure zone has not been explored below the White limestone and is probably cut off by the Mikado fault, which has a somewhat lower westward dip than the mineralized fissure zone. The two are so nearly parallel that the suggestion has been made that the Mikado fault itself was an ore channel. Considerable ore has been mined within the Mikado fault, but it has all been dragged from the replacement ore bodies (pl. 20, section A–A′). No veins have been found underlying the large shoots that extend from the Mikado and R. A. M. mines to the Wolftone mine. It is therefore inferred that the solutions which formed these shoots rose mostly along the Tucson-Maid fault zone, to a less degree along the premineral fissure zone in the Mikado mine and perhaps others not yet discovered. On reaching the Blue limestone, they spread for long distances along the strata beneath porphyry sills.

Limits of oxidation and sulphide enrichment.—Nearly all the ore mined below the first or White porphyry contact has been sulphide. In the more westerly shafts, however, where the lower horizons are nearer to the surface, oxidation has extended below the Parting quartzite. Thus the oxidized ore body that lies immediately beneath the Parting quartzite in the Upper Henriett mine changes to sulphide as it enters the Maid mine. East of this point the lower limit of the oxidized ore dips toward the east less steeply than the country rock and hence gradually rises through the several horizons, reaching the lower part of the first-contact ore in the Wolftone mine and White porphyry itself in the Greenback and Rialto mines. In the R. A. M. oxidized ores of lead, iron, and manganese occurred in insignificant amount beneath the White porphyry. Oxidized zinc ores extend in places below the general level of oxidation and have been found beneath sulphide ore, as shown in chapter 11.

The sulphide ore immediately beneath the oxidized zone contains a considerable portion of zinc blende. The ore at the lowermost horizons, however, especially in the Cambrian quartzite in the Wolftone mine and in the White limestone in the Greenback and Mahala mines, consists almost entirely of pyrite, accompanied by little zinc blende and extremely small quantities of copper and precious metals, except where locally enriched, as shown on page 258. The marginal shoots of zinc-lead sulphide ore in the Greenback and Mahala have already been noted. Where the ores in White limestone rise in a westerly direction into the workings of the Maid of Erin mine they have a generally higher silver content than where they are more deeply buried and farther removed from the lower limit of oxidation. It is probable that their greater richness toward the west is due to relatively thorough sulphide enrichment.

MIKADO WEDGE

The wedge-shaped block of ground between the Mikado and Iron faults may be considered in two parts—a productive southern part, which forms the upthrown continuation of the productive territory on the west, and a comparatively unproductive northern part, which extends from the Hawkeye and Del Monte shafts to the northern limits of the Leadville district.

In the productive part the ore has been obtained chiefly from the Snowstorm, Indiana, Highland Mary Nos. 1 and 2, Shenango, Old Mikado, Devlin, Venus, and Hermes mines. The ore horizons in this part are represented by column I of Plate 59. The beds that have been so productive above the main White porphyry sheet in the downthrown territory west of the Mikado fault have here been completely eroded. Five contacts remain, although in places the fifth contact is divided into a number of minor contacts separated by irregular branches of the Gray porphyry intrusive mass.

The contacts are (1) beneath the White porphyry or beneath a Gray porphyry body which in places lies immediately beneath the overlying White porphyry; (2) In the Blue limestone immediately above the Parting quartzite; (3) at the top of the White limestone immediately beneath the Parting quartzite, locally filling the entire space between the Parting quartzite and a sheet of Gray porphyry that cuts the White limestone; (4) beneath this Gray porphyry sheet, in the upper third of the White limestone; (5) in the lower beds of the White limestone and underlying shales, irregularly distributed along the contacts of a second Gray porphyry sheet. The ore of the fifth contact locally extends down to the Lower quartzite, and in a few places, as in the Boulder drift of the Shenango mine, layers of sulphide replace beds of the Lower quartzite itself.

The larger portion of the rich ore taken from this territory came from the Mikado mine. A considerable body, completely oxidized, was found on the first or upper contact, but by far the greater production of the mine came from ore at the lower horizons, immediately above and beneath the Parting quartzite. Oxidation was complete down to the Parting quartzite, but its lower limit was exceedingly irregular and extended downward along cracks and water channels into the Cambrian quartzite members of the sedimentary series. The oxidized ore contained large quantities of silver chloride and lead carbonate, and the sulphide ores were enriched in places. For the most part, however, sulphide enrichment seemed to have operated only to a minor degree, as many of the sulphide bodies were of comparatively low grade. A large body of sulphide ore north of the shaft on the fourth level of the Mikado mine in the White limestone was in places 200 feet wide and 40 feet thick, and carried only 2 to 4 ounces in silver to the ton.

It is noteworthy that the lower limit of oxidation in this mine is at a geologic horizon but slightly lower than that in the R. A. M. mine, west of the Mikado fault, although the rocks in the R. A. M. mine have been down-faulted for a vertical distance of more than 700 feet. In other words, the Mikado fault has apparently acted as a dam separating the hydrostatic basin on the east from a lower hydrostatic basin on the west. The ground water, as indicated by the depth of oxidation, seems to have been at an altitude of 10,340 feet east of the fault and of 9,270 feet west of the fault. In the chapter dealing with the oxidation of the ores other instances are cited of this condition, which in many places has characteristically affected the oxidation process in the Leadville district.

It is probable that the difference in the grade of the ores in this locality at the different horizons is due more to the action of enrichment upon the upper ore bodies than to original distinctions in the mineralogic and other characters of the material. It is certainly true that the unenriched sulphide ores remaining in this area are of comparatively low value; but abundant good ore has been extracted from the upper parts of the ore bodies and the oxidized ores immediately above them in the Mikado, Shenango, Highland Mary, and adjoining mines.

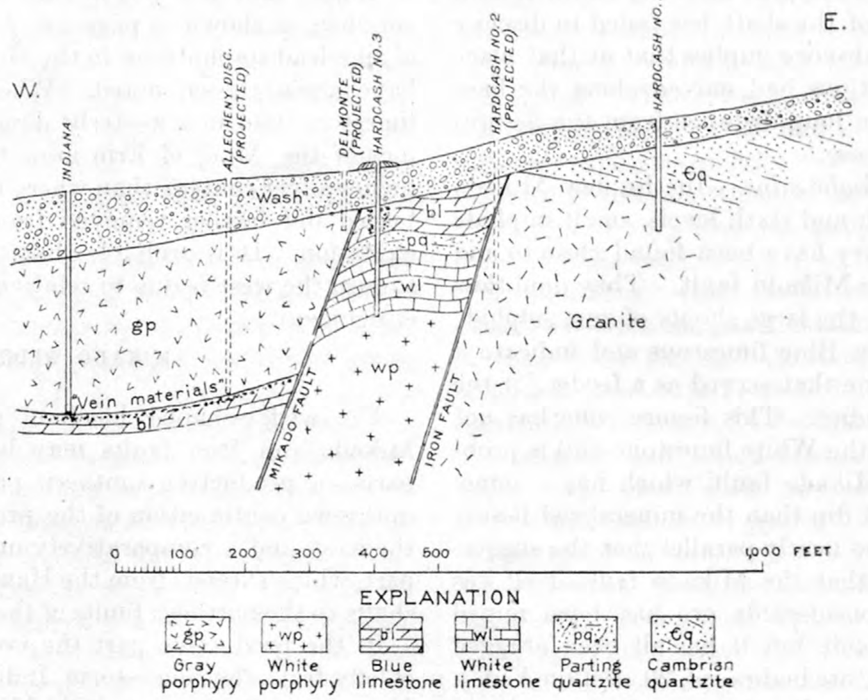


FIGURE 85.—Section through Indiana and Hard Cash shafts, showing probable structure and ore horizons between Mikado and Iron faults

The extensive mineralization at the horizons beneath the Parting quartzite may be related to the premineral fissure zone exposed in the New Mikado mine, just west of the Mikado fault. It may also be related to the extensive mineralization of White limestone in the Adelaide group, east of the Iron fault, but there has been no opportunity to study any of the deposits in White limestone east of the Mikado fault.

In the northern and less productive portion of the V-shaped area less exploration has been carried on, and much of it represents the mines that were in operation at the time the Leadville monograph was written. In this area there is a large mass of oxidized "vein matter" and included ore above the Parting quartzite in the Blue limestone. It has been opened up in the Chieftain tunnel and in the Cordelia Edmonson, Birdie Tribble, Bobtail, First Chance, Hawkeye, Dania, J. B. Grant, Scooper Nos. 1 and 2, Hard Cash, and Fairplay shafts. In some places the ore is in contact with the overlying porphyry, and in others it is well down in the body of the Blue limestone. Much of it lies directly underneath the "wash" and has been so found in the Birdie Tribble, Bobtail, First Chance, and Cordelia Edmonson workings. The Hard Cash and Fairplay shafts have penetrated below the Parting quartzite, but none of the other workings have reached the lower horizons. No ore is reported from the Hard Cash shaft below the Parting quartzite. (See fig. 85.) In the Fairplay shaft a small fault running parallel to the Iron fault and forming, indeed, a part of the Iron fault zone, has brought the lower quartzite up in the shaft. A singular body of ore occurs in this shaft, consisting of oxidized iron ore and lead carbonates deposited through the entire thickness of the Lower quartzite and extending from the upper surface of this formation down to the point where the shaft passes from the quartzite to the granite on the east side of the fault. (See fig. 86.)

Still farther north are the Abe Lincoln, Little Hoosier, and Elkhorn mines, from none of which has any production of note been obtained. The Little Hoosier and Abe Lincoln never penetrated the porphyry overlying the Blue limestone. The Elkhorn shaft, 860 feet in depth, penetrated the entire series of rocks, including 50 feet of Cambrian quartzite, but revealed no ore bodies of any magnitude. Another shaft 1,000 feet north of the Abe Lincoln penetrated the overlying porphyry and found "vein material" 5 feet thick in the Blue limestone beneath.

FRYER HILL GROUP

The Fryer Hill group of ore bodies includes those beneath the three low knolls Fairview Hill, Fryer Hill, and East Fryer Hill. Beneath Fairview and Fryer hills, which were collectively termed Fryer Hill in Emmons's original report, occur the famous Fryer Hill ore shoots. The group as a whole extends from the All Right shaft on the west to the Jamie Lee, Olive Branch, El Paso, and Cullen shafts on the east.

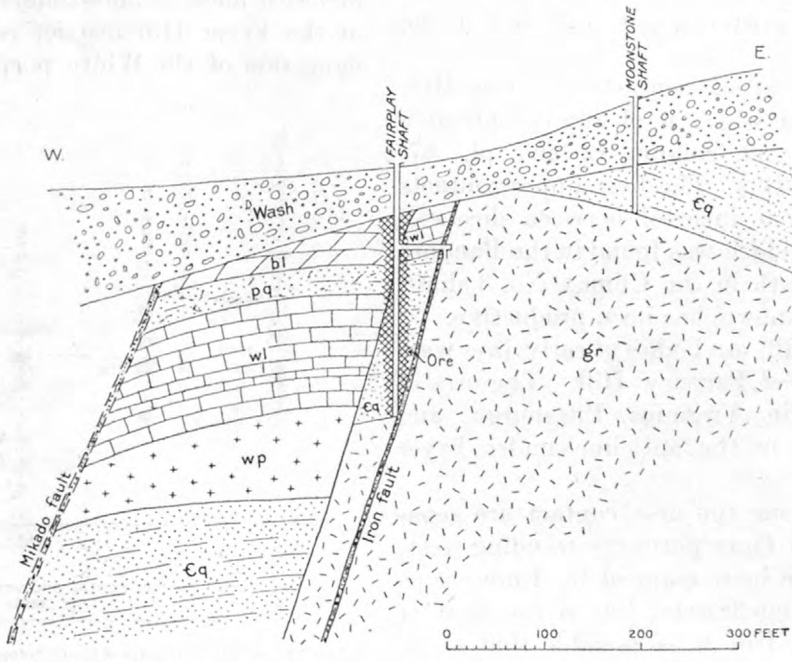


FIGURE 86.—Probable structure and ore horizons in Fairplay shaft and body of iron and lead in the Cambrian or Lower quartzite. wl, White limestone; bl, Blue limestone; pq, Parting quartzite; wp, White porphyry; Ꞓq, Cambrian quartzite; gr, granite

In the early days it was one of the most profitable of the Leadville district. The ore shoots between Fairview and Fryer hills, represented on Plate 67, are simply richer and more profitable portions of a body of low-grade "vein matter" which replaced almost the entire mass of limestone that intervened between the White porphyry sheets.

BOUNDARIES

The ore shoots of this group are bounded on the north by an area of comparatively unproductive territory that has been opened by the Prize, Buffalo, Katie, Pride, and Otis shafts, from none of which, to the writer's knowledge, was any considerable quantity of ore produced. The westernmost ore body in the group is in the Jason workings. South of this mine is the barren Poverty Flat. On the south, the Fryer Hill group is in a general way connected with the Carbonate Hill group, either continuously or through scattered ore bodies.

ORE "CONTACTS"

FAIRVIEW AND FRYER HILLS

The horizons of ore occurrence on Fairview and Fryer hills have a general similarity (pl. 59, section L). The upper contacts in this region were extensively explored in early days, and the best descriptions of them were those by Emmons[1] and Rolker.[2] The deposits at lower horizons, however, have been penetrated only by vertical shafts, and at the time of Irving's last visit they were comparatively unprospected. There is, therefore, little to be added to what Emmons has already written about this part of the district.

Ore has been found at six contacts on Fryer Hill, only the uppermost of which is of any considerable importance. (See pl. 59, column L, and pl. 67, sections A–A′ and B–B′.) The four upper contacts are along Blue limestone inclosed between sheets of White porphyry. The fifth was found in the Pandora No. 3 shaft and the sixth in the Climax No. 3 shaft, but neither, so far as known, has been productive.

The famous Fryer Hill ore bodies of early days were found in the syncline of Fairview Hill. The ores of the Matchless, Dunkin, Virginius, Pittsburgh, and Robert E. Lee occur in the anticline under Fryer Hill.

The large shoots along the first contact are separated by local dikes of Gray porphyry trending west-northwest, which have been mapped by Emmons as extending downward indefinitely; but in the light of developments in Iron Hill it is possible that these dikes also may be upward offshoots from the Gray porphyry sill that has been intruded into the White porphyry below the first contact. Another small Gray porphyry sill has also been injected between the uppermost White porphyry and the limestone and forms the roof of the first contact in the vicinity of the Little Chief shafts Nos. 1 and 4. The limestone of the first contact ranges from 10 to 100 feet in thickness, as shown in the sections of Plate 67.

Throughout the Fryer Hill area the mineralization was unusually intense, and practically the entire mass of limestone on the first contact has been replaced by ore and "vein material." Only here and there have irregular remnants of limestone—many of them entirely inclosed in ore—been left unmineralized. The ore shoots as represented on Plate 45 show only those portions which could be profitably mined at the time the Leadville monograph was written. Since then considerable lower-grade ore has been mined, and small shoots of high-grade silver-lead ore as well as a few small shoots of zinc carbonate ore have been extracted by lessees.

To the east and south of Fryer Hill the first contact continues but is underlain by a much thicker layer of White porphyry in the Small Hopes and adjoining mines.

The bodies of limestone at the second and third contacts, also one or two other subordinate contacts, are thin, mostly lenticular masses, 10 to 12 feet or rarely over 20 feet thick. They have not yielded ore except in the Vulture No. 2 mine, where the included mass attained a thickness of 59 feet, and in the Pandora and Kit Carson mines.

As the ore nearly everywhere replaces the entire included mass of limestone, the form of the ore bodies in the Fryer Hill district is determined by the configuration of the White porphyry contacts above and

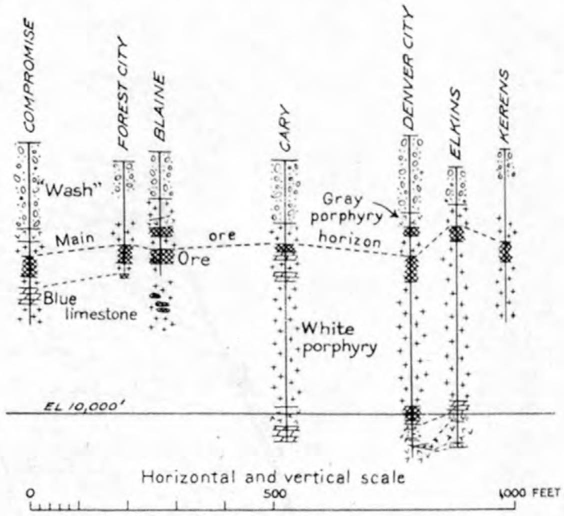


FIGURE 87.—Sections of some of the principal shafts of the Small Hopes mine, showing main ore-bearing contact above main White porphyry sheet. Shafts are all projected on a vertical plane striking N. 15° E.

below. The few remnants of unreplaced limestone are in part adjacent to the dikes of Gray porphyry that cut the White porphyry[3] and in part wholly inclosed in White porphyry.

In 1901, when the last visits were paid to this portion of the district (by Emmons or Irving), the contacts below the Parting quartzite had been but little explored, and, so far as known, they have not been explored more recently. The following shafts are shown by the records of S. F. Emmons to have penetrated the White limestone horizon.

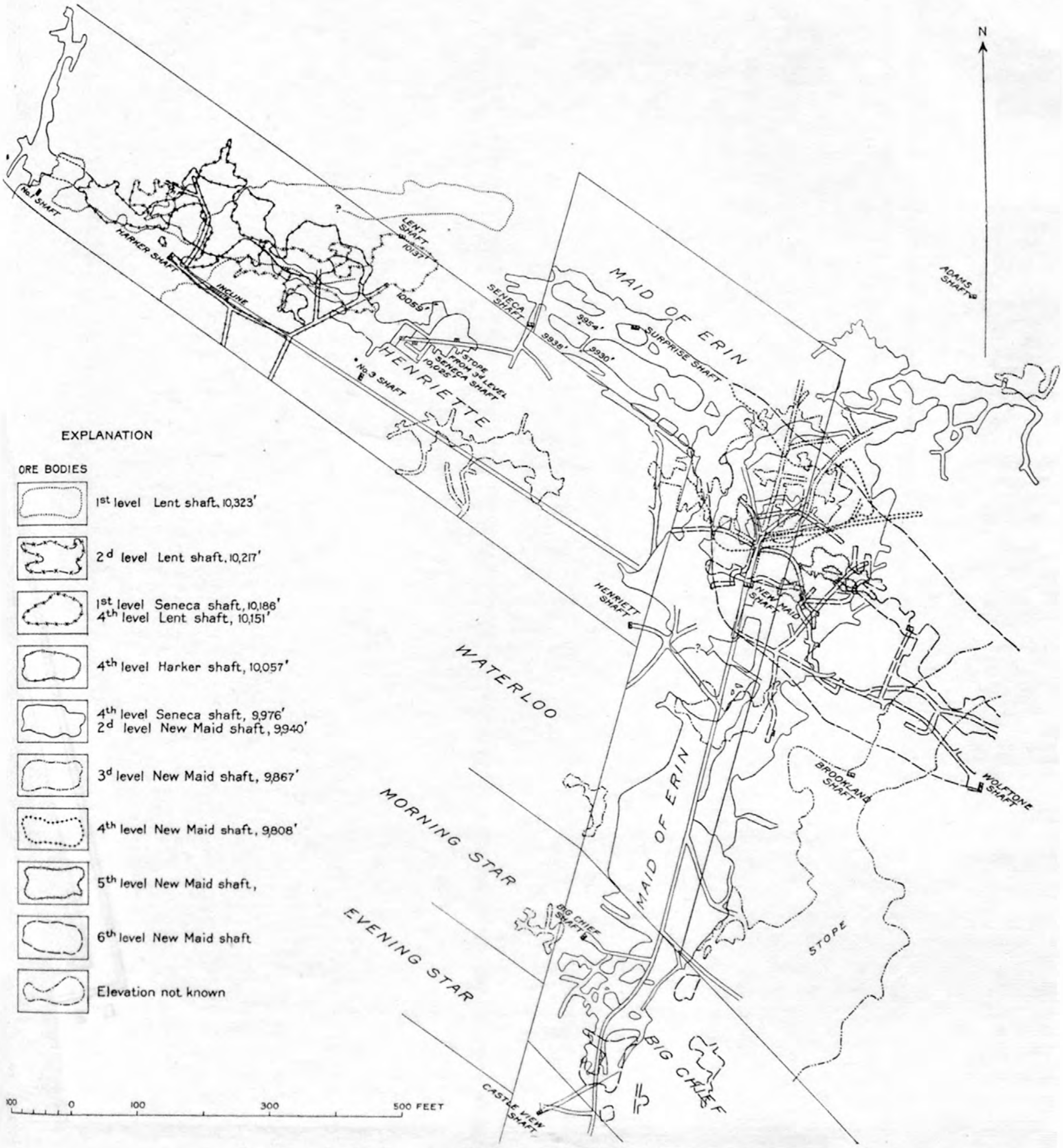
Buckeye shaft; sunk to Lower quartzite. No ore reported. (No record since 1880.)

New Chrysolite shaft and drill hole a short distance southwest of Roberts shaft; sunk to granite. No ore reported.

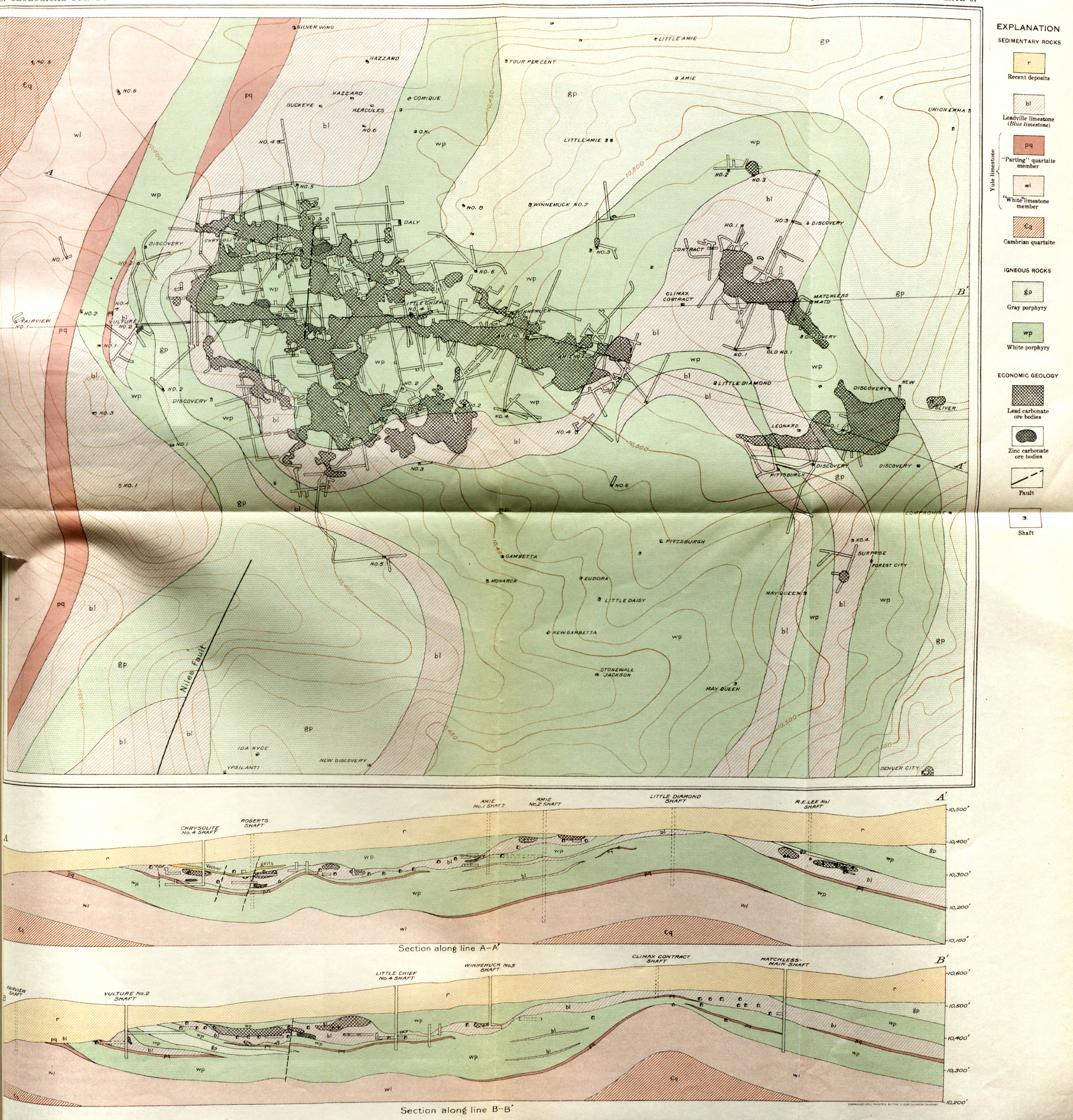
[1] Emmons, S. F., U. S. Geol. Survey Mon. 12, pp. 445–492, 1886.

[2] Rolker, C. M., Am. Inst. Min. Eng. Trans., vol. 14, pp. 273–292, 1886.

[3] This feature has been emphasized by C. M. Rolker (op. cit., p. 290) as having a peculiarly important significance in connection with ore genesis. To the writer (Irving) it appears merely as an accidental feature of the ore formation, of no special importance.



MAP OF HENRIETT AND MAID OF ERIN OLD WORKINGS



GEOLOGIC MAP AND SECTIONS OF FRYER HILL, LEADVILLE DISTRICT, COLO.

0 100 300 500 FEET

Contour interval 10 feet

New Discovery shaft No. 6; sunk 20 feet in White limestone. No ore bodies reported. (No record since 1886.)

New Discovery shaft No. 1; sunk to lower White porphyry below first contact. Drill hole in Lower quartzite in east drift. No ore reported below Parting quartzite. (No record since 1900.)

Dunkin Nos. 1, 2, and 3 shafts; sunk 20 feet in White limestone. Some ore below Parting quartzite reported. (No record since 1886.)

Matchless No. 6 shaft and drill hole; sunk into White limestone. No ore bodies reported. (No record since 1895.)

Except for these shafts but little exploration had been conducted, up to 1901, in the White limestone. The unsatisfactory results of the work done, however, may be inferred from the fact that the rocks below the Parting quartzite, though penetrated, were not extensively explored, a neglect which is the more remarkable because the richness of the ore bodies above might well have raised the hopes of the miners for valuable ore bodies below. All the ore on Fairview and Fryer hills from the White porphyry contacts was oxidized, although numerous and in places very rich residual masses of galena were found scattered through it.

EAST FRYER HILL

East of Fryer Hill there is a considerable area of productive territory bounded on the east by the Mikado fault, on the west by a line through the Harvard No. 2 and Little Sliver shafts, on the north by a line through the Price and Morris shafts, and on the south by a line through the Robert Emmet and Shenango shafts. The ore horizons differ somewhat in different portions of this area, as shown by Plate 59, sections K, M, N, and O.

There are four contacts in the Blue limestone in this area. The first is above the uppermost White porphyry and directly under the "wash"; the second and third are at depths of 40 and 70 feet, respectively, below successive minor sheets of about 40 feet of White porphyry; the fourth, 200 feet below the third, is under the main White porphyry sheet. The fourth contact has been cut in the Cary, Elkins, McCormick, and Denver City mines but has been productive only in the Denver City. The White limestone has been cut, so far as known, only by the McCormick shaft, where it was not found to be productive, although large ore bodies have been found in it in the Graham Park area, to the south (fig. 87). The first three contacts are oxidized and resemble the main contact of Fryer Hill in their undulating character. The main shoot, called the Small Hopes shoot, is at the second contact, and its positions in different shafts are shown in Figure 87. Much of the ore mined from this shoot was very rich, and the quantity extracted from less than 1 acre is reported to have yielded more than $6,000,000. Elsewhere at this horizon the ore was not so rich but compared favorably with ore in other parts of the district. The high grade of the ore was probably due to enrichment in the oxidized zone.

Available data on contacts a little to the east of the Small Hopes shoot are shown in Figure 88. The

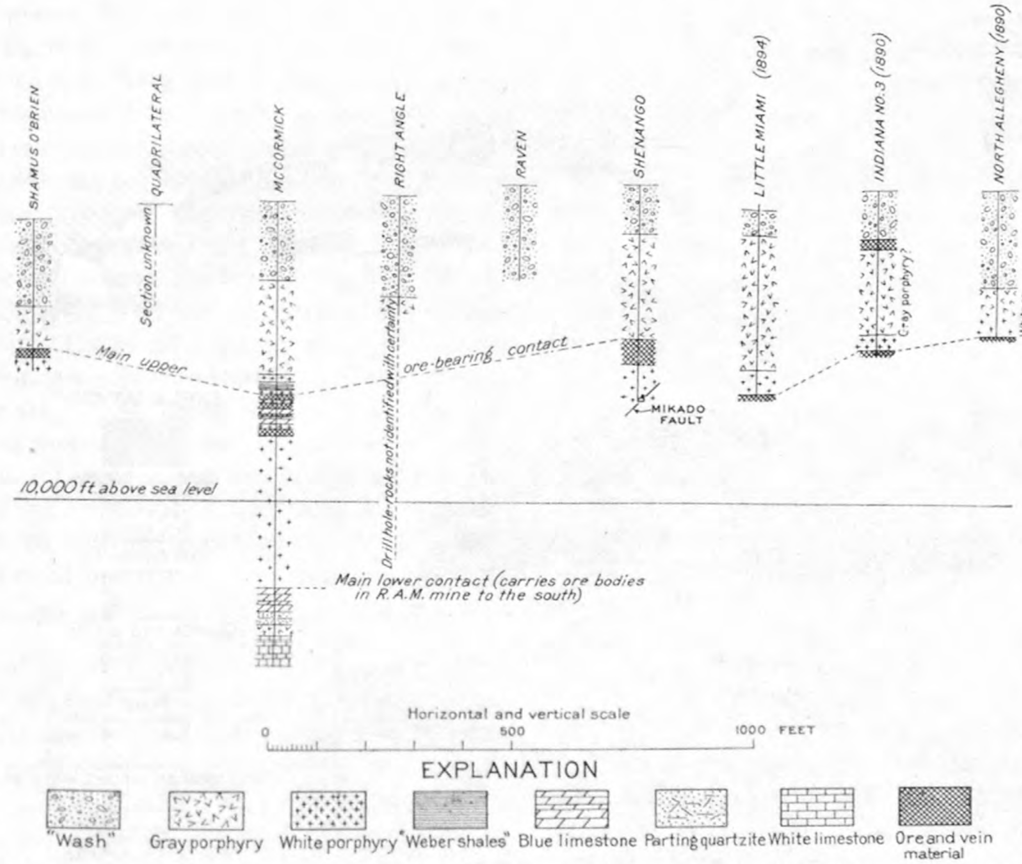


FIGURE 88.—Shafts in area between Small Hopes ore shoot and Mikado fault, showing persistence of upper Forest City contacts above main White porphyry to Mikado fault

principal production has been from the top of the main sheet of White porphyry through the Shamus O'Brien, McCormick, and Shenango shafts.

In the area west of the Mikado fault, between the Shamus O'Brien and Raven shafts on the south and the Morris and Harvard shafts on the north, ore has been found at two horizons, which have been extensively explored. One is below the uppermost thin sheet of White porphyry at the top of the Blue limestone and the other is within the Blue limestone. Just east of the Mikado fault in the Kennebec mine ore has been mined at two horizons in the upper part of the White limestone, one a little below the Parting quartzite and one at the top of the lower sill of White porphyry. The "second contact" has been most extensively developed in the Forepaugh, Olive Branch, and El Paso mines.

These ore bodies in Blue limestone were extensively mined in 1893–1896 by the Union Leasing & Mining Co., which produced 37,740 tons of ore having an average silver content of 76 ounces to the ton and a range of 17 to 260 ounces, according to Norman M. Estey.[4] The ore shipped was reported to be principally siliceous sulphide, but considerable iron and manganese oxide and low-grade zinc carbonate around the stopes prove that much oxidation had taken place. Iron was the principal base metal, and in some shipments it may have exceeded silica. Lead and zinc

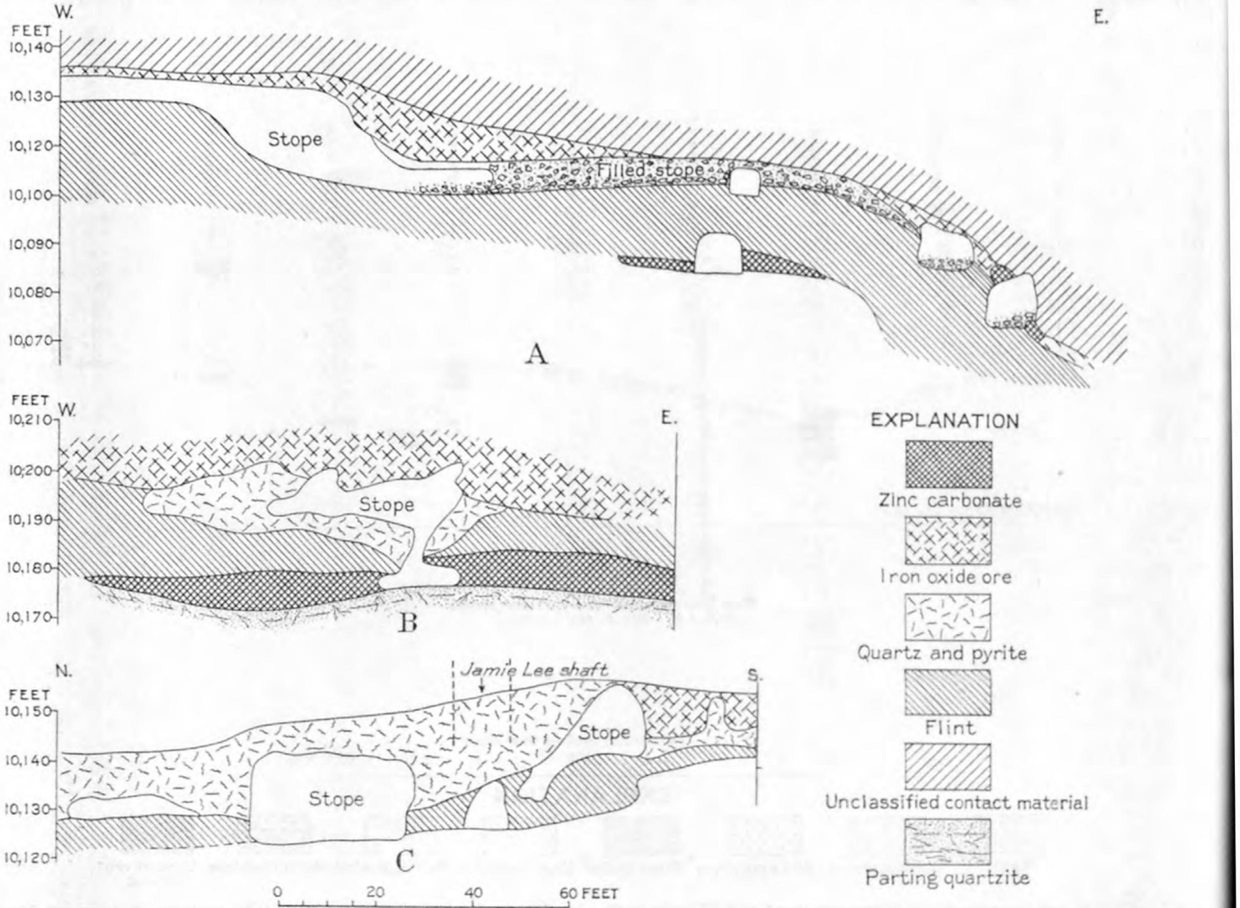


FIGURE 89.—Three representative sections showing distribution of ores and gangue along ore horizons of East Fryer Hill area. (After C. A. Allen.) A, 420 feet north of Bangkok shaft; B, 200 feet north-northwest of Tip Top shaft; C, 10 feet west of Jamie Lee shaft

ore horizons at the different shafts are shown in Figure 35.

The greater portion of the ore from the area has been obtained from the upper portion of the Blue limestone at or near its contact either with overlying black "Weber shales," White porphyry, or Gray porphyry. The ore departs from the immediate contact in many places—for example, in the Tip Top, Harvard No. 2, and Bangkok shafts—but for the most part it is at the immediate contact.

were generally low, but some shipments of sulphide ore contained as much as 25 to 30 per cent of zinc.

Operations were confined to the Blue limestone owing to the large amount of ground water, which was evidently lowered from its natural level of 10,205 feet sufficiently to drain the second contact. When operations were stopped by the general miners' strike in 1896 the mines were flooded. The Fryer Hill Mines

[4] Unpublished record dated January 23, 1915.

Co. later drained them again and did a little development work, including the sinking of the Harvard No. 2 shaft, but shipped no ore.

In 1917 and 1918 the mines were reopened by the United States Smelting, Refining & Mining Exploration Co., and ore was mined around the old stopes while prospecting by the diamond drill was being done in the White limestone. The ore around the old stopes comprised five classes—iron-manganese oxide, zinc carbonate, pyrite, siliceous pyritic silver ore, and zinc-silver sulphide ore.[5] The common relations of the ores and gangue, except massive pyrite, are shown in Figure 89. The stopes represent the ore mined by the Union Leasing & Mining Co., and doubtless the zinc-silver ore recently mined. Flint forms a persistent floor and in places along the second contact extends down to the Parting quartzite. In the zone of partial oxidation iron oxide irregularly overlies the pyritic ore and passes upward into "contact matter," an indefinite mixture of clay, silica, and iron oxide. Zinc carbonate is associated in small quantity with the iron oxide, but the principal deposits of it underlie the flint. Although comparatively rich samples were found at scattered points, the ores shipped in 1917–18 were of low grade. The zinc carbonate ore shipped contained from 14.8 to 19.7 per cent of zinc and as much as 0.6 ounce of silver to the ton. It came largely from the big stope just north of the Tip Top shaft and also from stopes near the Joe Davis and Olive Branch shafts. Large quantities of similar material containing 10 or 12 per cent of zinc were left unmined, as the minimum content accepted by the local zinc oxide plant was 14 per cent.

Representative smelter analyses of ores shipped from East Fryer Hill, 1917–18

	Silver (ounces per ton)	Zinc (per cent)	Iron (per cent)	Manganese (per cent)	Silica (per cent)	Sulphur (per cent)
Iron oxide ore	6. 9	------	28. 9	5. 4	35. 1	------
	8. 4	------	43. 2	------	3. 2	------
	9. 1	10. 2	25. 4	5. 0	23, 0	------
Zinc-silver-sulphide	8. 7	18. 0	------	------	11. 1	------
	10. 2	19. 0	------	------	10. 5	------
	11. 5	14. 2	------	------	9. 0	------
	16. 1	12. 5	------	------	------	------
	22. 0	20. 4	------	------	------	------
	22. 7	9. 5	------	------	------	------
Iron-silver-sulphide	7. 3	2. 5	43. 5	------	4. 3	46. 0
	7. 3	------	44. 2	------	2. 2	46. 5
	14. 3	12. 0	44. 8	2. 8	2. 5	------
	15. 9	------	45. 2	------	5. 1	------
Pyrite	1. 8	5. 3	------	------	------	46. 2
	3. 0	------	------	------	2. 0	47. 0
	1. 8	3. 4	------	------	------	47. 2
	1. 6	3. 3	------	------	------	48. 0
	3. 0	5. 1	------	------	------	49. 7

[5] According to company records, including a report by C. A. Allen, dated Jan. [illegible], 1917.

Shipments of ores represented by the first three groups in the above table were made while the price of silver was high, but when it dropped as low as 80 cents an ounce, late in 1917, much of the ore was of a little too low grade to pay for mining. Ore with 20 ounces or more of silver to the ton occurred only in small streaks and bunches. The pyritic silver ore came mainly from a body 100 feet southwest of the Jamie Lee shaft, and small quantities of high-grade (35-ounce) ore were mined by lessees near the Little Sliver and Forepaugh shafts. The sulphide ores represented above were low in silica, in contrast to the reported character of the ore formerly shipped (p. 282). The pyrite ore, shipped for the manufacture of sulphuric acid, differed from the pyritic silver ore in its very low content of silver and perhaps of silica also. Pyrite containing 45 per cent of sulphur was then worth $3.50 a ton f. o. b. mine, and a penalty or bonus of 15 cents a unit was applied to ore with lower or higher content. This ore was at first mined near the Tip Top shaft, but it graded into pyritic zinc ore, some of which contained too much zinc to be sold as pyrite and too little for zinc ore. Later shipments were made from a body about 400 feet southeast of the Tip Top shaft, north of an eastward-trending porphyry dike. This ore body was 8 to 9 feet thick and contained 3 ounces of silver to the ton and 2 per cent of silica. It had been topped by old workings, a fact which suggests that it graded into ore with higher silver content.

Explorations in the White limestone included the extension of the Jamie Lee shaft to a depth of 843 feet—the horizon of the "transition shales" below the White limestone—and the driving of several drill holes. One of these extended to the Cambrian quartzite below the shaft; another was driven eastward from the bottom of the shaft for 302 feet, with the intention of locating the Mikado fault, but was abandoned when it entered dolomite sand. A hole was driven westward from the bottom of the shaft for 250 feet, and another southward for 100 feet without promising results, although both extended beneath ore in the Blue limestone. Drifts from the Jamie Lee shaft also passed directly under the old stopes without disclosing mineralization. The only evidence of mineralization in the White limestone in this vicinity was a fissure 10 feet southeast of the shaft, striking N. 60° E. and dipping 53° NW., along which a little quartz and fine-grained sulphides impregnated the limestone.[6] Two drill holes, 80 and 260 feet south-southwest of the Tip Top shaft, reached the Cambrian quartzite and were reported to pass through 70 feet of Gray porphyry just above the quartzite; but no transition shale was recognized, although such shale

[6] Allen, C. A., unpublished report.

is present near by, and the rock reported as porphyry may be largely the shale. A few stringers, presumably of pyrite and quartz, were found in the bottom 1½ feet of this rock along its contact with the quartzite. The absence of ore in the White limestone here is in contrast with its presence in the Kennebec mine, just east of the Mikado fault.

The work done has failed to disclose any important course along which the ore-forming solutions could have risen, as they did in the Iron and Carbonate Hill areas. The considerable quantities of pyrite accompanied by quartz and manganosiderite southwest and south of the Jamie Lee shaft and 400 feet southeast of the Tip Top shaft imply that the solutions began to deposit their contents at these places and then deposited the mixed sulphides, which contain considerable zinc blende, but the course followed by the solutions was mainly along the bedding.

Most of the fractures noted by Allen in the walls of old stopes trend northeastward, whereas the ore channels trend in various directions but mostly northward. The ore channels lie along local undulations or "rolls" in the strata, where the limestone had doubtless been fractured more than elsewhere. Allen concluded that the intersections of northeastward-trending fissures with the axis of a "roll" were especially favorable places for ore deposition.

IRON HILL GROUP

In the Iron Hill and Rock Hill area, one of the two most productive areas in the district, sills of Gray porphyry are numerous, and ore has been found in one place or another at 10 contacts. The upper contacts when only partly developed were first described by Emmons and when more thoroughly developed by Freeland[7] and Blow,[8] but they had become inaccessible before the resurvey of the district was begun. The representations of ore bodies on Plates 22, 45, and 59 are based on these descriptions and more recent data and give a generally adequate idea of the location and extent of ore deposition, although certain ore bodies have doubtless been omitted from lack of information. Ores in the Cord and Tucson mines are described in some detail.

"FIRST CONTACT"

The "first contact," between the White porphyry and the first sheet of Gray porphyry below, has been thoroughly explored. (See figs. 90–95.) It is especially well developed in the workings of the Iron-Silver Mining Co., extending from the North Iron incline southward to the Doyle workings and eastward as far as the Louisville and Rubie shafts and Cord Winze. Southward from these points the uppermost sheet of Gray porphyry is in contact with the White porphyry, and the first contact is eliminated.

North of the Smuggler (along section H–H′, pl. 24) and eastward throughout the workings of the North Moyer mine, the sheet of Gray porphyry has separated from the White porphyry and the first contact is again present. In some places, as in the workings of the Accident shaft, shown on section K–K′, Plate 25, the upper sheet of Gray porphyry thins out entirely and the same ore body lies partly beneath the Gray porphyry and partly beneath the White porphyry.

The North Iron shoot and the South Iron shoot lie for the most part immediately beneath the White porphyry. The Gold ore shoot and the Rubie Channel shoot, as shown in section M–M′, Plate 26, lie mostly away from the contact. Their northeastern parts have greater vertical than horizontal dimensions and extend down along fissures to the Gray porphyry (section K–K′, pl. 25). The same is true of the Imes shoot (fig. 90). The White Cap and Smuggler shoots taper downward along fissures and pinch out before reaching the Gray porphyry.

In the workings of the Moyer mine, which lie west of the Adelaide fault, the upper ore horizon or "first contact" between the White porphyry and the first sheet of Gray porphyry is comparatively barren, but farther east, across the Adelaide and Mike faults, the ore bodies near the North Mike shaft and Habendum raise are probably at the "first contact."

"SECOND CONTACT"

In the southern part of Iron Hill and the adjacent part of Rock Hill as much ore has been produced from the "second contact" as from the first. On this "second contact" is a large irregular shoot which nearly parallels the Moyer fault. In the Moyer mine this shoot turns northward and parallels the Adelaide fault. The northward-trending part is known as the Moyer shoot. Near the A. Y. No. 3 shaft the shoot turns southward and extends under Rock Hill. This shoot is V-shaped and in places more than 40 feet in vertical diameter. In the vicinity of the Accident shaft this "second contact" shoot is interrupted by a steeply plunging mass of Gray porphyry, and a short distance to the northeast it joins the "first contact" shoot, which is cut off by the Adelaide fault.

The vertical dimensions of neighboring shoots in the Rock Hill area, like those of the Imes, Rubie, and other shoots in the South Iron Hill area, are greater than their horizontal widths, and these ore bodies also taper downward along fissures, or reach the Gray porphyry. From some of them mineralized fissures have been followed downward through the underlying Gray porphyry, but no work, so far as known, has been done to prove their persistence to deeper levels. For example, a sulphide ore body beneath Gray porphyry in the Moyer mine replaced Blue limestone on one side

[7] Freeland, F. T., The sulphide deposits of South Iron Hill, Leadville, Colo.: Am. Inst. Min. Eng. Trans., vol. 14, pp. 181–195, 1886.

[8] Blow, A. A., The geology and ore deposits of Iron Hill, Leadville, Colo.: Am. Inst. Min. Eng. Trans., vol. 18, pp. 145–181, 1890.

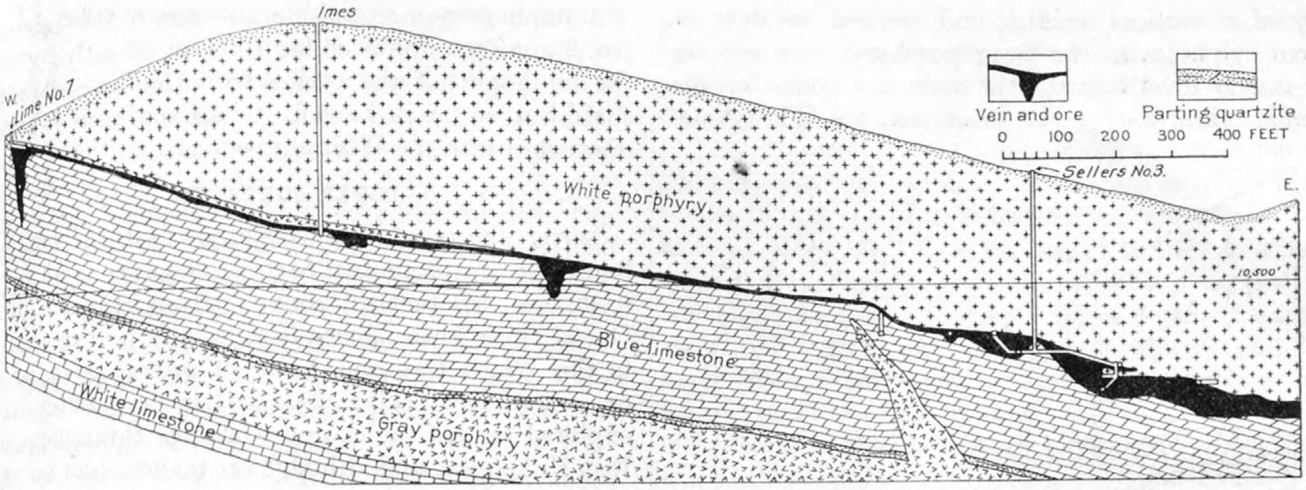


FIGURE 90.—Section through Imes and Sellers No. 3 shafts. (After Freeland)

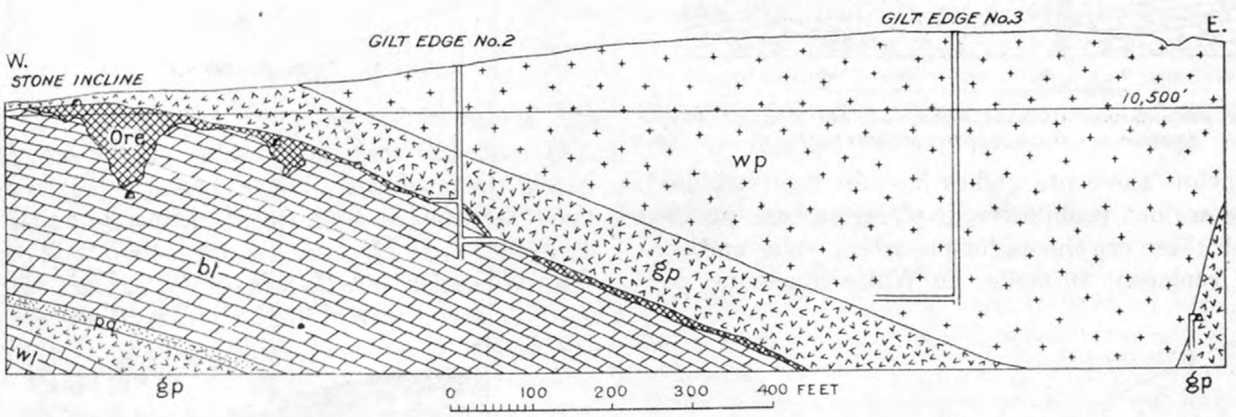


FIGURE 91.—Section through Gilt Edge shafts Nos. 2 and 3. (After Freeland.) wp, White porphyry; gp, Gray porphyry; bl. Blue limestone; pq, Parting quartzite; wl, White limestone

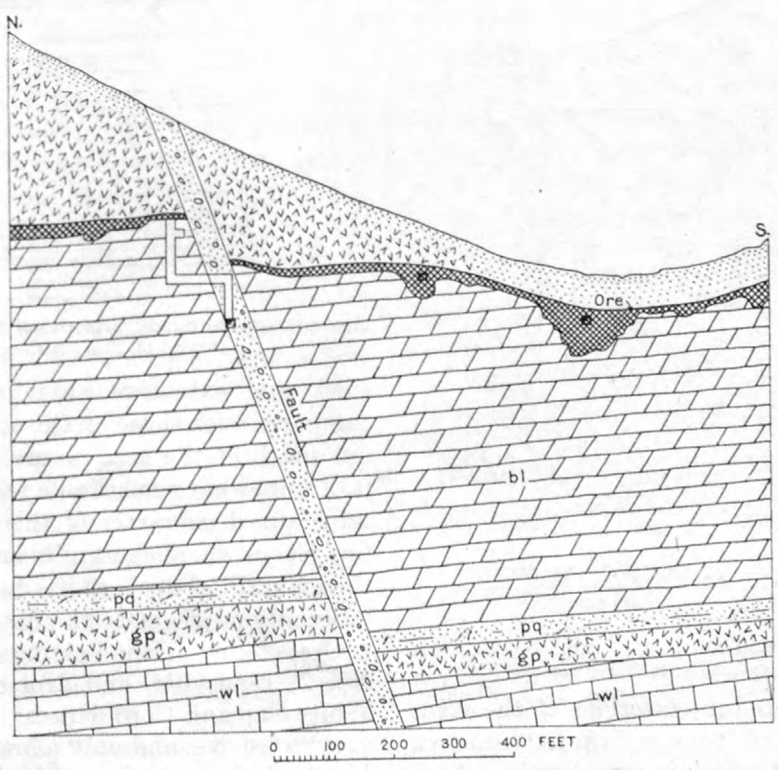


FIGURE 92.—Section across California Gulch west of Forfeit shaft and Stone incline. (After Freeland.) bl, Blue limestone; pq, Parting quartzite; gp, Gray porphyry; wl, White limestone

only of a vertical veinlet, and several veinlets of mixed sulphides in the Gray porphyry were cut on the second level beneath the main ore bodies of the Minnie mine; but, so far as known, the White lime-

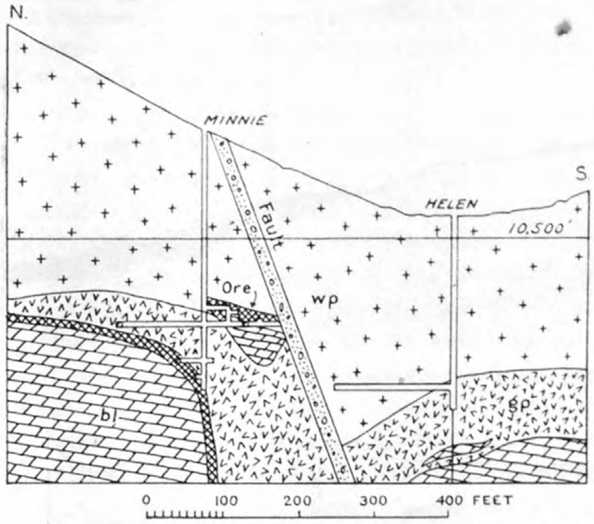


FIGURE 93.—Section through Minnie and Helen shafts. (After Freeland.) bl, Blue limestone; wp, White porphyry; gp, Gray porphyry

stone below these ore bodies has not been explored. If costs are not prohibitive, explorations are justified beneath these ore shoots for persistent veins and connected replacement bodies in White limestone, par-

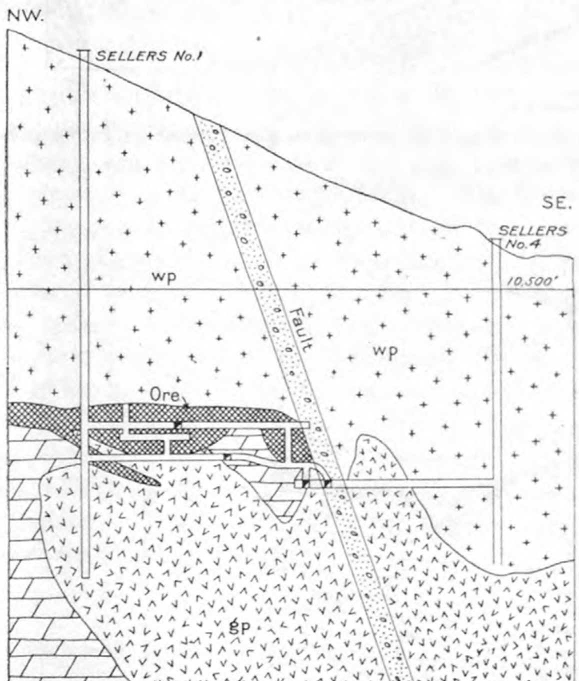


FIGURE 94.—Section through Sellers shafts Nos. 1 and 4. (After Freeland.) wp, White porphyry; gp, Gray porphyry; bl, Blue limestone

ticularly along the expected intersections of the veins with the Tucson-Maid fault zone and the little-known reverse fault G west of it, which is considered in chapter 5 (pp. 73–74).

A sulphide vein of considerable size in the Colorado No. 2 mine was followed for 100 feet directly beneath the ore shoot that was worked from the Ulster-Newton shaft, but, so far as known, it has not been followed downward into the White limestone.

LOWER CONTACTS

Lower sheets of Gray porphyry within the Blue limestone are present in parts of the area as offshoots from the persistent sill above or from irregular dikes. One of these lower sheets is especially well developed in the White Cap and Accident mines, as indicated on section F–F′, Plate 24. It has been extensively explored by drill holes and workings throughout the Iron Hill region, and although ore bodies occur beneath it in a number of places and some of them are fairly

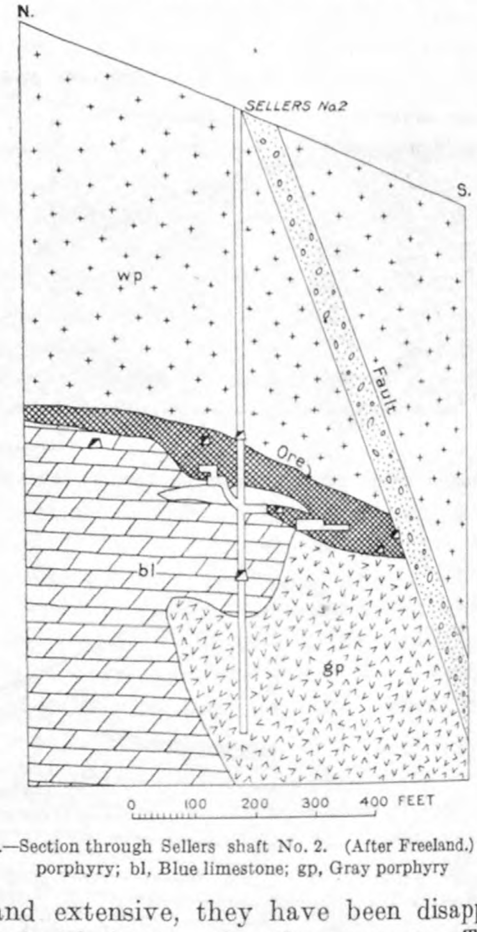


FIGURE 95.—Section through Sellers shaft No. 2. (After Freeland.) wp, White porphyry; bl, Blue limestone; gp, Gray porphyry

thick and extensive, they have been disappointing compared with those on the other contacts. Throughout much of the area no ore has been found beneath it, a somewhat remarkable fact in view of the heavily mineralized character of this part of the area. At a few places where short sills branch from dikes or from the main sill above, ore has been found beneath them, especially adjacent to the dikes.

Ore is found on the Parting quartzite in the Colorado No. 2, Louisville, and Horseshoe mines and in the White Cap and Cord winzes. This ore has not proved very extensive, and only a few bodies of it are known. Much of it merely forms the basal parts of ore shoots that lie mainly within the Blue limestone.

Ore is rarely found within the Parting quartzite in the Iron Hill area. The only productive shoot in this rock was found along the Cord vein where it crossed a member of the Tucson fault zone. Drill hole No. 71 from the Yak tunnel also disclosed a body of ore in the Parting quartzite.

Some ore bodies have been found at several "contacts" within the White limestone and underlying "transition shales" and quartzite in the Cord and Tucson mines and are described on the following pages. The "seventh contact," which is well marked from the Moyer mine on the northeast to the White Cap winze on the southwest, is unusual in containing large ore bodies that lie on top of a sheet of Gray porphyry but are separated from the ore immediately beneath the Parting quartzite by an intervening zone of barren limestone.

IRON HILL

CORD MINE

The most instructive group of ore bodies in the western part of the district comprises the Cord vein and associated stockworks and replacement bodies which have been worked below the Yak tunnel between the Cord and White Cap winzes. As shown on page 206 and in Figures 18, 19, and 21–24, it has been followed from the Blue limestone down into the Cambrian quartzite and crosses the reverse faults within the Tucson-Maid fault zone. A parallel vein just east of the White Cap winze has been followed downward from the Yak tunnel level to a junction with a small replacement body, but nothing further is known about it.

The lowest ore shoots mined included a distinct vein on the eighth level midway between the two winzes. At No. 58 raise the ore shoot expanded to a pipe 14 feet in diameter, which was followed upward for 60 feet and found to be connected with a limestone replacement body. The ore mined in the raise was siliceous pyrite with a relatively high gold content. The vein was followed northward and downward, and on the ninth level, where it crossed two members of the Tucson fault zone, it opened into a stockwork or "brecciated ore body" in Cambrian quartzite, which had been stoped in 1919 for a length of 100 feet and a width of 20 to 35 feet. The two branches of the Tucson fault formed northeast and southwest walls and the hanging wall of the Cord vein a distinct southeast wall. On the northwest side the ore graded into pyritic quartzite of too low grade for mining. The ore in this stockwork consisted of vuggy veinlets of pyrite and quartz cementing the quartzite fragments and partly replacing them. It closely resembled the ore of the South Ibex stockwork in Breece Hill. The gold content was very irregularly distributed, and samples taken close together ranged from 0.1 ounce in gold and 7 ounces in silver to 2 ounces or more in gold and 100 ounces in silver to the ton. Some of the high-grade ore was thickly coated with chalcocite, but some of it appears quite unaltered and can not be distinguished from low-grade pyrite without an assay.

The shattered zone containing the stockwork, although not continuously productive, was followed up to the sixth level, where another stockwork was found in Gray porphyry. This stockwork in 1919 had been stoped in a roughly circular area with a northwest-southeast diameter of 120 feet and a northeast-southwest diameter of 100 feet. Its northwest end lay partly in White limestone, which underlay the porphyry, and its northeast end was connected horizontally with a replacement body in White limestone. The ore in this stockwork was similar in character and variations to that on the ninth level.

Elsewhere in the porphyry sills that cut the White limestone the ore occurred in veinlike form, but the deposits were too thin to be profitably worked. Where the veins passed into White limestone, however, they expanded into large bodies that partly or completely replaced the limestone. The ore in these replacement bodies was mixed sulphide but varied from practically pure pyrite to practically pure zinc blende. The zinc shoots formed flat to lens-shaped segregations in the pyrite, ranging from a few inches to several feet in length and thickness. Ore from the exceptionally large ones was shipped as zinc ore without concentration. Galena, on the whole, was very subordinate to the zinc blende but was conspicuous in a few places. In some places the two minerals were rather evenly mixed, but in others they were practically independent of each other. No chalcopyrite was seen, but its presence is indicated by assay records. The gangue was mainly dense quartz or jasperoid, which formed from 2 to 18 per cent of the ore bodies above the fifth level and about 40 per cent of those below it. It was less prominent within the ore bodies than around their margin, where it replaced limestone and porphyry. The top of the replacement body at No. 58 raise, already mentioned, is marked by a continuous layer of finely pyritized jasperoid that had been regarded as quartzite but proved under the microscope to be thoroughly silicified porphyry. The only other gangue mineral noted was barite in small crystals or aggregates thinly scattered through the ore.

Ore was mined between the second and third levels from a stockwork that extended into the hanging wall of the vein. This stockwork was inaccessible to the writer, but, according to John Pendery, who had previously mapped it, extended along one or more transverse fissures and was mainly in Parting quartzite but tapered downward in Gray porphyry and upward in Blue limestone. It is approximately in line with members of the Tucson fault zone exposed at lower levels. The ore was pyrite with more than 1 per cent of copper and a relatively high content of silver. Only 2 out of 28 samples contained zinc or lead.

Workings in the Blue limestone were inaccessible, but a few small ore bodies have been found along the vein in its lower part, and one large ore body near the Cord winze is represented in the profile of the workings (fig. 24). Plate 25, section K–K′, shows a large "first contact" ore body directly above the Cord vein and presumably connected with it.

A study of the differences in the ores at different levels and in contact with different rocks was made from representative assay records selected in 1918 by John Pendery, formerly engineer for the Yak tunnel properties. A condensed list of these assays appears on page 2. Only six assays represent the vein below the eighth level, which had been newly opened at that time, but the ores between the eighth and fifth levels were represented by 25 assays, those between successive higher levels by 24 to 27, and those between the Yak tunnel level and the White porphyry above by 27. Only a few of these assays are presented here to show the range in composition of the ores.

The ore in No. 58 raise below the eighth level was mainly quartz and pyrite, with low percentages of other sulphides here and there and an average of 0.525 ounce to the ton of gold. The gold ranged from 0.08 to 2.05 ounces to the ton, the minimum quantity occurring in ore that contained the most zinc, lead, and copper and the maximum in practically pure pyrite. Silver also varied considerably. No assay records of the stockwork on the ninth level are at hand, but the ore is reported to have been high and variable in gold, like that in No. 58 raise. It showed some evidence of enrichment, but that in No. 58 raise showed little or none. The similarity of the siliceous pyritic ore in the Cord mine to that in the lodes of the eastern part of the district is very close.

Ore remaining in the stockworks on the ninth and sixth levels in 1921 was low in gold and for the most part in silver but in other respects was similar to that in No. 58 raise. The replacement bodies in White limestone between the eighth and fifth levels were also on the whole siliceous pyrite, though a few assays showed iron in excess over silica, and a few were comparatively high in zinc or lead or in both. Except in one assay, gold was very low and silver showed the the same general range as ore in the stockworks and vein. The sample that was exceptionally rich in gold and silver happened to contain considerable galena, but another sample with more lead was low in silver and very low in gold. In short, the precious metals were independent of each other and of the other constituents, so far as detailed comparisons were concerned, but the higher gold contents were as a rule irregularly distributed in siliceous pyrite ore between siliceous wall rocks.

Between the fifth and fourth levels the ore was less siliceous but had not changed materially in other respects. The same was true of the ore between the fourth and third levels, except that one-third of the samples were rather high in gold (0.14 to 0.64 ounce to the ton), and the average was correspondingly raised. The average copper content was also higher. From the third level up to the Yak tunnel level the ore continued to be pyritic with more iron than silica and with relatively high copper, but the gold was low again. Zinc and lead were prominent in a few samples but averaged low. Above the Yak tunnel, however, zinc and lead were much more abundant, and all the samples were classed as zinc-iron or zinc-iron-lead sulphate. Silver was lower than in the pyritic ore below the Yak tunnel, and gold was characteristically low.

Unfortunately, the Cord vein could not be studied continuously up to the White porphyry, but the direct connection between the pyritic ores low and high in gold and the presence of typical zinc-iron and zinc-iron-lead ore within the pyritic ores were sufficient to show that all these varieties of ore were found along one trunk channel and that the pyritic ore predominated at the lower levels in and close by the vein.

Representative assays of sulphide ore from different levels of the Cord mine

Between base of White porphyry and Yak tunnel level

[Average represents 27 assays]

Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)	Iron (per cent)	Silica (per cent)
0. 03	3. 2	0. 4	9. 8	19. 1	36. 4	1. 8
. 06	5. 2	. 0	1. 8	13. 6	34. 2	3. 2
. 03	2. 8	Trace.	5. 2	7. 6	34. 1	2. 2
. 02	4. 2	Trace.	3. 8	22. 4	25. 8	3. 4
. 04	4. 6	Trace.	7. 8	31. 2	20. 8	4. 8
----------	14. 2	-------	26. 0	22. 5	-------	-------
----------	5. 9	-------	7. 0	39. 0	-------	-------
Av -----	5. 1	-------	4. 8	17. 6	29. 6	-------

Between tunnel and first level below

[Average represents 27 assays]

Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)	Iron (per cent)	Silica (per cent)
0. 05	13. 7	1. 4	0. 0	0. 0	42. 6	5. 8
----------	10. 8	Trace.	12. 2	20. 0	-------	4. 0
. 01	3. 7	. 7	1. 5	23. 0	29. 2	2. 2
. 04	3. 1	. 0	4. 4	4. 8	34. 8	8. 4
. 03	2. 0	. 0	3. 6	9. 4	34. 8	5. 2
. 03	3. 2	. 0	2. 8	9. 4	38. 4	2. 7
. 06	30. 8	3. 0	. 0	. 0	40. 1	3. 5
. 06	28. 0	4. 1	. 0	. 0	40. 2	4. 6
. 05	13. 7	1. 4	. 0	. 0	42. 6	5. 8
Av. . 04	9. 6	1. 1	1. 2	3. 7	39. 4	4. 9

Representative assays of sulphide ore from different levels of the Cord mine—Continued

Between first and second levels

[Average represents 27 assays]

Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)	Iron (per cent)	Silica (per cent)
0.03	2.8	-------	8.7	14.9	-------	-------
.05	5.1	0.2	4.9	35.1	17.8	6.5
.04	5.1	.0	.2	2.6	33.5	15.8
.06	29.4	.2	.0	.0	36.5	4.6
.26	34.2	1.6	.0	.0	38.8	9.2
.02	3.0	.3	.0	.0	39.9	4.8
.05	7.4	.8	Trace.	1.2	42.8	2.1
Av.. 06	14.0	2.1	.6	2.7	38.6	7.2

Between second and third levels

[Average represents 28 assays]

Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)	Iron (per cent)	Silica (per cent)
0.04	201.0	2.5	20.8	19.0	20.8	6.7
.06	4.1	.0	.0	2.1	33.7	17.2
.10	71.3	.0	.0	.0	38.7	7.2
.05	28.6	3.2	.0	.0	42.2	3.2
.04	6.7	.9	.0	.0	43.1	2.3
.01	1.6	.0	.0	.0	44.0	5.8
Av.. 05	23.4	1.2	.7	.8	40.3	5.2

Between third and fourth levels

[Average represents 24 assays]

Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)	Iron (per cent)	Silica (per cent)
0.05	22.1	22.4	0.2	4.8	31.2	1.1
.04	7.0	6.5	.0	14.8	33.1	-------
.03	4.4	.8	.4	9.4	36.2	6.9
.30	43.0	.0	.0	.2	37.8	17.9
.64	5.2	.2	.6	Trace.	41.2	6.2
.28	1.6	.0	.0	.0	42.1	7.8
Av.. 13	10.4	1.6	.2	2.0	37.9	8.0

Between fourth and fifth levels

[Average represents 25 assays]

Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)	Iron (per cent)	Silica (per cent)
0.03	4.0	-------	10.3	20.8	-------	11.2
.02	4.0	0.0	2.3	29.5	17.7	7.1
.05	8.6	.0	2.3	3.1	31.9	17.8
.01	1.2	.0	Trace.	16.1	32.0	8.1
.13	32.6	.0	.2	2.4	38.4	11.9
.05	18.4	2.8	.0	.0	39.1	8.2
.06	11.8	1.0	.0	.0	42.4	4.2
Av.. 05	10.9	.7	1.1	4.8	36.7	8.8

Between fifth and eighth levels

[Average represents 25 assays]

Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)	Iron (per cent)	Silica (per cent)
0.02	3.0	0.0	0.0	0.0	5.7	74.4
.02	1.5	.0	.0	.0	10.2	74.6
.03	9.1	.5	15.7	19.5	12.8	26.8
.01	1.2	.0	.0	.0	13.8	71.0
.44	440.0	2.3	11.3	.0	21.2	36.6
.05	22.5	1.4	2.1	.0	36.3	17.2
Av.. 06	28.0	.5	2.1	2.4	22.5	43.7

Representative assays of sulphide ore from different levels of the Cord mine—Continued

Below eighth level (winze below No. 58 raise)

[Average represents 6 assays]

Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)	Iron (per cent)	Silica (per cent)
0.12	4.5	0.2	Trace.	0.0	12.8	71.0
.08	18.0	2.1	2.9	3.9	28.2	28.0
2.05	24.5	.0	.0	.0	45.2	1.6
Av.. 53	15.0	.6	1.1	.9	27.6	37.8

TUCSON MINE

No veinlike deposits have been developed in the Tucson mine for any great distance, but the ores connected with auxiliary fissures on the footwall side of the Tucson fault and locally within the fault have certain similarities to those mined in distinct veins. Ore has been mined at all levels from the base of the White porphyry or "first contact" down into

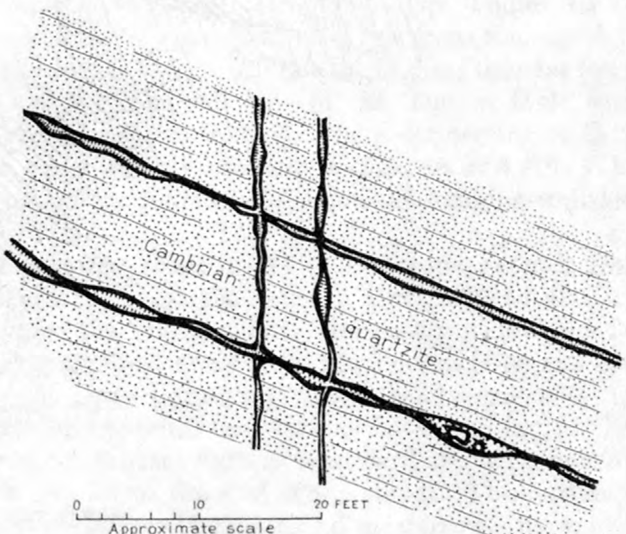


FIGURE 96.—Fissures in Lower or Cambrian quartzite, Tucson mine, North Iron Hill, showing crustified linings of sulphides and manner in which they connect with irregular solution centers, which follow the eroding of the quartzite and are now lined with incrustations of sulphides. Scale about 4 feet=1 inch

the Cambrian quartzite as far as the tenth level (figs. 18, 20, 96, and 97). Those at and below the fourth level lie in or near the Tucson fault and are described in ascending order.

Deposits in Cambrian quartzite.—Between the tenth and the eighth levels an ore body very rich in silver and gold has been mined in Cambrian quartzite. The ore (figs. 84, 85) has replaced and filled cavities in a certain bed of quartzite along a network of vertical fissures, the strongest of which trend east-northeast, about at right angles to the strike of the Tucson fault.

There is no connection with the fault, however, the ore stopping 100 feet away from it. The workings were flooded when the mine was visited in 1913, and the following description[9] is quoted from a paper by George O. Argall, manager of the mine:

The Cambrian quartzite in the vicinity of the Tucson shaft is shattered by a series of vertical fractures striking approximately northeast and southwest. Along these fractures occur open cavities of varying dimensions from oval-shaped conduits a few inches wide to channels 10 feet wide and 4 feet high along the strike of the quartzite beds. Incrustations of ore, from a few inches up to 2 feet in thickness, completely line these openings, but where the large cavities occur the roof ore is often found on the floor with fragments of the quartzite roof caved down upon it. * * *

It would appear from the thickness of the mud deposited on this caved ore and quartzite, often 10 inches in depth, that the collapse of the roof is not by any means a recent occurrence. Furthermore, this brown mud deposit might indicate the downward circulation of meteoric waters from the Silurian [White] limestone ore deposits immediately above. The longest distance so far opened in a vertical fissure in the quartzite is 80 feet; this fissure shows three chimneys, the largest 3 feet by 1½ feet, standing vertical and lined with the same minerals. The openings in the fissures vary from a width of 18 inches down to a mere film or incipient fissure, often difficult to follow. Cross fissures also occur carrying the same mineralization, while open joints in the rock are often coated with pyrite or blende.

The ore occurs in the fissures and cavities mainly as a crusted structure with a regular succession of mineralogically different layers, as follows: Argentiferous sphalerite, pyrite, galena, and chalcopyrite. The sphalerite and galena are found throughout the entire length of the fissures, while the pyrite and chalcopyrite occur at infrequent intervals. At points where these cavities take a sudden pitch downward and where "potholes" or

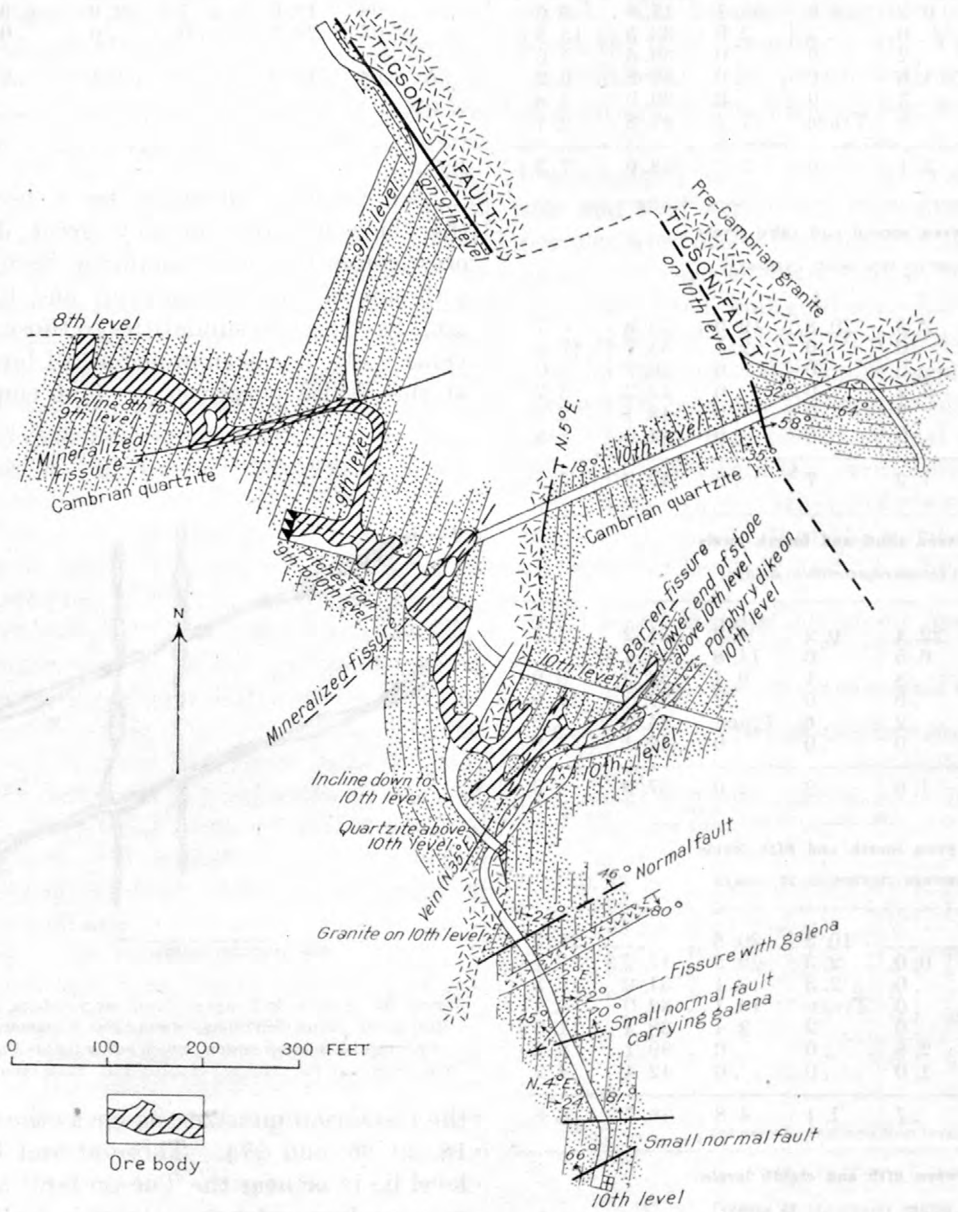


FIGURE 97.—Plan of ore body in Cambrian quartzite between eighth and tenth levels of Tucson mine. (From map by F. A. Aicher, Iron Silver Mining Co.)

[9] Argall, G. O., Recent developments on Iron Hill, Leadville: Eng. and Min. Jour., vol. 89, p. 263, 1910.

other irregularities occur in the floor, pockets of a rich silver sulphide mineral are found.

The quartzite often shows a honeycomb structure where the channels split up into numerous small cavities, usually along a bedding plane. The cavities are always lined with ore. Invariably a small seam of ore connects one cavity with another, and on being followed * * * these seams eventually lead into a large single cavity where the ore has been deposited in much thicker layers.

The ore minerals, besides forming crusts, impregnate and replace the quartzite to some extent. The replacing sulphides form a fine, even-grained mass which passes abruptly into the coarse-grained crystals that line the cavities. Partly replaced quartzite fragments are inclosed in ore. In one thin section there is a perfect gradation from pure quartzite through a transition zone where the interstices are filled with sulphides to a rim where quartz grains as well as the original interstitial matrix are almost wholly replaced by sulphides. Siderite impregnates and replaces the quartzite just within the rim and is also abundant among the coarse-grained sulphides outside the rim. The fine-grained sulphides in the quartzite are chiefly pyrite and zinc blende with a little galena; the adjacent cavity filling consists essentially of galena and siderite with some zinc blende, coated by the argentite-bismuthinite intergrowth "lillianite." Of the minerals filling the cavities zinc blende was deposited first, followed by siderite and galena, in part intergrown but with galena also forming veinlets in the siderite.

No chalcopyrite was noted in this thin section, but specimens were collected showing chalcopyrite in relatively large grains scattered among mixed sulphides and also in relatively pure masses. Specimens were also found showing pyrite with a little chalcopyrite and a minor amount of unreplaced quartz but no zinc blende or galena.

Specimens broken from cavity linings were cellular; they showed crystals of all the sulphide minerals and of siderite, the last in minute yellowish-brown flat rhombs. Where an order of crystallization was distinct pyrite and blende were evidently formed before the galena and chalcopyrite, and siderite finished crystallizing last. A polished surface of quartzite and ore was described by Argall[10] as consisting of (1) an inner zone one-sixteenth inch thick of fine galena with a little blende and pyrite on quartzite, (2) a band one-fourth inch thick of blende and pyrite with a few spangles of galena, forming a distinct crust, (3) irregular grains of chalcopyrite lying mostly in cavities between the outermost crystals of (2), and (4) massive crystals of galena 1 inch thick, some of them coated with a film of the argentite-bismuthinite intergrowth. This film Argall considered to be a secondary deposit from descending waters.

[10] Op. cit., p. 264, fig. 5.

The dissolving of cavities in the quartzite indicates that the solutions first passing upward through it were undersaturated in silica and did not deposit ore and gangue minerals until they had got farther along in their course. At a later stage solution of the quartzite was accompanied by deposition of pyrite and subordinate zinc blende and was followed by deposition of the sulphides and siderite in open cavities. The minerals in the cavity filling represent a solution that had already been depleted in pyrite and silica and may be regarded as a product of the waning stages of ore deposition, which took place in cavities that had been opened in an early stage. The mud in the cavities, derived from shaly material above, shows that some material has been deposited by descending waters and lends support to Argall's inference that the coatings of argentite-bismuthinite intergrowth are of supergene origin; but the other minerals are identical in character with those of undoubted hypogene origin elsewhere in the district, and there is no proof that the intergrowth also is not hypogene.

Deposits in White limestone.—Ore bodies in the White limestone occur at intervals from the eighth up to the fourth level. All but the highest thus far found are on the footwall side of the Tucson fault, some wholly separated from it, others connecting with it, and one probably crossing it (figs. 18 and 20). One stope, on the fourth level, is on the hanging-wall side of the fault.

The lowest stope in White limestone extends from the eighth up to the seventh level, 300 to 400 feet south of the Tucson shaft. Its east wall is from 180 to over 250 feet away from the Tucson fault and consists of Gray porphyry, which locally crosscuts the strata and extends eastward as far as the fault. The porphyry contact flattens westward above the seventh level and forms the roof of the stope. The outline of the stope is very irregular, and the narrower parts have generally northeast trends, parallel to the more conspicuous fissures in the quartzite stope, which lie 200 feet or more to the north. The ore is a mixture of pyrite and zinc blende, with little or no galena and low silver content. This stope terminates downward in a narrow sulphide vein[11] along the margin of the porphyry mass.

Another stope has its lowest point in the Tucson fault above the seventh level and about 100 feet southeast of the shaft. It rises with irregular outline in the fault up to the sixth level and is continuous with a blanket replacement deposit 13 to 19 feet thick, which extends in a generally north-south direction for over 300 feet and has a maximum width of nearly 200 feet. The outline of the stope suggests that the ore body formed along a series of intersecting north-south, east-west, and northeast-southwest fissures (fig. 20), which

[11] Argall, G. O., op. cit., p. 265, fig. 6.

lie at angles of about 45° and 90° to the local trend of the Tucson fault (N. 40° W.). The stope lies almost directly above the ore body in the quartzite, and it is believed that the solutions rising through the quartzite during the early stage deposited the ore by replacement of White limestone along the impervious barriers formed by the porphyry sill and by the gouge and quartzite hanging wall of the Tucson fault. The ore body is bordered on the southwest by manganosiderite accompanied by patches and streaks of magnetite ore. It is a varying mixture of pyrite, blende, galena, and chalcopyrite and includes three commercial varieties, zinc, zinc-lead, and copper ore. A blende-pyrite mixture commonly predominates at the top of the stope, whereas blende and galena, the latter in thin distinct layers parallel to the bedding, are found in its lower part. The silver content of these ores is low. Chalcopyrite is inconspicuous in the stope except close by the Tucson fault, but it forms prominent lenses in the lowest part of the stope, which occupies the fault between walls of siliceous rock, quartzite, and porphyry. It also extends with the other sulphides a short distance into the quartzite hanging wall. This one ore body, in short, shows a gradation from the gold-copper ore characteristic of the lodes in the eastern part of the district to the mixed sulphide ores characteristic of the "blanket" ores in the western part of the district. According to Argall [12] chalcopyrite accompanied by chalcocite impregnates the zinc ore in the stope along fissures or watercourses. He states that enriched ore, composed of chalcopyrite, chalcocite, and a silver sulphide, was concentrated in the fault and for a distance of 30 feet from it; but no specimens of such ore could be obtained when the mine was visited in 1913.

At one place in the fault, 50 feet northwest of the shaft and 30 feet below the sixth level, a lens of arsenopyrite was found. The lens was 4 or 5 feet long, 3 feet wide, and 1 foot thick, lying parallel to the pitch of the ore shoot in the fault. At another place a pocket in the hanging wall of the fault at the sixth level contained distinct blende crystals one-fourth inch in diameter, with a few of chalcopyrite inclosed in the outer parts of blende crystals or perched upon them. Distinctly later than these was a deposit of fine galena crystals, some in drusy aggregates lining depressions among blende crystals but many in small stalactites grown upon blende crystals. The galena was largely coated with a fine dust, which may represent a secondary silver mineral, as the ore at this place contained 80 ounces of silver to the ton. The appearance of the galena is strongly suggestive of secondary origin, although it may be impossible to draw a sharp line between primary and secondary galena, as both have crystallized later than the blende. The facts, however, accord with observations and the results of experimental work which have been discussed by W. H. Emmons [13] and which show that secondary galena may be deposited on blende or pyrite, whereas secondary silver sulphide may be deposited on galena, blende, or pyrite.

The stope is continuous up the fault to the fifth level, where it extends along the west side of the Tucson fault for about 150 feet. It is roofed by another porphyry sill, which has a slight southeastward pitch. Two other stopes on the sixth level, about 300 and 600 feet northwest of the shaft, have the same general character and variations as the stope just described. They both extend up to the fifth level.

On the fifth level about 100 feet south of the shaft is a stope extending about 130 feet from east to west and 80 feet from north to south. It crosses the line of the Tucson fault, both walls of which at this place are White limestone. The footwall part of the stope lies between two porphyry sills, which converge westward. The hanging-wall part replaces the shattered basal beds of Cambrian "transition shales" and passes eastward into a low-grade material, which extends a considerable distance farther. The shaly character of the "transition shales" is not very marked in this vicinity, and as they are not readily distinguished from the lower part of the White limestone, it has been the local custom to regard the White limestone as lying directly upon typical Cambrian quartzite. (See fig. 20.)

The only stope opened on the fourth level in 1913 was about 700 feet northwest of the shaft in the White limestone hanging wall of the fault, against a footwall of Parting quartzite. When visited it had been opened only for a short distance, and no adequate idea of its outline could be formed. It lay approximately at water level, and its ore, a zinc-lead sulphide mixture was partly oxidized, oxidation working inward from numerous fractures and bedding planes.

Ore in cross faults.—Some of the cross faults in the quartzite hanging wall are metallized. One is said to contain zinc blende, pyrite, limonite, and a little copper stain on the seventh level about 200 feet east of the shaft, showing that locally oxidation has extended considerably below the fourth level. Another cross fault has been worked on the sixth level, about 260 feet northwest of the shaft. The ore at this place runs 2 ounces of gold to the ton. It consists chiefly of pyrite, blende, galena, and a little chalcopyrite scattered through a quartz or quartzite gangue. Sooty chalcocite has been deposited along fractures and has replaced all the sulphides to a small extent. Scattered grains having a blue color suggestive of covellite and green specks of malachite are also present. A little chalcedony or opal was deposited after the black material. This local downward enrichment in copper implies

[12] Op. cit., p. 265.

[13] U. S. Geol. Survey Bull. 625, pp. 137-140, 1917.

that the high gold content also may be due to downward enrichment.

Deposits in Blue limestone.—The ore above the fourth level is all oxidized. Three stopes of moderate to small size have been mined in Blue limestone on the third level. The largest stope, about 400 feet due south of the shaft, lies approximately where the Tucson fault should cross the third level if it were continuous to that height. Its major axis lies at about right angles to the trend of the fault, but its branches follow the same directions as those of the lower stopes, suggesting that the ore replaces Blue limestone along a network of fissures related to the Tucson fault. Another ore body, shown in figure 18, lies along the fault at the second level, and still another lies not far east of the fault beneath a Gray porphyry sill. This last-mentioned ore body as outlined by stoping, is 300 feet long and averages 100 feet in width. Its western half trends southwest, at right angles to the fault, and its eastern half trends a little south of east. Short branches from it trend northwest, north, and northeast. Directly above it is the great North Iron ore shoot, which also trends northeast, parallel to the mineralized cross faults and other mineralized fissures at lower levels. Oxidation prevents close comparison between these upper ore bodies and those in White limestone along the Tucson fault, but the large quantities of siliceous iron and manganese oxides and zinc carbonate along the North Iron shoot (fig. 18) show that it was originally similar to the zinc-iron-lead ores on the fourth, fifth, and sixth levels, although the ratio of lead to other metals may have been higher.

Representative assays of ore between the fourth and tenth levels are shown below. The ores that were highest in gold and silver were much less in quantity than the others, as may be realized from the plans and sections of the stopes. The most striking feature bearing on genesis is that ores represented by analyses 3, 4, and 5, which strongly resemble ores of the Winnie-Luema lode, occurred along the same premineral fault as ores represented by analyses 1 and 2, which are typical of ores in the blanket deposits of the western part of the district.

Assays of ores in Tucson mine, along the Tucson fault and in the Cambrian quartzite

	Gold (ounces per ton)	Silver (ounces per ton)	Lead (per cent)	Copper (per cent)	Silica (per cent)	Iron (per cent)	Manganese (per cent)	Zinc (per cent)
Fourth level stope:								
Oxidized ore	--------	13.7	14.9	--------	32.1	22.8	1.8	2.3
Sulphide ore	--------	8.0	11.65	--------	--------	--------	--------	26.2
Sixth level, mixed sulphide ore from bottom of White limestone trending into Tucson fault	0.45	148.0	13.2	2.8	16.8	5.9	--------	34.3
Seventh level, sulphide ore in Tucson fault	.045	17.15	--------	2.7	24.0	27.3	--------	4.5
	.52	125.00	12.3	9.95	15.4	18.3	--------	11.45
Ninth level:								
Rich (sorted) silver-gold ore in Cambrian quartzite	14.45	3,987.0	44.7	--------	--------	--------	--------	--------
	15.27	4,109.0	42.5	--------	--------	--------	--------	--------
Remaining ore in quartzite channels [a]	.3	140.0	15.0	--------	17.0	--------	--------	35.0

[a] Sulphur, 25 per cent.

ADELAIDE PARK GROUP

The Adelaide Park group includes the small, wedge-shaped block between the Iron and Adelaide faults and the adjoining area between the Adelaide fault and the Eureka pipe of rhyolitic agglomerate. The wedge-shaped block has been developed through the Argentine and Camp Bird tunnels and the Adelaide Nos. 1 and 2, Terrible Nos. 1 and 2, Ward, Humboldt, Frenchman, and Flagstaff shafts. In the early eighties a considerable quantity of ore was mined in this area, but the workings have long been inaccessible, and records of them are insufficient to permit a satisfactory discussion of the ore horizons or to supplement the data presented in the Leadville monograph.[14]

Column J on Plate 59 represents the horizons at which ore is known to have been found. The Argentine tunnel, which was driven southward from Stray Horse Gulch, cut strata of steep southeastward dip beginning with White limestone and extending into the main sheet of White porphyry, which here has cut downward to the lower part of the Blue limestone. Other sills of porphyry, cut at different intervals, are represented in Plate 13.

Most of the ore first found in Adelaide ground was east of the tunnel. It consisted of small bodies of relatively high-grade carbonate ore and lay for the most part immediately under the Parting quartzite. Later developments in the Ward shaft of the Adelaide mines found ore at a still lower horizon, apparently in the transition beds beneath the White limestone. Ore was also found in the workings of the Frenchman, Humboldt, and Flagstaff mines, still farther east, but its exact geologic relations in these mines could not be ascertained. The Flagstaff workings are said to have cut the Adelaide fault. In one place drifts were run for several hundred feet along the fault, which contained considerable dragged-in galena ore.

East of the Adelaide fault a considerable quantity of ore is reported to have been mined in the Park Benton, Morning Glory, and Lady Alice mines, and

[14] U. S. Geol. Survey Mon. 12, pp. 401-408; atlas sheets 26 and 27, 1886.

in the Park No. 2 shaft a body of low-grade pyrite was found at a depth of 65 feet; but neither the outlines of these ore bodies nor their geologic horizons are known. The ores in these mines, particularly the Park Benton, contained varying quantities of magnetite and specularite and in this respect are closely related to the ores of the old Breece iron mine and other mines in the Penn group to the east. Gold-bearing sulphide ore was also found in the Park Benton mine.

PENN GROUP

The Penn group of ore bodies which lies beneath the northwest slope of Breece Hill, includes one productive vein and several blanket deposits, some of which are of considerable size. The vein was first cut on the first level 95 feet west of shaft No. 3 and 80 feet below the surface. It consists of a zone of much broken and decomposed porphyry between fairly well defined walls, with a comparatively narrow seam of ore occupying the middle of the crushed zone. Its trend is nearly north, but its south end bends slightly to the east of south and its north end slightly to the west of north. It dips 85° W. and ranges from 3 to 6 feet in width. It was not followed upward to the surface, nor to its end in either direction. The workings on the vein at the time of visit consisted of four drifts at depths of 80, 155, 500, and 800 feet below the surface. Along the strike it had been opened up for a distance of 200 feet.

The ore in the upper levels was a soft, oxidized, iron-stained material with a high content of gold, in the middle of a clayey mass. At the lower levels it changed to sulphide, chiefly pyrite much enriched by sooty chalcocite, which contained as much as 8 per cent of copper and from half an ounce to 5 ounces of gold to the ton. A connection between this vein and the blanket ore bodies above could not be observed in the mine workings, although one may exist.

The most productive portion of the area and that portion within which the blanket ore bodies are closely spaced and comparatively extensive comprises the flat ore shoots worked from the Penn No. 2, Penn No. 3, Nettie Morgan, Big Six, Little Prince, Ballard, and President shafts. These ores replace Blue limestone beneath an earlier replacement mass of magnetite, specularite, and silicates. The unproductive part of the limestone has been so greatly changed by metamorphism and by subsequent hydrothermal alteration and oxidation that it is now difficult to judge of the original character of the rock or to determine at what horizon the ore bodies occur.

The available maps of the mines in this area are insufficient for the determination of any dominant trends to the ore bodies of the group. The altered sedimentary formations extend southward past the Penn No. 3 shaft, beneath a capping of Gray and White porphyries, and are finally lost in the great stocklike mass of porphyry. The Chippewa shafts Nos. 1 and 6 were sunk to depths of 230 and 500 feet, respectively, without penetrating the porphyry.

On the east the Penn group is separated by the Weston fault from ground which has been productive but of which no records remain. Ore has been worked in the Eliza and adjacent mines east of the fault, and the ground between the groups of ore bodies shown on Plate 45 may not actually be barren, although no production from it is on record.

On the west the ore-bearing rocks are cut out by the Eureka pipe of agglomerate. There are no records of the Kent and Ishpeming mines, southwest of the Penn No. 1 shaft, and here again the apparent gap between the ore bodies of the Penn and Adelaide Park groups may be due to the lack of records as well as to destruction of ore bodies by the agglomerate.

Northeast of the agglomerate the limits of the Penn group are still more indefinite. The only data obtained on mines in this vicinity since Emmons's first survey are furnished by recent developments in the Great Hope mine. There the ore has been found in Blue limestone, which is also known to be mineralized in the White Prince, Bosco, and Across the Ocean mines. This portion of the Leadville district seems to have remained comparatively idle for a long period and not to have had the attention paid to it which its favorable conditions would seem to justify. The work done has been above ground water. The ore of the Great Hope mine is described on pages 225–226. The workings indicated on Plate 45 were completed by 1882 but still represent the area fairly well, as probably less than 1,000 tons of ore has been shipped from it since then.

YANKEE HILL AREA

The Yankee Hill area, between the Fryer Hill and Penn groups of ore bodies (pl. 13), is not known to have contained any important ore bodies or to have produced any considerable amount of ore. It presumably is one of the several comparatively barren and unproductive areas that intervene between the more heavily mineralized portions of the district. Extensive exploration has been carried on in this area, however, and has apparently resulted in the discovery of some small, discontinuous deposits.

Northeast of Yankee Hill the Mammoth Placer shaft has been sunk on the north side of Evans Gulch just south of the thick glacial moraine. Sulphide bodies of low grade and of considerable size have been disclosed in the lower workings of this mine but have not been worked at a profit. Some high-grade ore also is said to have been found. The possible extension of the Colorado Prince reverse fault in this direction has been suggested (p. 76) and if proved will be a favorable structural feature. Very little is known of the geologic structure here, however, and considerable exploration will be necessary before prospecting can be established on a sound geologic basis. If the Canterbury Hill tunnel eventually drains this ground, as planned, conditions for exploration will be considerably improved.

PRINTER BOY GROUP

Both veins and blanket deposits are present in the Printer Boy Hill area, but no evidence establishing their relations was found during Emmons's first survey or later. The only deposits of which anything is known are the Printer Boy vein and the blanket deposits of the Lilian or Florence mine.

The Printer Boy vein was very productive from 1866 to 1870, and was operated through the Upper Printer Boy and Lower Printer Boy shafts. Only the lower shaft was open during Emmons's first visit, and no information about the vein has been obtained since then. According to Emmons [15] the vein in Lower Printer Boy ground was double, and the two branches were separated by 10 or 12 feet of decomposed Gray porphyry. The gangue of the ore was also thoroughly decomposed porphyry, and scarcely any metallic minerals were visible in the vein. The rich ore in the old workings contained visible gold, and that in the deeper workings considerable pyrite and chalcopyrite, as well as some galena and tenantite. The gold was present in both pyrite and galena, and one show specimen contained galena crystals connected by a filament of wire gold. Selected specimens were said to have contained 122 ounces of gold to the ton, and the average content was said to be 3 to 4 ounces.

The width of the vein ranged from 1 inch to 4 feet and averaged about 7 inches. From the surface to a depth of 200 feet branches, some as much as 3 feet thick and containing the same kind of ore as the main vein, extended into the west wall. South drifts from the Upper Printer Boy shaft were said to be cut off a few hundred feet from the shaft by a "cement deposit" which Emmons interpreted as "lake beds."

A number of small gold-bearing veins were found in the Gray porphyry near the Printer Boy vein. The most productive of them was the Five-Twenty vein. It was opened by a tunnel which also cut a body of lead carbonate ore, not worth considering at that time and so far as known not developed later.

The blanket deposits of the Lilian or Florence mine are considerably to the east of the veins (pl. 45) but are similar in containing relatively large quantities of gold. They are in Blue limestone, and all but one are at the upper or White porphyry contact. The one exception is at the top of the Parting quartzite. These deposits are only 2 or 3 feet thick. The ore minerals, according to Emmons, [16] contained, besides the usual lead carbonate and silver chloride, "several minerals not common in the district, among which may be mentioned native gold, visible to the naked eye, and a sulpho-carbonate of bismuth." The bismuth minerals, according to Guyard,[17] were bismuthiferous lanarkite and schapbachite, the latter of which was proved later by Laney's microscopic study to be an intergrowth of bismuthinite and argentite with some galena.

In a tunnel directly below the main workings Emmons noted a vein of galena several feet thick in limestone. It connected with a blanket body but pinched out a short distance below it and could not be regarded as representing the channel through which the solutions rose; nor although the elongate shape of all the blankets indicates that they have developed along fissures, have any such feeders been recognized. The blankets are surrounded by "contact material," which replaces the uppermost part of the limestone in the area between the eastern and western dikes of Gray porphyry shown in Plate 13.

East of the Lilian mine the Minor tunnel was driven several hundred feet along the contact without finding ore, but ore of good grade was reported in the First National mine, farther east. West of the Lilian mine some ore was shipped from the Wilson, Brian Barau, G. M. Favorite, and others, but nothing is known of its quantity or quality.[18]

IBEX GROUP

The Ibex group includes veins and blanket deposits within the Ibex mine itself and the adjacent Golden Eagle and Little Vinnie mines, on the west, and the Garbutt and Modoc veins, on the east. On the south and southwest it can not be sharply separated from the Antioch stockwork and the Forest Queen, Tribune, and other minor veins. On the north it is connected with the Big Four group by the vein designated No. 20–b in Plate 57.

IBEX MINE

BLANKET ORE BODIES

SILICEOUS OXIDIZED AND SULPHIDE ORES

The deposits in the Ibex group include blankets of magnetite ore, veins and blankets of siliceous pyritic ores and their oxidized equivalents, and blankets of mixed sulphide ores and their oxidized products, the silver-lead and zinc carbonate ores. The first ores were discovered in the outcrop of Blue limestone at the Little Jonny shaft. They were the usual oxidized ores typical of the large blanket deposits in the western part of the district. They contained much lead and considerable though varying quantities of silver, but very little gold and no zinc or copper, although zinc carbonate ore with more copper than usual was

[15] U. S. Geol. Survey Mon. 12, p. 514, 1886.
[16] Idem, p. 510.
[17] Idem, p. 616.
[18] Idem, p. 511.

later found beneath some of them. These lead-silver ore bodies extended as far south as the No. 3 shaft and downward to the second and third levels, 300 to 350 feet below the surface, where they were most extensively developed.

Deeper exploration showed that the lead-silver ore was succeeded by blankets of highly siliceous gold ore. This ore contained 60 to 70 per cent of silica and consisted mostly of loosely compacted quartz crystals accompanied by a more solid cavernous iron-stained jasperoid. Its content of gold generally ranged from 1 to 4 ounces to the ton, and the gold could not be detected by panning; but all through the mine down to the seventh level pockets of ore rich in free gold were found, lots of a few to 100 pounds, containing 4 or 5 ounces to the pound, and one small lot containing 50 per cent of gold. Some of these siliceous blankets graded into the oxidized lead-silver blankets, but other lead-silver blankets, so far as could be learned, were apparently isolated.

Near the third level the oxidized ore changed to pyritic ore, in which iron was usually in small excess over silica. In this respect it differed from the oxidized siliceous ore, from which considerable iron had been leached. Its content of gold was generally less than half an ounce to the ton, but its silver content ranged as high as 40 ounces to the ton, and it uniformly contained copper, which in many shipments ranged between 8 and 15 per cent. Some blankets of sulphide were found, but these were given little attention because of their low value, and their relations to the siliceous pyritic ore were not definitely determined. They were presumably similar to those in the Golden Eagle workings, described on page 300.

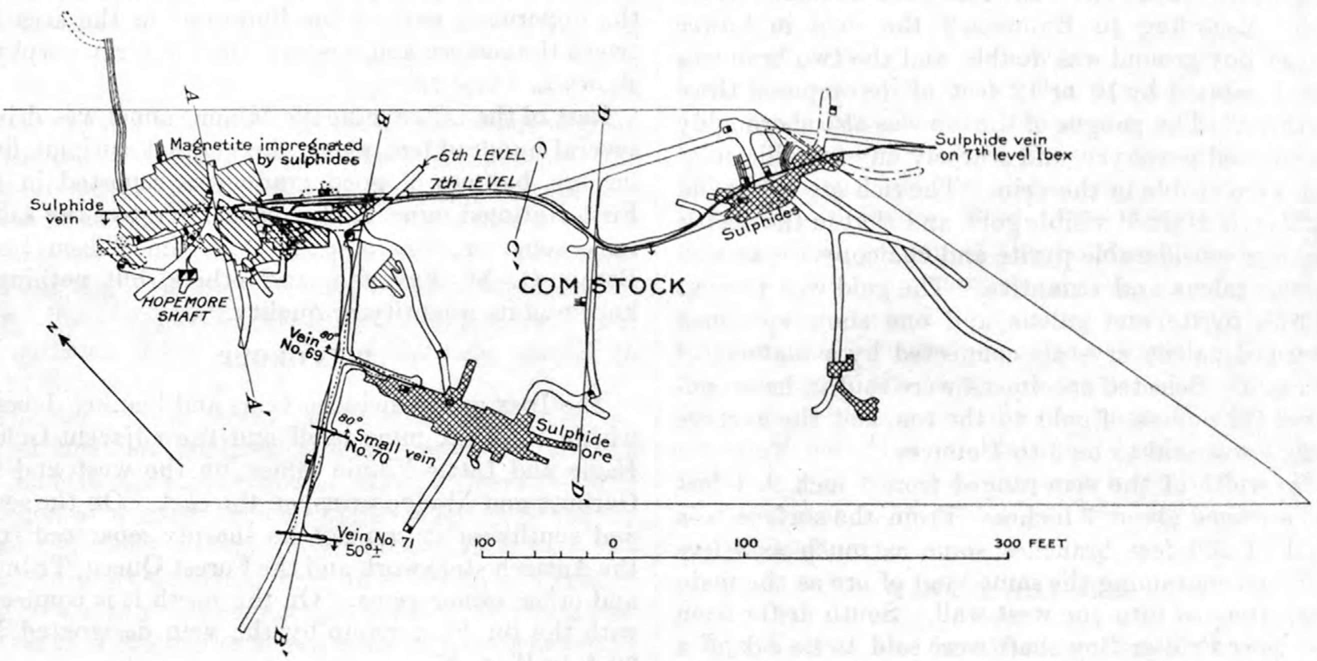


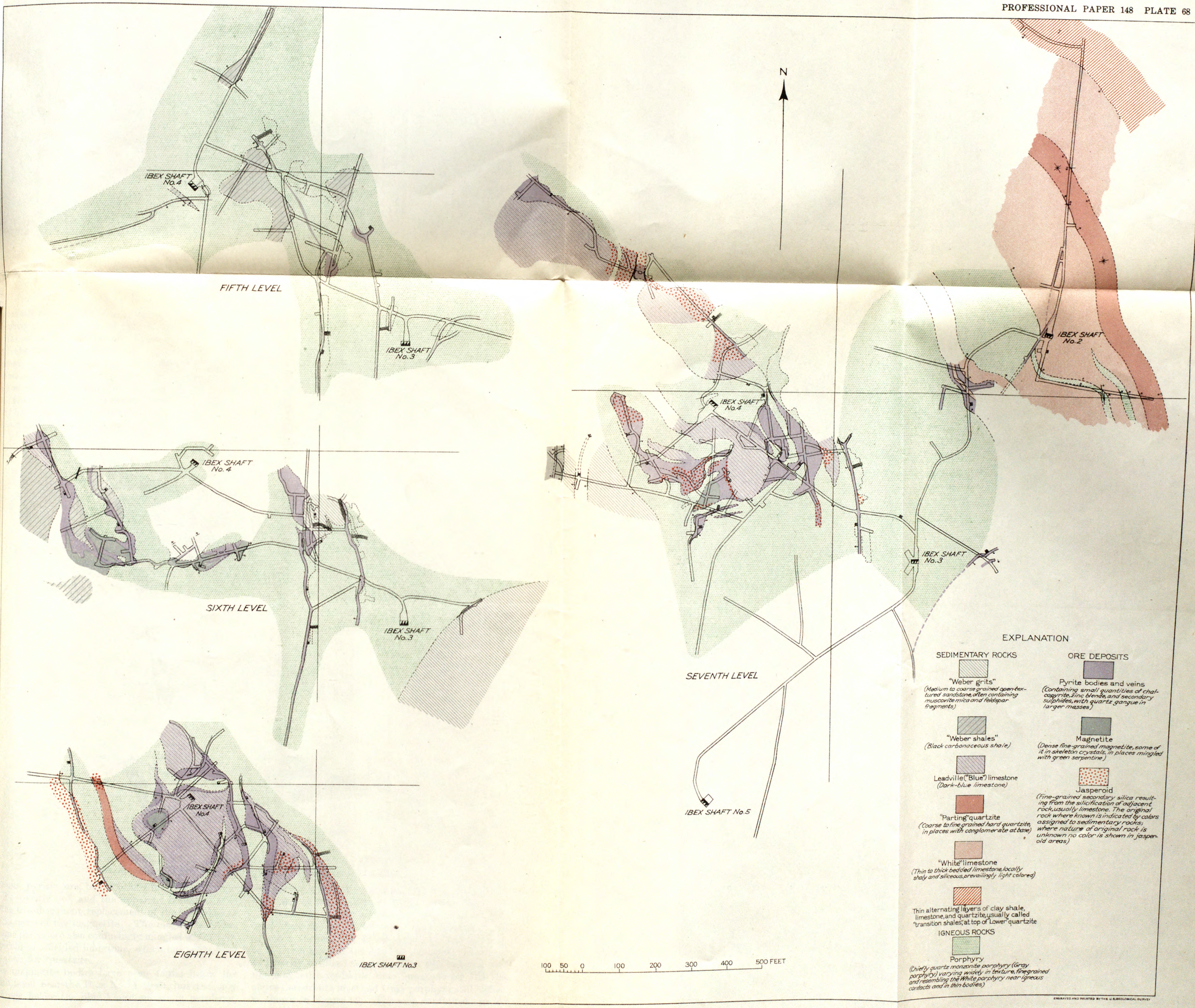
FIGURE 98.—Plan of ore bodies in Comstock workings. A–A', etc., lines of sections in Figure 99

The sulphide blankets in developed ground are most abundant between the third and fifth levels and have been worked as low as the seventh level; but some of the veins with which they are connected have been mined down to the bottom level, 1,300 feet below the surface. The blankets around shafts Nos. 1 and 2 are in Blue limestone, and those recently worked north and east of the Little Vinnie shaft are in White limestone. Around shaft No. 3, however, some of the sulphide blankets may be in the Weber (?) formation, which the southward pitch of the strata has brought below the fifth level. Farther south the Blue limestone has been downthrown along the east side of the Garbutt vein, and its position has not been determined, as the few crosscuts to the east have been in porphyry. The structure east of the Garbutt vein and south of the Modoc vein is obscure, but prospecting for ore bodies in the limestone there is justified. The upward-tapering wedge between the Garbutt vein and the Ibex No. 4 vein is also complicated by porphyry intrusions and little understood; it apparently deserves further exploration, but it may terminate upward below the base of the Blue limestone. (See sections on pl. 28.)

MAGNETITE DEPOSITS

On the west side of the Ibex No. 4 vein down faulting has brought the Blue limestone down to the sixth, seventh, and eighth levels, where it has been explored in the vicinity of the Ibex No. 4 and Hopemore shafts. (See pls. 57 and 68.)

Near both shafts it is extensively replaced by bodies of sulphide ore and also by magnetite serpentine, which is not worth mining and therefore is but little developed. The magnetite-serpentine bodies are very irregular,



GEOLOGIC MAP OF FIFTH, SIXTH, SEVENTH, AND EIGHTH LEVELS OF IBEX MINE principally because of the irregular intrusions of Gray porphyry that form most of their boundaries.

The serpentine commonly forms casings around the purer masses of magnetite. The magnetite, described in detail on page 150, is accompanied by specularite, small amounts of pyrite, a little chalcopyrite, and usually manganosiderite. It contains 40 to 48 per cent of excess iron, 1 to 4 ounces of silver to the ton, very little gold, and usually less than 1 per cent of copper. In some places it apparently grades into siliceous pyritic ore, but in others it is distinctly cut by the pyritic ore, and the apparent gradation may be due to subsequent replacement of the limestone at the margins of the magnetite. The magnetite bodies in some places are also confusingly mingled with bluish jasperoid or silicified limestone, which has often been mistaken for quartzite.

No magnetite bodies have been found below the eighth level near the Ibex No. 4 shaft, but the only workings below the Blue limestone are in porphyry, and nothing definite is known of the location or mineralization of the White limestone west of No. 4 vein.

The magnetite just east of the Hopemore shaft, in the Comstock workings, is of particular interest in showing the relations of magnetite to siliceous pyritic ore. It is above the seventh Ibex level, through which it was worked. When studied by Irving it had been opened for a length of 200 feet in a northwest-southeast direction and a width of 90 feet (fig. 98), but its limits had not been fully determined. It was bounded on the northeast by the Ibex No. 4 vein, and on the southwest it graded into limestone.

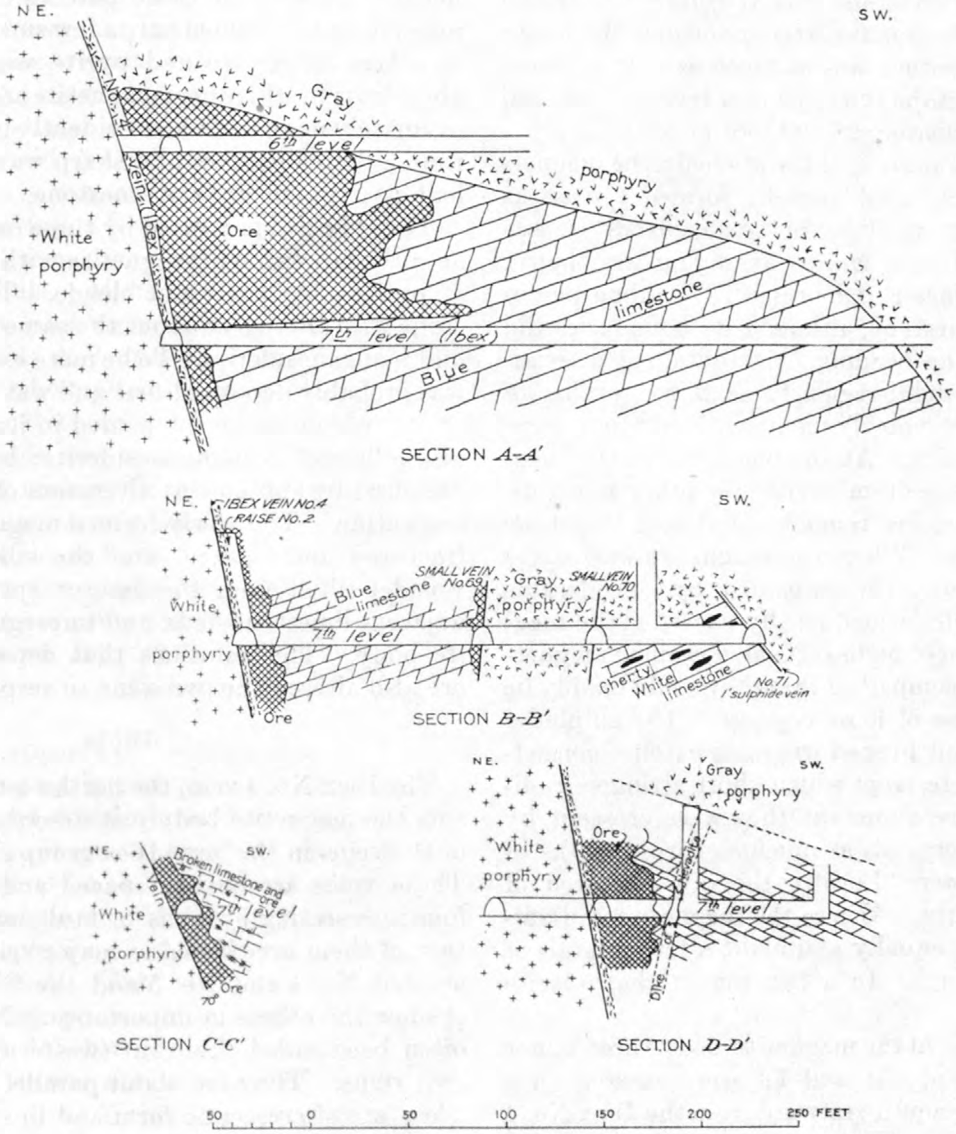


FIGURE 99.—Cross sections of ore bodies in Comstock workings. For lines of sections see Figure 98

A raise was put up for 290 feet above the seventh level along the dip of the vein. The footwall of the vein was slickensided White porphyry, and the edge of the vein along it consisted of somewhat brecciated and partly oxidized sulphide ore. The hanging wall was magnetite replacing Blue limestone for 125 feet above the seventh level and Gray porphyry still higher, as shown in Figure 99. The vein continued upward between the two porphyries but was of too low grade for mining.

The ore body adjacent to this raise extended 60 to 100 feet east from the vein fissure into the limestone, and it was stoped up for a vertical distance of 100 feet to the overlying Gray porphyry. The larger portion of the ore mined from it was composed of rather coarsely crystalline pyrite with some chalcopyrite and subordinate quantities of magnetite. This ore had a rather high content of gold and silver with some copper, and its high grade was attributed by Irving to enrichment. In small scattered portions of the sulphides the gold content was as much as 2 or 3 ounces to the ton. The stope at the time of Irving's visit had produced approximately 25,000 tons of ore.

In the unmined portion of the ore body the magnetite, with negligible gold content, formed a mass as much as 20 feet thick. In some places it was very fine grained, with grains averaging less than 1 millimeter in diameter and preserved bedding planes of the original limestone, although its boundaries did not conform to the bedding. It contained disseminated sulphides and irregularly scattered grains of white material, presumably manganosiderite or a claylike replacement of it. At one place, where the magnetite was most free from cavities or other minerals, it inclosed an unreplaced remnant of altered limestone or manganosiderite. Where the magnetite was coarse grained it was usually accompanied by considerable quartz and sulphides, which locally exceeded the magnetite. Some isolated bodies of coarse-grained magnetite were so loosely compacted that they could readily be crumpled to a mass of loose crystals. The sulphides where less abundant formed irregular patches consisting mainly of pyrite, from which short stringers radiated. Where more abundant they were crosscut by veinlets of pyrite crystals as much as three-eighths of an inch in diameter. Locally the ore consisted of sulphides and quartz. Where the magnetite and sulphides were about equally abundant a few crystals of vivianite were found. In a few places chalcopyrite exceeded pyrite.

To the southwest of the magnetite body three minor pyrite veins (Nos. 69, 70, and 71) were exposed in a crosscut extending southwestward from the Ibex No. 4 vein (figs. 98 and 99). These contained, besides pyrite, considerable sooty chalcocite and some bornite and were coated with water-soluble sulphates of iron, zinc, and copper.

At the beginning of this crosscut the ore along the southwestward-dipping Ibex No. 4 vein was 20 feet thick and graded into Blue limestone on its southwest side. It was free from magnetite. Barren limestone intervened between this vein and the next vein, No. 69, 100 feet to the southwest, which dipped 80° NE., converging downward with the westward-dipping No. 4 vein, of which it may therefore have been a branch. Its footwall was slickensided Gray porphyry and its irregular hanging wall Blue limestone. It was 2 to 3 feet thick and was followed for some distance southeastward and upward to the blanket of sulphide shown in Figure 98. Both vein and blanket were free from magnetite.

Veins Nos. 70 and 71, farther southwest, were also sulphide veins free from magnetite. The limestone between them was considerably serpentinized and contained irregular patches of sulphides mixed with magnetite. In some of these patches the magnetite was massive and contained only a few small grains of pyrite; in others magnetite and pyrite were about equally abundant; in still others magnetite and zinc blende were intimately mixed and had evidently grown at the same time. These patches had sharp wavy boundaries and had clearly replaced the limestone.

The evidence presented by these ore bodies indicates an early deposition of magnetite with a minor quantity of pyrite and locally zinc blende. The adjacent limestone was altered at about the same time to pyroxene and manganosiderite. To be more exact, the pyroxene was probably deposited first and was followed by magnetite, which was accompanied in its later stages and also followed by manganosiderite; but the evidence is obscured by subsequent alteration of the pyroxene to serpentine. The newly formed magnetite bodies were fractured and faulted, and the siliceous pyritic ore was deposited along the fissures, spread along certain adjacent limestone beds, and impregnated the magnetite body. The solutions that deposited the pyritic ore also altered the pyroxene to serpentine.

VEINS

The Ibex No. 4 vein, the northwestern part of which cuts the magnetite body just described, is the longest of the veins in the large Ibex group shown in Plate 57. These veins are closely spaced and occupy at least four intersecting systems of faults and fissures. Fifteen of them are classed as major veins, but those designated No. 4 and No. 5 and the Garbutt vein overshadow the others in importance. Nos. 4 and 5 have often been called the front (western) and back (eastern) veins. They are about parallel in strike and dip. They are of crescentic form and in strike are concave to the west, but in dip they are convex to the west, as illustrated in Figure 54. The No. 6 vein parallels the No. 4 on the west and is so closely connected with it by blanket replacement deposits that it may be regarded as an auxiliary vein. The No. 63 vein is without doubt the upward continuation of the No. 4 vein.

The No. 4 vein extends from the thirteenth or Yak tunnel level upward to the third level, where it assumes a low angle of dip and connects with blanket bodies above. (See pl. 28, sections K–K′ and L–L′.) In its central part it bulges enormously to a lenticular form and in some places attains a width of 200 feet. This bulge is undoubtedly due to the ready replacement of shattered Blue limestone on the footwall side of the fault and where widest, on the seventh level, connects the No. 4 with the No. 6 vein. The length of the vein varies on different levels, but it is greatest on the seventh level, where the vein has been explored from a point 100 feet northwest of the Hopemore shaft for 2,800 feet to a point nearly 600 feet south of the Ibex No. 5 shaft.

The ore in the No. 4 vein was predominantly pyrite, part with a quartzose matrix and part without. It contained gold and silver and commonly considerable copper in the form of chalcopyrite. In the central bulge the ore consisted of pyrite crystals, single and in clusters, set in a solid grayish matrix of quartz or jasperoid. Where it was oxidized the pyrite crystals were removed, leaving a honeycombed rusty mass of quartz, in which the openings had the form of the dissolved pyrite crystals. Much of the partly oxidized ore consisted of a loose aggregate of pyrite crystals mingled with grains and crusts of quartz and loose particles of iron and copper sulphates. The vein was largely oxidized on the second level (vein No. 63) but consisted of sulphide ore south of the No. 3 shaft, where the country rock is "Weber grits."

The No. 5 vein is relatively narrow, attaining a maximum thickness of about 15 feet. On nearly all levels it was followed on the strike for about 500 feet or somewhat less. Its ore was similar to that of No. 4 vein. It also passes into flat blanket bodies just above the second level. (See sections M–M′ and N-N′, pl. 28.)

The No. 1 vein appears to belong to this same system but was definitely known to Irving only on and above the first level, from which it extended almost up to the surface. It was extensively developed on the first level, where it had a known length of 860 feet. The No. 1 vein was usually from 6 to 12 inches wide in its productive portions but narrowed down to a mere streak in others. This vein was in porphyry throughout the larger portion of its length but passed into carbonaceous "Weber grits" to the south. In the porphyry the ore was all oxidized and had a high gold content, but in the "Weber grits" it was sulphide of comparatively low grade. The change was abrupt.

The No. 2 vein extends upward from the second level through the first to the C level, and its lowest exposed portion is well above the blanket bodies in the immediate neighborhood. Its greatest explored length is 350 feet. It belongs to a northeast-southwest group but appears to be of the same age as the crescentic veins Nos. 4 and 5. Little could be learned regarding it.

The No. 3 vein is a curved vein on the second level which may be a continuation of No. 5. East of the No. 3 shaft is a complex group of small veins carrying pyrite and chalcopyrite. They are Nos. 14, 15, 16, 17, 32, 33, 34, 35, 36, 37, and 38. They form an interlocking series and are connected with the large blanket body on the third level. Their character may best be seen on Plate 57 in plan and on sections O–O′, P–P′, Q–Q′, Plate 28. The No. 15 vein is probably a northward continuation of the Garbutt vein. Its northern part forks, and both forks (veins Nos. 14 and 15) curve sharply eastward and fall in line with the Modoc vein, to the east. The presence of these veins where the Garbutt and Modoc faults should join emphasizes the suggestion that prospecting is justified in the down-faulted limestone to the southeast of the junction.

The No. 7 is a north-south vein which has been most extensively worked on the ninth and thirteenth levels. Its intersections with other veins have not been exposed. It dips eastward. The No. 8 is a minor vein known only on the ninth level. It dips 75° NE. The No. 8a vein has likewise an easterly dip and has been worked on the eighth level.

The No. 10 vein, sometimes called the Hahnewald vein, is worked on the eleventh, twelfth, and thirteenth levels. It has a total known length of 806 feet on the eleventh level. It contains chiefly sulphides and resembles in most respects the other veins of the area but differs in producing from the Hahnewald stope a large amount of very rich gold ore. The gold was found as thin films in sheeted porphyry.

The No. 20a vein has been worked on the tenth level and thence almost up to the seventh level, where it widens into a blanket body in limestone. Only its position on the tenth level is shown on Plate 57. The vein is reached by a long crosscut eastward on the tenth level, and its north end lies about 150 feet southeast of the No. 2 Ibex shaft. It strikes slightly west of north, dips about 80° E., and has been followed for 380 feet, but its southward termination has not been reached, and on the north it terminates at a fault, beyond which its continuation has not been found. It is distinctly a filled fissure and not a replacement vein. It is from 3 to 9 inches or more thick and consists of pyrite, mostly coarse grained, mixed with chalcopyrite and considerable chalcocite and accompanied by no gangue. The filling, for the most part, adheres tightly to the well-defined walls. The walls, wherever observed, are porphyry. The ore in the vein was of good grade, containing 10 per cent of copper, 30 to 40 ounces of silver, and half an ounce of gold to the ton, and little or no zinc. The blanket body connected on the seventh level contained 15 to 20 per cent of zinc but was much poorer in copper, as downward enrichment was there unable to take place so readily as in the vein itself.

All these veins, both large and small, either connect with or terminate in blanket deposits of greater or less size, and unquestionably fill the conduits through which solutions arose to replace the strata with ore.

GOLDEN EAGLE VEINS AND BLANKETS

The Golden Eagle ground lies to the north and northwest of the Ibex No. 2 shaft. It comprises the Little Vinnie claim and parts of small claims immediately north and northeast. The only part of it studied was that leased to John Cortellini and others in 1922, at and below the Ibex seventh level. The country rock there exposed includes the White limestone, the Parting quartzite, the lower part of the Blue limestone, and several sills of bleached porphyry. Correlation of this porphyry as White porphyry is in accord with Plate 13, but, owing to the similarity of the altered White and Gray porphyries in this vicinity some of the sills may be bleached Gray porphyry. The strata undulate to some extent, but the prevailing structure is synclinal (fig. 55), with a northeast limb dipping at least 45° SW. and a southwest limb dipping 20–30° NE.

The principal vein in this ground is the Ibex No. 9, called the "Big vein," which fills a fault fissure trending north-northeast and dipping 70° E. on the seventh level and below. It sends out branch veins at a few places and is also connected with blanket replacement deposits in the White limestone. The No. 9 vein projected upward would connect with old blanket stopes on the fourth and third levels.

Near the Little Jonny shaft, 50 and 100 feet east of the No. 9 vein, there are two veins which parallel the No. 9 in strike but dip 70° W. They are developed along the strike for 80 feet or more and also connect with blanket replacement deposits. The easternmost vein, locally called the "east vein," is intersected by a small vein striking about S. 80° E., and ore was followed in a sinuous course along the general line of intersection for 140 feet in the "corkscrew" raise. The raise was not accessible at the time of visit, but the local structural conditions suggest that the raise stopped at or near the base of a porphyry sill.

West of the No. 9 vein two linear groups of blanket replacement deposits have been developed along the courses of small veins, as shown in Plate 57 and Figure 55. So far as records show, only one small replacement body (on the third level) has been found in the Blue limestone above them, and the ground appears undeveloped and promising; but here, as elsewhere, records of old workings may not have been kept. The ground west of these linear groups of ore shoots is also worthy of prospecting for ore of similar grade and extent.

Available data on the ore shipped from this ground are given below. The ore shipped in 1922 came from the replacement shoots on the Ibex seventh level, but the sources of earlier shipments are not definitely known.

Contents of ores shipped from the Little Vinnie and adjoining claims, 1902–1922[a]

Year	Operator	Class of ore	Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)	Silica (per cent)	Iron (per cent)
1902	Golden Eagle Co. (Little Vinnie claim)		0.40	20.0	0.9				
1905	do		2.50	8.0	.003	0.3			
1906	do		.18	7.0		5.5			
1911	New Vinnie Co	Dry siliceous sulphide	0.30–2.50 .704	5.2–11.7 7.05	 .8		4.9–8.1 6.5	40.0	0.18
1911	do	Dry iron sulphide	.38	9.5	.7	1.15	6.3		
1915	do	Dry siliceous sulphide	.408	10.81	[b]1.8	[b].5			
1917	do	Dry siliceous oxide	1.249	4.79	.8	.1		52.7	.17
1918	do	Dry siliceous sulphide	.573	5.40	.5	.7			
1919	do	Dry siliceous oxide	.936	1.57				57.7	21.3
1919	Golden Eagle lease	do	1.656	4.83	.4	.05		55.2	21.4
1920	New Vinnie Co	Dry siliceous sulphide	.900	5.93	.6				
1921	do	Siliceous copper oxide	.784	13.96	2.5	.4	3.0	44.0	24.0
1922	Golden Eagle lease	Dry siliceous sulphide	.788	12.72	2.2	.9			

[a] "Oxide" ore includes all containing less than 10 per cent sulphur. [b] Wet.

GARBUTT VEIN

The Garbutt vein (pl. 57 and fig. 29) is one of the most continuous in the district. It has been developed for a horizontal distance of nearly 2,000 feet and to a maximum depth of 1,300 feet. So far as developments show, it forms the east boundary of the Ibex group from the Ibex No. 3 shaft southward. Its northern part trends a few degrees east of north and approaches a subgroup of short crescentic veins that curve sharply from northward to northeastward and fall in line with the Modoc vein (pl. 57). In the vicinity of the Garbutt shaft, about 300 feet from its northernmost openings, the Garbutt vein curves to a south-southwest direction, which it follows for 1,300 feet before it again curves to a north-south course and narrows to a few inches in width. About 800 feet south-southwest of the Garbutt shaft the Garbutt and Ibex No. 4 veins come very close together at a very low angle, and the Ibex No. 4 merges with the South Ibex stockwork. The No. 4 passes within 20 feet of the stockwork and is connected with it by mineralized fractures.

The dip also varies. From the surface down nearly to the tenth level (Ibex seventh level), a depth of 700 feet, it is about 70° W. From the tenth to the twelfth level (150 feet) it is vertical. Then the vein thins to a mere streak and extends for a short distance eastward in a horizontal position before it assumes a dip of 60°-65° E., which persists down to the bottom (Ibex thirteenth) level.

The succession of wall rocks (fig. 29) has been determined only where the vein was accessible in 1919 and 1922. The vein had been reported to lie entirely in porphyry except at its lowest levels, but the upper levels are in "Weber grits" cut by porphyry sills. The vein fissure, as shown on the fifth (Ibex fourth) level, is clearly a fault between a footwall of Gray porphyry and a hanging wall of "Weber grits," but the amount and direction of faulting can not be determined. From the fifth to the thirteenth (Ibex tenth) level the west wall could not be studied. Neither could the east wall between the seventh and fourteenth levels. On the thirteenth level the west wall is Cambrian quartzite overlain by the dark "transition shales," which dip steeply eastward near the vein owing to downdrag during faulting. The east wall on the thirteenth and lower levels is mainly Gray porphyry with a few inclosed large slabs of dark shale that have been dragged into a moderate to steep eastward dip. Although the Blue and White limestones have been found along the Ibex No. 4 vein 300 feet to the west, no limestone has been reported along the Garbutt vein. The position of these formations on the west side of the vein is approximately indicated in Figure 29, but the corresponding position on the east side can not be reliably indicated until it is known whether the dark shales on the lower levels are certainly "transition shales" at the top of the Cambrian quartzite and not deeply down-faulted "Weber shales" and until the structural details of the Gray porphyry intrusions are better understood.

Ore has been mined from the outcrop on the Negro Infant claim, 1,000 feet south-southwest of the Garbutt shaft, down to the lowest levels, but the better grades of ore have been found in cylindrical or cigar-shaped shoots that pitch southward at a very low angle, parallel to the pitch of the beds in the walls. So far as accessible workings afforded evidence, the vein pinches where one or both walls are shale, and the shoots are found between these pinches. The shale beds in the "Weber grits" as well as the Cambrian "transition shales" are effective barriers to ore shoots. The ore is pyritic and is typically though irregularly enriched. The higher grades are commonly crumbly and stained black by chalcocite; the unenriched ore is hard granular pyrite, much of which is too lean to pay for milling.

On the fifth (Ibex fourth) level the vein merges with a blanket replacement deposit in coarse-grained "Weber grits," which has been mined for 200 feet or more along the strike and for an average width of 50 feet. Its thickness ranged from 8 feet or more down to a few inches. About 20 feet west of the shaft it pinches and plunges to the next stratum of grit below, and 50 feet farther west it pinches to a thin layer which joins a minor vein parallel to the main Garbutt vein. This shoot, like those within the vein, is controlled by shaly beds above and below the replaced beds.

Although the vein has been prospected thoroughly through a great part of its extent, detailed mapping of the shaly and other beds and the porphyry intrusions is likely to indicate promising ground that has not been adequately explored, both at places along the main vein, and at places where minor veins intersect limestones or limy beds of the "Weber grits." As the bottom level is the lowest that can be drained by the Yak tunnel, exploration at greater depth will be more expensive; but the presence of enriched ore at the bottom level should encourage deeper development if detailed mapping of the strata indicates that the structure is favorable for ore shoots.

Drifting southward has ceased on the different levels after continuing for some distance along very narrow parts of the vein, and it thus appears that mineralization has been weaker to the south of the South Ibex stockwork than it has been to the north, especially in the structurally complex ground around the Ibex Nos. 3, 4, and 6 shafts. Crosscuts westward from the southernmost exposures of the Garbutt vein on the second and Negro Infant levels have exposed some small veins of approximate north-south trend, one of which has been followed for 150 feet on the Negro Infant level without marked success. The Agwalt tunnel, about 300 feet below the Garbutt second level, has also crosscut the ground in this vicinity, evidently without opening veins of workable size. In spite of these adverse indications, however, further prospecting may be more successful. The turning and pinching of the Garbutt vein and the presence of the small parallel veins west of it suggest that there has been a break in the continuity of fissuring and that at a moderate though indefinite distance farther south the fissures may resume a south-southwest trend toward the Printer Boy and Lillian deposits. The amount of bleached mineralized rock on the surface also suggests that at some place in this area there may be one or more veins of workable size and grade. The local structural details, however, are too little known to serve as definite guides for prospecting.

SOUTH IBEX STOCKWORK

The South Ibex stockwork is 800 feet southwest of the Garbutt shaft. It is of lenticular outline, and its long axis strikes N. 33° E. and dips 68°-70° W., nearly parallel to the dips of the Garbutt and Ibex No. 4 veins which are east of it (pl. 57). Its strike length is 330 feet, and its dip length 550 feet. A considerable part of it is as much as 60 feet thick, and it is locally as much as 120 feet thick where offshoots are present. This stockwork was discovered on the Garbutt second level 25 feet west of Ibex No. 4 vein and was followed down to the seventh level. It was worked from 1915 to 1919. The production ranged from 200 to 250 tons a day and shipments averaged 0.21 ounce of gold and a few ounces of silver to the ton. Some shipments contained 1 ounce or more of gold to the ton. This deposit is of special mineralogic interest because of the presence in it of the tungsten minerals wolframite and scheelite.[19]

The ore body occupies a shattered zone in "Weber grits," which contain sills of Gray porphyry. The relative proportions of the two rocks are not definitely known, but the "Weber grits," which have been locally called "quartz porphyry," predominate. Both rocks are silicified, sericitized, and pyritized, and their identity in places is uncertain without microscopic study. In the most thoroughly altered rock the minerals are more coarsely crystallized than elsewhere, and the identity of the rock is completely destroyed.

The ore occurs as a network of veinlets and irregular bunches which bind together the fragments of altered rock. Ore of shipping grade occupies the outer and upper parts of the ore body and incloses a lenticular core of milling ore which decreases in value inward. On the second level a well-defined footwall with a thin gouge is exposed for 50 feet, and recent work has disclosed at one place a slickensided hanging wall. In general, however, there are no distinct walls, and the ore grades outward into material of similar appearance but of low value. This prevailing absence of walls prevents a correlation of the shattered zone with the intersections of fissures, but it is surmised that the major dimension has been controlled by one or more fissures parallel to those containing the Garbutt and Ibex No. 4.

Since the foregoing was written Augustus Locke has examined the South Ibex deposit and noted similarities between it and certain other ore bodies, notably that of the Pilares mine at Nacozari, Mexico. According to his interpretation, rising solutions were at first able to enlarge their conduits by dissolving the wall rock. The removal of support by this process allowed the wall rock to be shattered by pressure of the overlying rock mass. The solution penetrated the shattered mass, and dissolving and shattering accompanied by slumping continued as long as the solution could dissolve rock matter without depositing an equal volume of material in its place. The limits of the slumped mass of corroded fragments are marked by vertical slickensided fissures, along some of which the amount of slumping can be measured. The inclination from vertical of the poorly exposed walls of the South Ibex mass may be attributed to tilting during postmineral faulting. The stage of corrosion was followed by one of partial replacement, and finally by deposition of ore and gangue in crusts around the fragments.[20] This explanation has much to commend it, but evidence in the South Ibex deposit does not show to what extent shattering was due to complex premineral fracturing as opposed to fracturing induced by the corrosive action of the solution. There is no doubt as to the corrosion of rock along the complex fractures, once they were formed.

The principal vein minerals are quartz, pyrite, wolframite, and scheelite. Sericite in parallel growth with quartz lies along the walls of the veinlets. The quartz occurs mostly as typical colorless crystals 2 inches in maximum length, which line cavities and are in part enveloped by or in parallel growth with pyrite. Locally, where the crystals are crowded together, the quartz has a massive milky appearance.

The pyrite is well distributed throughout the veinlets and occurs mostly in groups of rather large crystals. Single crystals of cubic form with edges 5 inches long have been found. The prevailing type of crystal is a combination of the cube and pyritohedron with several less common forms represented by small faces. Some of the striations on the cube faces are unusually large and are more aptly described as ridges. Besides the parallel growth with quartz, the pyrite shows in places a marked intergrowth with wolframite. Parallel growth with scheelite, though noted, is not common. The pyrite ranges from very hard to crumbly. The crumbly variety, especially where tarnished or coated with black films, has the higher gold content. The large crystals as a rule are poor in gold, but they have proved very efficient as detectors in the radiotelephone.

The two tungsten minerals are found along the walls of vugs and are too thinly and irregularly scattered to be regarded as a commercial source of tungsten. They are distributed throughout the middle part of the western pay shoot of the ore body and are closely associated; but the scheelite is more abundant on the upper and the wolframite on the lower levels.

[19] Fitch, R. S., and Loughlin, G. F., Wolframite and scheelite at Leadville, Colo.: Econ. Geology, vol. 11, pp. 30-36, 1916.

[20] Locke, Augustus, Formation of certain ore bodies by mineralization stoping: Econ. Geology, vol. 21, pp. 431-453, 1926.

Contents of ores shipped from the Garbutt lode and South Ibex stockwork, 1913–1922

Claim and class of ore	Year	Ore (tons)	Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)	Silica (per cent)	Iron (per cent)	Sulphur (per cent)
St. Crispin:										
Average contents			0. 15	25. 0	2. 0	0. 2				
Representative lots—										
Dry siliceous sulphide			. 09	35. 45		2. 35				
Do			. 11	2. 15	1. 1					
Do	1913	2, 253	1. 30	11. 45	1. 4					
Do			. 64	13. 84	2. 2					
Copper sulphide			. 46	20. 10	3. 8					
Do			. 27	40. 22	4. 5					
Do			. 29	46. 65	5. 9			10	36	
Dry siliceous sulphide	1914	185	. 115	10. 65			5. 1	23	31. 6	
			. 175	5. 55			1. 0	21. 6	35. 7	
Do	1916	22	. 635	5. 82	. 2	1. 3				
Do	1617	132	. 299	8. 20	. 9	. 2				
Do	1918	93	. 232	10. 71	2. 3					
Dry iron sulphide	1918	22	. 218	11. 05	. 28					
Garbutt:										
Dry siliceous sulphide—										
Range	1914	2, 089	. 085–. 475	3. 55–30. 75	. 2–1. 8	?–2. 35	. 8–4. 8			
Average			. 200	10. 70	1. 0	. 9	2. 8			
Dry siliceous sulphide	1915	2, 636	. 786	. 726	[a] . 4	[a] 1. 7				
Do	1916	155	. 233	12. 39	2. 5	. 5				
Dry siliceous oxidized	1916	79	. 612	1. 03						
Dry siliceous sulphide	1917	870	. 841	10. 41	1. 5	1. 2				
Do	1918	646	. 289	11. 21	1. 8	. 6				
Dry iron sulphide	1918	85	. 062	5. 08	. 5					
Do	1918	434	. 312	11. 57	1. 2	. 9				
Dry siliceous sulphide	1919	429	. 787	8. 35	. 8					
Do	1920	122	. 114	14. 96	1. 6	. 6				
Dry iron (?) sulphide	1920	72	. 699	12. 10		. 8				
Dry siliceous oxidized	1921	50	. 026	3. 18				57	19	
Dry siliceous sulphide	1922	139	1. 243	12. 59	1. 7	2. 15				
Maud Hicks:										
Range			. 08–. 56	3. 2–38. 15	. 08–3. 00		1. 9–6. 2	9. 5–25. 9	29. 9–38. 7	
Average			. 120	19. 73	1. 1	0. 2	3. 5	16. 3	35. 0	
Representative lots—	1914	3, 836								
Dry iron			. 08	26. 15	. 7		2. 2	9. 5	38. 7	
Do			. 29	9. 7	. 7			25. 9	29. 9	
Copper iron			. 11	36. 45	3. 0			14. 9	35. 5	
Dry sulphide	1917	76	. 118	2. 88	. 5	. 1				
Dry siliceous sulphide	1918	61	. 875	8. 51	. 9					
Dry iron sulphide	1918	213	1. 138	8. 40	. 6	. 5				
Dry iron oxidized	1918	27	. 230	7. 37	. 6			27. 9	32. 3	
Dry siliceous sulphide	1919	540	. 306	7. 11	. 4					
Copper-iron sulphide	1920	41	. 054	12. 17	3. 1					
Springfield:										
Dry siliceous sulphide	1917	20	. 461	6. 15	. 3	1. 1				
Do	1919	49	. 745	5. 33	. 6					
Mary Alsberg:										
Dry iron sulphide—										
Range	1914	1, 962	. 19–. 73	3. 75–19. 0	. 4–2. 25	0–1. 3	1. –2. 5	12. 6–28. 0	29. 9–37. 9	
Average			. 294	8. 16	. 6	. 9	1. 8	18. 5	35. 1	
Lead-copper sulphide	1915	1, 222	. 611	4. 37	5. 6	25. 5				
Dry sulphide	1916	189	1. 374	4. 55	. 5	. 5				
Do	1917	170	1. 965	3. 54	. 1					
Dry siliceous sulphide	1918	126	3. 337	3. 36	. 6					
Do	1918	181	2. 478	2. 55	. 1					
Do	1919	55	. 611	4. 89	. 5					
Nonie:										
Dry iron and siliceous ores—										
Range	1914	7, 691	. 19–1. 97	. 35–11. 60			. 0–1. 20	15. –69. 6	14. 8–38. 4	
Average			. 846	2. 61	. 2	. 2				
			. 876	. 58	[b] . 05	. 006				
			1. 495	1. 00				63. 1	18. 1	11. 7
			. 66	. 90				53. 8	21. 2	21. 7
Dry siliceous sulphide (representative lots)			. 81	. 55				51. 4	23. 3	24. 4
	1915	14, 013	. 96	. 70				53. 2	21. 3	23 7
			. 98	. 95				43. 0	25. 4	27. 7
			. 655	. 65				54. 4	19. 2	21. 6
			1. 17	. 70				37. 8	28. 1	31. 1
			2. 62	. 60						
Dry siliceous oxidized—										
Average	1915	6, 850	1. 05	. 49	. 1					
Representative lot			1. 21	. 90				68. 8	15. 2	9. 3

[a] Wet.

[b] Recovered.

Contents of ores shipped from the Garbutt lode and South Ibex stockwork, 1913–1922—Continued

Claim and class of ore	Year	Ore (tons)	Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)	Silica (per cent)	Iron (per cent	Sulphur (per cent)
Nonie—Continued.										
Dry siliceous sulphide	1916	2, 390	0. 682	0. 81	0. 02					
Dry sulphide	1916	6, 399	. 705	3. 05	. 2	0. 7				
Dry siliceous oxidized	1916	235	. 568	. 67	. 1	. 8				
Dry sulphide	1917	3, 844	. 824	1. 47	. 2	. 1				
Dry siliceous sulphide	1918	1, 387	1. 519	1. 76	1. 7					
Do	1918	22	1. 586	2. 36	. 8					
Dry iron sulphide	1918	149	. 626	. 62	. 3	. 5				
Dry siliceous sulphide	1919	735	. 832	1. 65	. 7					
Dennis:										
Dry sulphide	1917	49	2. 811	3. 33	. 1					
Dry siliceous sulphide	1918	54	19. 248	7. 02	. 4					
Dry sulphide	1918	51	4. 504	4. 29						
Dry siliceous sulphide	1919	206	2. 067	4. 57	. 02					
Dry sulphide	1920	42	1. 221	2. 76						
St. Paul:										
Sulphide	1917	22	1. 205	7. 00						
Dry siliceous oxidized	1917	140	1. 629	7. 32		. 3		5. 75	19. 4	
Dry siliceous sulphide	1919	276	. 496	7. 32		. 07				

MODOC VEIN

The Modoc vein, worked through the Elk, Donovan, and Modoc shafts, lies in the northeastern part of Breece Hill, east of the Ibex and northeast of the Garbutt (pl. 27). The country rocks north of the fault consist of a thick capping of Gray porphyry underlain by Blue limestone, Parting quartzite, and White limestone, which dip on the average 33° SW. The rocks south of the fault consist of another thick sheet of Gray porphyry within the Weber (?) formation. The vein strikes N. 72° E. and dips 73° SSE.

The Elk shaft passes through 60 feet of glacial "wash" and 450 feet of Gray porphyry and continues for 150 feet in "Weber shales" and "Weber grits." Levels have been run at depths of 400, 490, 550, and 645 feet. The first three levels extend to an ore shoot in the vein, between a footwall of Blue limestone and a hanging wall of the Weber (?) formation. The vein is 50 feet wide on the first level and 30 feet wide on the second and third levels. It consists mainly of extremely crushed "Weber grits," "Weber shales," and Gray porphyry bounded by well-defined walls. On the first and second levels this material is replaced and cemented by silica into a solid mass of siliceous ore containing disseminated cerusite in the oxidized zone and disseminated sulphides below. It has been followed in the Elk mine for 350 feet along the strike. Any limestone fragments in the vein have been completely replaced. This ore shoot had a veinlike form and terminated abruptly against the wall of silicified limestone on the north and that of the Weber (?) formation and Gray porphyry on the south. It has been followed for 200 feet down the dip but was evidently not productive above the Blue limestone.

The silicified Blue limestone or jasperoid in the footwall contains enough metal to justify exploration. Toward the Ibex No. 1 shaft a few small irregular deposits of oxidized lead-silver ore have been found between the Blue limestone and the overlying Gray porphyry, but have not been profitably worked, as were the larger deposits close by the Ibex No. 1 and Little Jonny shafts.

The workings in the Ibex mine immediately west of the Modoc vein were not accessible, and the continuation of the vein and its relation to the vein of the main Ibex group could not be established.

FOREST QUEEN AND MINOR VEINS NEAR BY

The Forest Queen shaft, on the crest of the northwesterly slope of Breece Hill, was sunk to a depth of 627 feet, and a drill hole continued to a total depth of 1,353 feet. Three levels were run from the shaft at depths of 400, 450, and 600 feet. (See fig. 100.)

The country rock found in the mine is entirely porphyry, although the drill hole and the Yak tunnel below cut the lower members of the "transition shales" between the White limestone and the Lower quartzite. At 70 feet east of the shaft, on the third level, a drift cuts the Weston fault, the fissure of which has at this point a width of 10 feet. This fault is also cut in the Yak tunnel about 150 feet farther west and shows a similar width (pl. 15, Yak section).

A vein that strikes N. 6° E. and dips 73° W. was found on the first and second levels just west of the shaft. It was about 6 feet wide. In the two upper levels it consisted for the most part of a yellow clayey oxidized material which contained from 3 to 5 ounces of silver and from half an ounce to 1½ ounces of gold to the ton, showing here and there remnants of the original sulphides, mainly pyrite. One wall was rather ill defined, but the other was sharp.

On the 600-foot (third) level the ore contained a large mass of enriched sulphide ore, carrying as much as 5 per cent of copper. Its gold and silver contents are not known.

The vein here is exactly parallel to the Weston fault both in strike and dip, but it pinches out above the level of the Yak tunnel. The parallelism of strike and dip in this vein strongly suggests that it fills a minor fissure of the Weston fault zone, but no mineralization within the main fault zone has been reported. This part of the Weston fault (see p. 78) may have been formed subsequent to ore deposition. The Ella Beller and Clear Grit veins, in Iowa Gulch, occupy minor fissures formed at the same time as the Weston fault

Several minor veins have been cut in the Agwalt, Tribune, and Yak tunnels, in the western part of

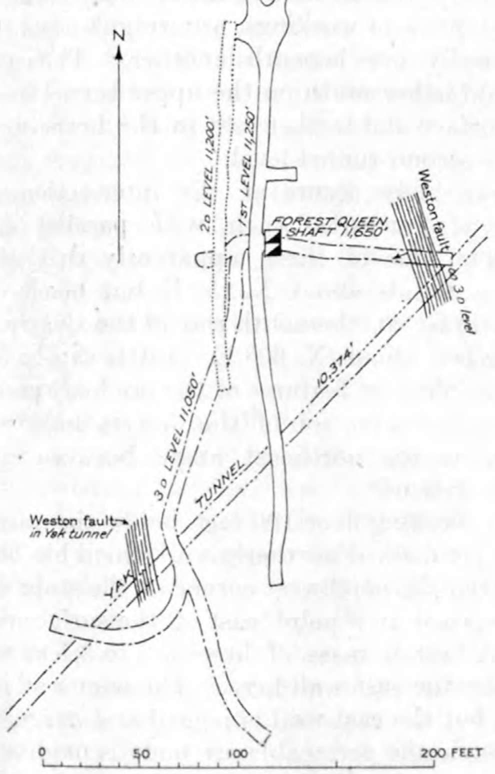


FIGURE 100.—Plan of workings of Forest Queen shaft, showing Weston fault and fissure vein

Breece Hill. Throughout these workings the porphyry contains large quantities of pyrite, and the joint planes in the rock are characteristically lined with crystalline pyrite, which in some places makes out into the body of the porphyry in irregular replacement bunches. In addition to the joint planes, definite veins have also been found, as indicated on Plate 56. Four such minor veins were found in the Tribune tunnel at distances of 400, 900, 1,000, and 1,025 feet from its junction with the Agwalt tunnel. They had a north-northeast strike and a northwest dip and ranged from 1½ to 6 inches in thickness. They were filled with crystalline pyrite and showed here and there small quantities of galena. None of them had been followed along the strike at the time of Irving's visit, but the large quantity of water that entered the workings when they were cut seems to indicate that they were extensive. The material contained in them all assayed more than 1 ounce in gold to the ton and some assays ran as high as 2½ ounces. One vein carrying some galena assayed as high as 8 per cent of lead and 36 ounces of silver to the ton. The galena enveloped pyrite crystals. The porphyry throughout the Agwalt tunnel is heavily impregnated with pyrite and assays from 0.04 to 0.05 ounce of gold to the ton.

What is believed to be the Weston fault was cut in the northwestern end of the Agwalt tunnel and consisted of a broken zone about 2 feet wide, filled with clay selvage in which were included layers of fine crystalline auriferous pyrite. Another strong fissure, which is believed by some to be the Weston fault, is cut by the Agwalt tunnel 280 feet southwest of its junction with the Tribune tunnel.

ANTIOCH STOCKWORK

The Antioch mine (fig. 101) is on the west brow of Breece Hill 2,300 feet S. 18° W. from the Ibex No. 4 shaft. The bedrock surface, which is nearly bare, slopes westward at an angle of about 10° but steepens rapidly toward the west.

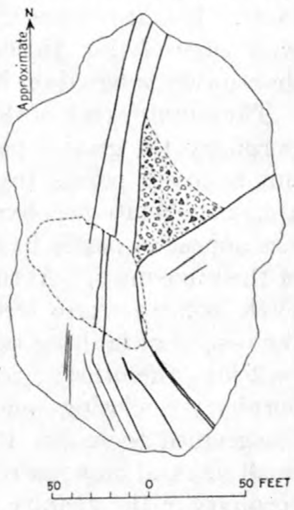


FIGURE 101.—Plan of Antioch mine, looking down into the quarry from the surface, showing the north-south fracture system intersecting the northeast system and a mass of brecciated porphyry between the two systems

The workings of the mine are shown in Figure 101. The main surface workings consist of a large open quarry of roughly elliptical form with its longer axis trending N. 17° E. The longer diameter measures 215 feet, and the shorter 150 feet. The walls are precipitous but converge downward, and at the deepest point the open cut is approximately 200 feet deep. The altitude of the north rim of the quarry ranges from 11,595 to 11,630 feet. The mine was worked at first by simple quarry methods, but the open cut soon became too deep, and an adit 200 feet long was driven from a point 60 feet vertically below the quarry rim. A second adit 600 feet long was later driven from a point 160 feet below the quarry rim. From the end of this adit an incline leads downward to a stope floor 30 feet below the second tunnel level. A third tunnel, the Agwalt tunnel, only a portion of which is shown in Figure 101, was then driven from White Gulch and a drift run from it to the ore body, 559 feet below the quarry rim. Practically no mining was done from this tunnel because the presence of clay in the ore prevented profitable operation.

The Antioch mine was one of the earliest important gold-producing properties, aside from placers, to be worked in the district. It was first worked by Frank Brooks, apparently in 1885, and appears, from such records as could be procured, to have been continuously productive in 1885 and 1886. From that time until 1889 it was worked intermittently. During the first two or three years it produced from 15 to 100 tons daily. The ore is reported to have assayed $10 in gold to the ton and to have yielded $7 to the ton on the plates in the stamp mill. It was hauled to a small mill in White Gulch but during a part of the time was handled in the Oro mill. The working was profitable as long as mining costs were low. According to Emmons, the open cut lies about 140 feet west of the Weston fault, the exact position of which north of the Garibaldi tunnel was known to him. Irving regarded the fissures in the Tribune tunnel as part of the Weston fault zone. According to a map of the Agwalt tunnel furnished by John Harvey, of Leadville, a strong sheer zone in Gray porphyry was cut 250 feet west of the Tribune tunnel and is believed by him and others to be the Weston fault. If so it reaches the bedrock surface close to the west edge of the Antioch open cut. The following description is based on Emmons's notes.

The country rock of the Antioch ore body is intrusive porphyry, the greater part of which is Gray porphyry; but at many points in the mine the fine-grained to aphanitic White porphyry is found. The two porphyries appear in places to be merely textural variations of the same mass. Abrupt changes from one porphyry to the other are also frequent, but these appear to be the results of faulting rather than the intrusion of one rock into the other. Some evidence exists of a Gray porphyry inclosing angular fragments of an earlier fine-grained rock, but this intrusion appears to be of small size and may not represent the main mass of Gray porphyry in the vicinity.

The ore body in the Antioch consisted of a mass of broken or brecciated porphyry cemented by a fine-grained reddish iron oxide, which filled fractures and interstices between fragments of porphyry and stained the fragments themselves. This iron oxide was evidently derived from pyrite, but oxidation was complete from the surface to and below the lowest workings. Emmons states that the gold content varied in direct proportion to the amount of this matrix of iron oxide. In some places the iron oxide was free from boulders of porphyry for considerable distances. The best ore was near the surface and continued to a depth of about 90 feet. Below that depth there appears to have been less limonitic matter and a greater volume of porphyry fragments.

The drift from the Agwalt tunnel found the ore well defined between the same walls as in the upper workings, though its thickness was somewhat less. The fragments of porphyry were in much larger proportion and the red matrix much less; but the matrix was even richer than that above and contained as much as 3 or 4 ounces of gold to the ton when separately assayed. It did not amalgamate, however, and contained too much clay to be economically separated by washing.

The ore body appears to have been an irregular chimney-shaped mass, wider at the top and with approximately the cross section indicated by the present rim of the quarry but narrowing downward. Successive horizontal sections of the ore body, as indicated by the stopes and workings, are irregular and do not lie vertically one beneath another. Thus the ore extended farther south on the upper tunnel level than at the surface and farther east in the lower workings from the second tunnel level.

The ore body occurs at the intersection of two systems of fractures, each with parallel sheeting (fig. 101). One of these, apparently that which is dominant, trends about N. 15° E. but bends toward the southeast at the south end of the quarry. The other trends about N. 60° E. Little can be learned about the physical features of the ore body previously exploited, but a portion of the breccia mass remains unmined in the northeast angle between the two fracture systems.

In the working floor 190 feet below the quarry rim is a sharply defined northerly wall which has been followed from the northwest corner of the stope for 125 feet eastward to a point east of the surface rim (fig. 101). A barren mass of breccia 2 to 3 feet wide extends into the east wall here. The west wall is fairly regular, but the east wall is jagged and irregular.

Although the permeable ore body is oxidized down to the lowest levels, the adjacent porphyry, even in the upper tunnel (60 feet below the quarry rim), contains unaltered pyrite as disseminated grains and veinlets.

BIG FOUR GROUP

LOCATION AND GENERAL FEATURES

The Big Four group of veins lies beneath the hillside a short distance north of the Ibex mine. Immediately north of the Ibex group the hill is steep and precipitous, but the slope becomes nearly horizontal before reaching the bed of the gulch. On the steep hillside the Blue limestone and lower strata, cut by porphyry sills, are steeply upturned against the rather ill defined Colorado Prince fault, but the angle of dip decreases southwestward toward the Ibex workings. Northeast of the fault the only formations present are Cambrian quartzite and pre-Cambrian granite separated by a sill of White porphyry, and the large pipes of rhyolitic agglomerate shown in Plate 27. The developed veins in this group are the Big Four, Big Four East, Gold Basin, Louise, No. 20–b Ibex, South Winnie, St. Louis, and Colorado Prince Nos. 1 and 2. The first five of these and the St. Louis belong to the north-northeast system, the South Winnie to the north-northwest system, and the Colorado Prince Nos. 1 and 2 to a west-northwest system.

The spaces of ground which intervene between these veins and in which veins have not so far been opened up are rarely less than 400 feet, being thus much wider than those in the Ibex group. Many extremely small mineral-bearing veins, however, which have not been mapped, lie between the major veins. Some veins of the north-northeast system dip eastward and some westward, and they thus appear more nearly like a normal conjugate system than those of the Ibex group.

The two small west-northwest veins of the Colorado Prince occupy what are believed to be parallel slips of the Colorado Prince fault, but the mineralization extends along the strike for comparatively short distances. The reverse character of the Colorado Prince fault and its interpretation as the result of shearing in the limb of an anticline imply that this fault, like the Tucson fault, in Iron Hill, is for the most part too tight to permit circulation of ore-forming solutions.

The eastward and northward extension of the veins of the Big Four group is limited by the large neck of rhyolitic agglomerate, which cuts some veins abruptly and either enters between the walls of others, breaking up the contained ore, or cuts across them as dikes. In a direction a little west of north lies a comparatively large area of pre-Cambrian granite in which little extensive exploration has been carried on. This group of veins may be eventually found to continue in that direction.

With the exception of the Big Four vein, the veins of this group are short and narrow and are not yet known to extend upward to the bedrock surface. The St. Louis vein is known to terminate upward before reaching this surface, but the exact nature of its connection with the blanket ores of the Miner Boy and Kentucky mines is not known.

The Big Four mine is opened by a shaft whose collar has an altitude of 11,348 feet (old datum). The shaft has been sunk to a depth of 600 feet, and from this point a drill hole was put down for an additional 600 feet. The records of the shaft are unsatisfactory, as no clear distinction has been drawn between the "transition shales" beneath the White limestone and the various porphyries which have been intruded into them. The geologic section must therefore be inferred largely from the information gained from the surrounding workings. The workings of the Big Four mine have not at any time been accessible to the writers, and the accompanying description is therefore compiled from the statements furnished by the management.

The collar of the shaft is 20 feet south of the outcrop of the Colorado Prince fault. The fault here dips northward at an angle of 51°. The geologic structure is shown by section B–B′, Plate 28. On the south side of the Colorado Prince fault the upper portion of the shaft is in the White limestone or the underlying "transition shales," which are turned upward at a steep angle against the Colorado Prince fault. It is probable that the rocks cut in the upper first 320 feet of the shaft belong mainly in the "transition shales" beneath the White limestone, although they are recorded by the company as porphyry. These shales have been frequently mistaken for porphyry. The workings of the third level of the Ibex mine, which have been visited, extend northward to the workings of the Big Four mine and clearly indicate the sedimentary nature of the geologic formations cut in the upper levels of this mine. The record of rocks cut by the drill hole below the shaft is also open to question. The material supposed by the company to be the lower sheet of White porphyry and the quartzite beneath it may prove to be granite, and if so the succession conforms to that on the south side of the Rawlings fault.

The country rocks north of the fault are not cut in any of the workings of the mine, all of which lie within the upturned strata on the footwall side of the fault. The Rawlings fault crosses the shaft at a depth of 190 feet. The dip slip along this fault has not been determined in the Big Four mine but is about 175 feet in the Fannie Rawlings mine (section A–A′, pl. 28). This fault meets the Colorado Prince fault at the bedrock surface immediately west of the Big Four shaft.

The workings of the Big Four are shown in Figure 102 and also on Plate 27. Levels were run eastward and westward from the Big Four shaft at depths of 190, 246, 306, 385, 455, 524, and 599 feet.

BIG FOUR VEIN

Two veins were found in the Big Four mine. The comparatively small and unproductive "East vein" was cut on the second level 300 feet east of the shaft and followed for 150 feet. It was also worked on the fourth level for more than 300 feet. Its general trend, as shown by these workings, is N. 25° E. and its average dip 27° E. The wall rocks of this vein are exclusively Lower quartzite and White porphyry.

The second or main vein of the Big Four mine reaches the bedrock surface under 60 feet of glacial "wash," close by the shaft (fig. 102). It has been followed downward from the bedrock surface for 670 feet and has been worked on six levels. The average strike of the vein is N. 26° E., but, as shown on Plate 56, it has a number of marked though gradual curves. This main vein extends from the southern boundaries of the Big Four property, where it is widest, to the point where it is cut off by the body of agglomerate that lies between the Gold Basin and Big Four shafts. It is also interrupted by three dikes of agglomerate, which are evidently branches of the main pipe. The vein in the upper levels from the bedrock surface down as far as the third level (250 feet) is practically vertical. From the third level downward it gradually assumes a westward dip of about 75°. On the strike the vein has been explored for a distance of 700 feet. At the south end it continues in undiminished strength but passes into the property of the Ibex Co., by which it had not been worked up to the time of Irving's visit.

The wall rocks of the vein include in descending order the "transition shales" beneath the White limestone, the underlying part of the Lower quartzite, and a great thickness of intrusive White porphyry. The vein, so far as worked, cuts the "transition shales" only in the upper levels in the southern portion of the mine, southwest of the Colorado Prince fault.

The thickness of the vein ranges generally from a few inches to 6 or 7 feet and in one place attains 10 feet. The vein is wide and productive in the upper portions and widest at the south boundary of the property. It gradually narrows to the north and downward. At the sixth level it becomes practically barren.

Between the second and third levels the vein splits into several portions, which were worked separately. These, however, pinch downward except one, which continues as a single vein on the fourth, fifth, and sixth levels. Several horses of granite occur between the walls of the veins on the second and fourth levels.

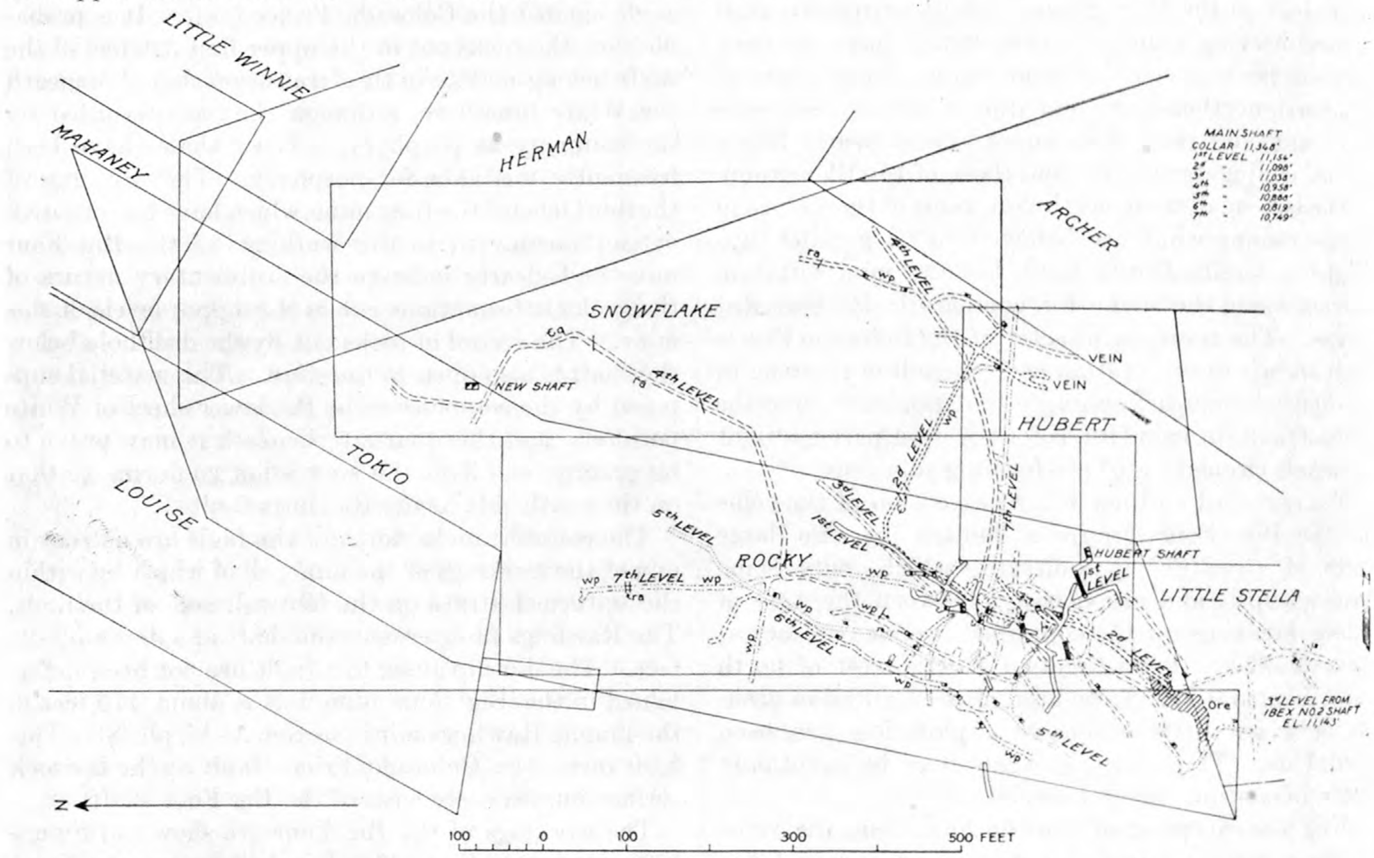


FIGURE 102.—Map of workings of Big Four, Fannie Rawlings, and Gold Basin mines. ra, Rhyolitic agglomerate; pw, White porphyry; €q, Cambrian quartzite

The ore bodies consist of a mixture of sulphides or oxides and crushed and broken rock. The ore at some places occupies the whole width of the fissure, at others only a part of it.

In several places the ore is reported to have branched out along certain beds in the sedimentary rocks, but these branches were subordinate in tenor and quantity to the main vein. The original ore consisted chiefly of pyrite with some chalcopyrite and a little blende, and galena. Above the third and fourth levels the ore was oxidized. From the lower limit of oxidation down as far as the vein had been explored the ore was irregularly enriched.

The range in contents of the ores based on smelter returns for different years is shown on page 309.

Range in contents of ores from Big Four mine

[Zinc not determined]

Year	Class of ores	Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Silica (per cent)	Iron (per cent)
[a]1903	(?)	0.59–8.5	4.4–130	1.0–13.9	(b)	(b)	(b)
1908	Sulphide	.1–10.945	23.20–79.45	3.50–8.00	[c] 1.15–4.3	(b)	(b)
	Oxide	.105–1.972	1.35–18.50	(b)	[d] 0.5–1.2		
1909	(?)	.120–1.950	.95–79.75	(?)–9.00	(?)–3.75	(b)	(b)
[e]1914	Oxide	.090–2.430	.85–10.00	(?)–.75	(b)	34.8–92.8	0.5–26.5
	Copper	.410	23.5	3.35	(b)	76.6	2.2
1915	Oxide	.090–2.115	.83–3.35	(b)	(b)	89.3–92.4	2.9–3.9

[a] Does not include one lot of less than half a ton which contained 20.956 ounces of gold and 68.0 ounces of silver to the ton and 6.9 per cent of copper.
[b] Not determined.
[c] Wet.
[d] Dry.
[e] Contains less than 6 per cent of sulphur.

According to these figures the vein originally contained ore of two classes—the pyrite-chalcopyrite ore and the highly siliceous ore. The richer ores were mined in 1909 and earlier years. In 1908 the sulphide ore was much more enriched than the oxidized ore. The records do not show from what parts of the vein the ores were mined. Most of the ores were presumably siliceous. The contents of the ore shipped in 1914 do not suggest enrichment unless to a minor extent in gold. The ore with high iron content must have been much oxidized, whereas that with minimum iron content and the one lot of copper ore may have been mostly unoxidized, though classed commercially as oxide ore. The most siliceous ores shipped in 1914 and 1915 evidently consisted of quartz with 6 to 8 per cent of pyrite, perhaps partly oxidized, and their gold varied independently of the other metals.

Study of individual shipments of ores represented in the above table shows the general independence of gold, although certain of the richer ores suggest a relation between gold and copper. The average content of silver, especially in oxidized ores, varies roughly with that of gold, but individual shipments both of oxidized and sulphide ores show no such relation. Shipments in 1903 showed a close though not constant relation between silver and copper, which suggests the presence of silver-bearing tetrahedrite or the precipitation of silver by chalcocite.

According to information obtained by Irving, the average gross value of the ore in 1909 and earlier years was $45 a ton and the average net value $3 a ton.

GOLD BASIN VEIN

The Gold Basin shaft, or, as it is sometimes known, the Lower Big Four, is on the south side of South Evans Gulch, about 600 feet north-northeast of the Big Four shaft. It has been sunk to a depth of 310 feet, passing through about 25 feet of "wash," 200 feet of Cambrian quartzite, and 85 feet of White porphyry. Two levels have been driven from the shaft, one at 240 feet and the other at 310 feet below the collar (pl. 27).

A small vein was found in the White porphyry west of the shaft. On the lower level it crossed the drift 14 feet west of the shaft and on the upper level 50 feet west of the shaft, which gives a dip of approximately 53° E. It has been followed northward on the lower level and both northward and southward on the upper level and has been explored for a total length of 350 feet. It has not been followed upward into the quartzite. The White porphyry along the vein is usually very dense and hard and not appreciably altered except in the immediate vicinity of the vein.

The vein occupies a sheeted zone which in the upper level has a maximum width of 3 feet. This zone contains small stringers of pyrite and chalcopyrite which have become completely oxidized in portions of the upper level. At the lower level the vein consists of a few small stringers ranging from half an inch to 2 inches in width, and its width as a whole has decreased. Some of the sulphide stringers were very rich, containing as high as 27 ounces in gold to the ton, and in places sooty chalcocite brought the tenor in copper up to 7 per cent; but the small size and irregularity of the vein have prevented any extensive and profitable operations.

SOUTH WINNIE VEIN

The South Winnie shaft is on the south slope of South Evans Gulch, 170 feet north-northeast of the Miner Boy tunnel. The shaft is sunk for a depth of 307 feet in White porphyry close to the southern margin of a large body of agglomerate, which is cut by the shaft 2 feet from the bottom. The contact between the agglomerate and White porphyry is nearly vertical but inclines slightly toward the south. Its general trend near the shaft is east, but a short distance west of the shaft it curves northward.

Two drifts have been run at a depth of 202 feet, one eastward and one southeastward from the shaft. (See fig. 103.) The southeast drift branches 160 feet from the shaft. The northeastern branch cuts a vein 178 feet east of the shaft. This vein has an average strike of N. 26° W. At the level where it was first found it was included between walls of White porphyry and extended for a distance of 150 feet from its narrow southern extremity to the agglomerate body where it was abruptly cut off.

A dike of agglomerate extends southward from the main mass along the east wall of the ore body, and disconnected dikelike masses of agglomerate are also found along the western wall. These apophyses from the agglomerate do not extend to the narrow southern extremity of the ore body. The upper part of the ore body is reported to lie between walls of

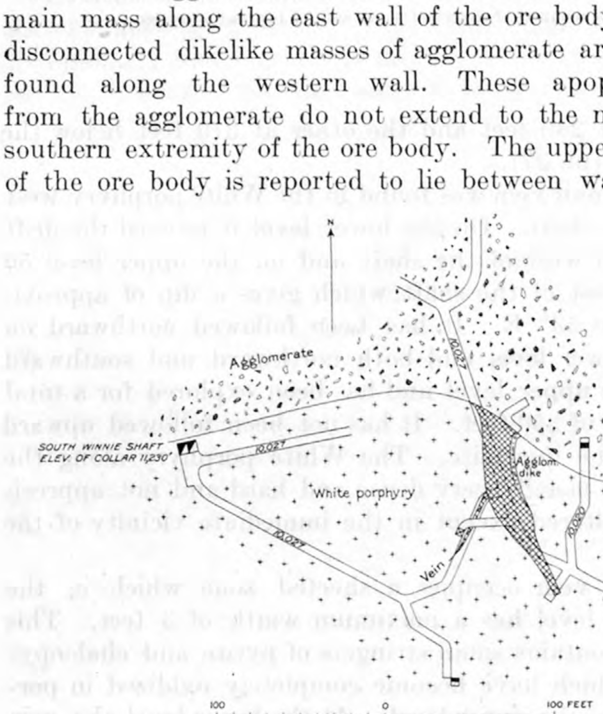


FIGURE 103.—Plan of South Winnie mine, showing abrupt termination of ore at contact with agglomerate. Figures show altitude of drifts above sea level

limestone, presumably a mass inclosed in the White porphyry; but as the geologic map (pl. 27) shows Cambrian quartzite to be the bedrock surface above the ore body, the presence of the limestone is not readily explained. It is possible that a casing of massive carbonate has been mistaken for limestone.

In form the ore body is a lens-shaped mass which is widest on the 202-foot level (fig. 103), where it has a maximum width of 22 feet. Followed upward in a raise it was found to narrow to 6 feet, and a winze sunk on it for 50 feet proved that it narrows downward also. Toward the south it pinches to a very narrow streak.

The ore in the upper portions of the ore body consisted of a mixture of manganese and iron oxides, lead carbonate, and a considerable amount of zinc carbonate or silicate. Throughout this oxidized material were scattered residual fragments of pyrite, galena, and sphalerite. In the lower and wider portions of the ore body the ore was chiefly sulphide. The richest portion of it lay along the western or footwall side, and a few assays of the ore from this portion showed as much as 40 ounces in gold to the ton. Streaks of galena along the footwall cut the main body of the ore and, when separated from the rest of the ore by sorting, carried 5 ounces of gold and 60 ounces of silver to the ton.

The center of the ore body consisted of low-grade pyrite. The richest portion of the ore body lay immediately adjacent to the agglomerate mass, presumably because at this point the loosely compacted nature of the agglomerate had permitted the maximum amount of enrichment.

ST. LOUIS (COLORADO PRINCE) VEIN

The St. Louis or Colorado Prince mine has been idle most of the time since the early days of the Leadville district but was being worked by lessees in 1924. It is on the south side of South Evans Gulch, one-fifth of a mile northwest of the Big Four mine. The mine is opened by the St. Louis tunnel, whose portal is 60 feet above the bottom of the gulch, just below the very steep escarpment of Cambrian quartzite. The tunnel extends S. 9° W. for 500 feet, has a slightly more westerly trend for 200 feet, and finally continues S. 17° W. for 460 feet.

The rocks cut in this mine are shown on section J–J', Plate 16. The tunnel first passes through the White porphyry, which lies between the Lower quartzite and the granite, the contact dipping southward at low angle. It then penetrates the overlying Cambrian quartzite and the "transition shales" at its top. At 400 feet from the portal the Colorado Prince fault, containing 2 feet of breccia and dipping north, is exposed.

Thirty feet south of this fault is a small parallel fissure that also shows evidences of faulting. Both the Colorado Prince fault and the small parallel fissure contain ore and have been plotted on Plate 56 as veins. About 100 feet beyond the Colorado Prince fault is a second fault with a similar dip and strike. The rocks between these two faults have a much steeper southward dip than those to the north. Beyond the more southerly fault the tunnel is entirely in sedimentary rocks. These form a local anticline whose crest is about 50 feet south of the southern fault and whose axis is nearly parallel to the strike of the fault. The tunnel, after passing through the crest of the anticline in White limestone, enters the Parting quartzite and Blue limestone.

The St. Louis vein was cut 175 feet from the portal of the tunnel in the White porphyry. Where found it trends nearly north, almost at right angles to the strike of the faulted and folded sedimentary rocks and their included porphyry sheets. Beyond this point it turns a little westward and was followed in the driving of the tunnel. Its dip is vertical, and its width is from 3 to 6 inches. It passes without interruption from White porphyry into Cambrian quartzite, through the Colorado Prince fault and through the small parallel vein to the south. It finally enters the "transition shales," where it becomes lost.

The pay streak within the vein is from 2 to 3 inches thick and is usually bounded by a zone of broken quartzite and porphyry which lies between it and the adjacent solid rock. It is significant that where the vein cuts the Colorado Prince fault no displacement is observable, although the fissure containing the vein was evidently formed later than the Colorado Prince fault. The ore shoots in this fault and its smaller parallel fault are here called the Colorado Prince No. 1 and No. 2 veins. They are branches of the St. Louis vein and extend for 20 feet along the strike on each side of it. Farther from the main vein the two faults are barren.

At the point where the vein enters the "transition shales" a winze was sunk for 15 feet, and the vein was found to continue this far down without interruption. It was reported by Emmons [21] that this vein widens to 20 feet in the "transition shales" at the top of the Cambrian quartzite but that part of the mine was not accessible during the resurvey.

The ore from the St. Louis vein consisted of broken material, mostly oxidized. The vein had no very distinct walls. Below the drift, where it joined a cross vein, it contained a solid filling of chalcopyrite with a corresponding high content of copper accompanied by 2 or 3 ounces of gold to the ton. The chief metal of value in the vein as a whole was gold, some of the ore yielding as much as 100 ounces of gold and 190 ounces of silver to the ton. A little lead was also present.

At the junctions with the two cross veins the ore in the main vein was richer than elsewhere. This difference may have been due to enrichment by waters whose downward circulation was concentrated along these junctions. Blanket deposits of oxidized lead-silver ore have been found at the contact of Blue limestone and White porphyry in the uppermost workings of the mine, and one was reopened by lessees in 1924; but their location and dimensions in general are not known, and they can not be accurately indicated on the map. Other deposits were mined beneath "wash" in the remnant of White limestone on the northeast side of the Colorado Prince fault in the Colorado Prince, Miner Boy, and Black Prince mines.

WINNIE-LUEMA GROUP

WINNIE-LUEMA VEIN

GENERAL FEATURES

The Winnie-Luema vein is the longest, most thoroughly explored, and most productive single vein in the Leadville district. It extends for nearly 4,000 feet in a northerly direction from the north edge of the Ollie Reed pipe of agglomerate in South Evans Gulch, which cuts it off on the south, into the southern part of Prospect Mountain, where it appears to die out in a number of diverging fissures. The upper part of the vein, above its productive part, is probably cut off by the Josie pipe of agglomerate near the Silver Spoon shaft. The vein was first developed in its southern part, through the Winnie shaft, and later and more extensively in its northern part, through the Luema (Valley) shaft and Silver Spoon tunnel. Its middle part has also been somewhat developed, but no data on this part of the vein have been obtained.

The vein occupies a sheeted fault zone, from which mineralized branch faults, some of which are connected with blanket replacement deposits in limestones, extend in an east-northeast direction, as described on page 81 and shown in Plates 27 and 69 and Figures 104–107. Owing to lack of exploration on the west side of the vein, it is not known whether similar branch faults are present there also, but the changes in altitude of formation boundaries in the Luema and Silver Spoon ground suggest their presence, as shown in Figure 107. Minor veins east of the main vein have been worked close by the Luema and Silver Spoon shafts.

The main vein strikes due north in the Winnie ground, but its northern part curves gradually westward, and its north end strikes N. 25° W. The undulations along its course are inconspicuous. The dip is vertical in its southern part, and the deviations from vertical to east and west in the Luema and Silver Spoon workings (figs. 104, 105) are very slight.

The accompanying figures, together with Plate 27, show that all the rock formations of the district are found at one place or another along the walls of the vein. The "Weber grits," however, are present only where the northernmost part is opened by the Silver Spoon tunnel.

The strata throughout the length of the vein dip from 15° to 40°, averaging about 25°, north to northeast. The dip is north in the Silver Spoon but north-northeast to northeast elsewhere. The steeper dips along the vein, especially on the east side, are due to drag.

White porphyry forms a sill between Cambrian quartzite and underlying granite in the southern part (pl. 14, sections B–B′ and C–C′), and another at the top of the Blue limestone in the northern part. Two small sills are present within the Cambrian quartzite and White limestone in the Luema mine. An irregular sill of Gray porphyry lies between the Cambrian quartzite and White limestone in the southern part. A dike of porphyry, highly altered, impregnated with pyrite, and cut by stringers of ore, has been reported to lie in the main fault zone and to constitute the vein in the Winnie ground, and altered porphyry has also been reported in the vein in the Luema ground;

[21] Op. cit., pp. 504–505.

but except for the sills shown in Figure 104 no porphyry was found in the Luema. In its stead there was a large amount of white sericite and claylike material filled with fine grains of quartzite, which resembled decomposed porphyry containing quartz phenocrysts but was in reality a gouge derived largely from granite, quartzite, "transition shales," and limestone. Very little limestone unreplaced by ore remained, however. Close examination may prove that the reported porphyry in the Winnie ground is gouge also. If it is in reality a porphyry, it is exceptional and must be younger than both White and Gray porphyries; the fissure that it occupies must have been formed subsequent to the intrusion of Gray porphyry and reopened subsequent to the intrusion of the dike and prior to deposition of the ore.

There has been little opportunity for observation of formations on the west side of the vein. It is known that the formation cut by the Blue Ribbon and Chautauqua shafts are Cambrian quartzite and White limestone, dipping eastward, but there has been no opportunity to examine the two properties in detail. On the east side of the vein the rocks in the Winnie mine have a much steeper dip than on the west side, apparently having been dragged upward in the fault movement.

The main vein is itself slightly offset by a later fault exposed 1,100 feet north of the Winnie shaft at the extreme northern limit of the Cleveland workings. This fault is vertical and has a trend of N. 60° E. Its northern wall has been offset 12 feet eastward and perhaps 200 feet downward, but lack of exploration leaves the amount of movement in doubt.

The vein ranges from 4 to 40 feet in thickness and consists of the gouge material, resembling decomposed porphyry crisscrossed by small veins and bordered by larger veins of high-grade ore. In some places, particularly in the north end of the Winnie and along the middle levels of the Luema mine, ore occupies the full width of the vein. There is little or no evidence of cavity filling, and the ore occurs as bands or lenses, formed by replacement of the crushed rock along fractures in the fault zone. Typical vein quartz is inconspicuous on the whole, and the highly siliceous gangue is mainly the gougy material. The main ore shoots end along the shale beds at the top of the quartzite and in the White limestone, although certain favorable beds within this shaly zone have been replaced

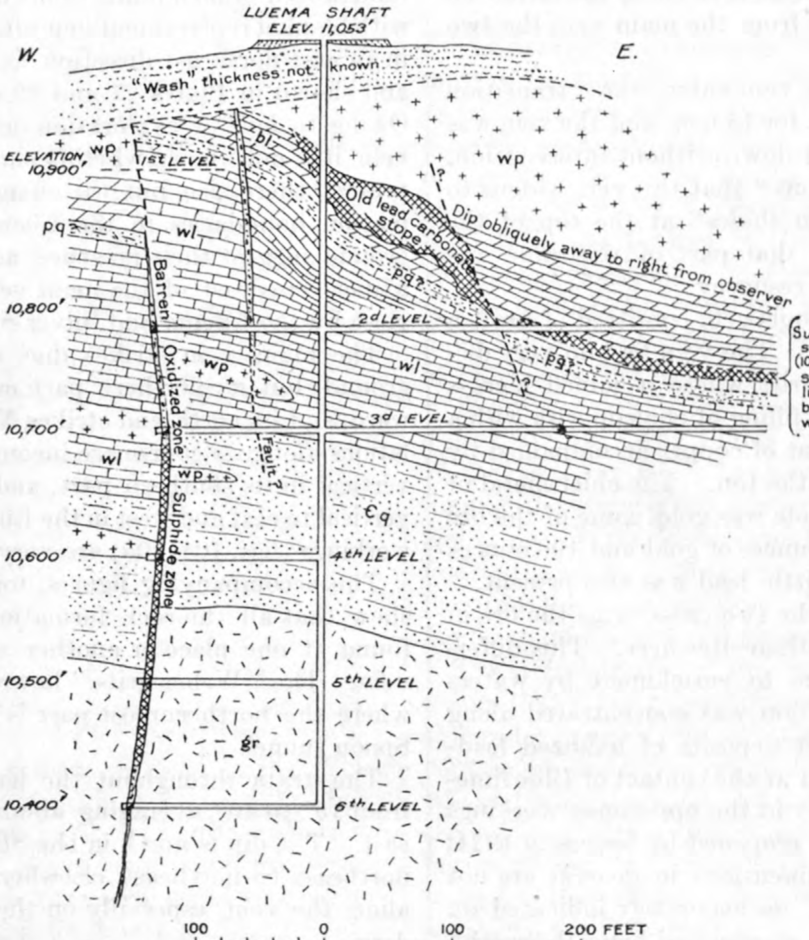
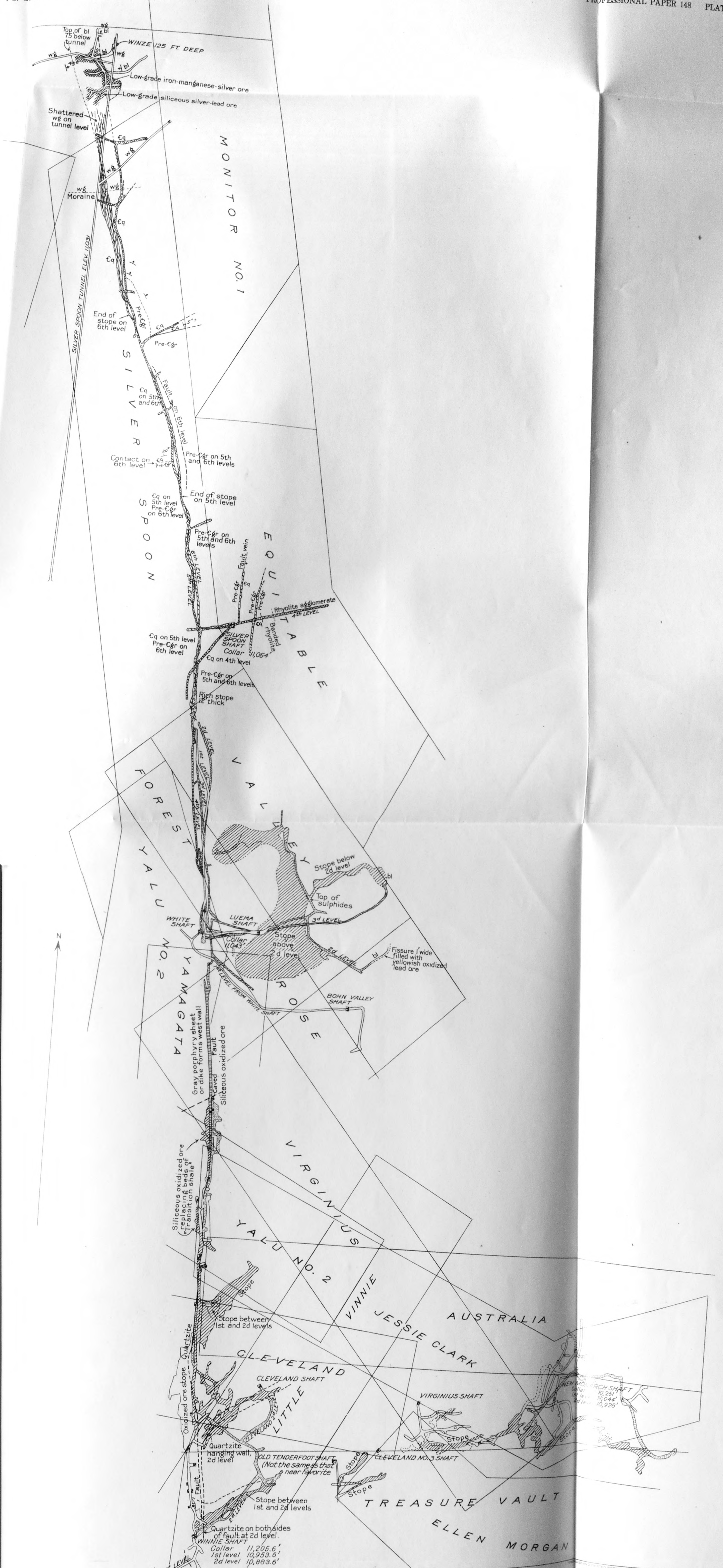
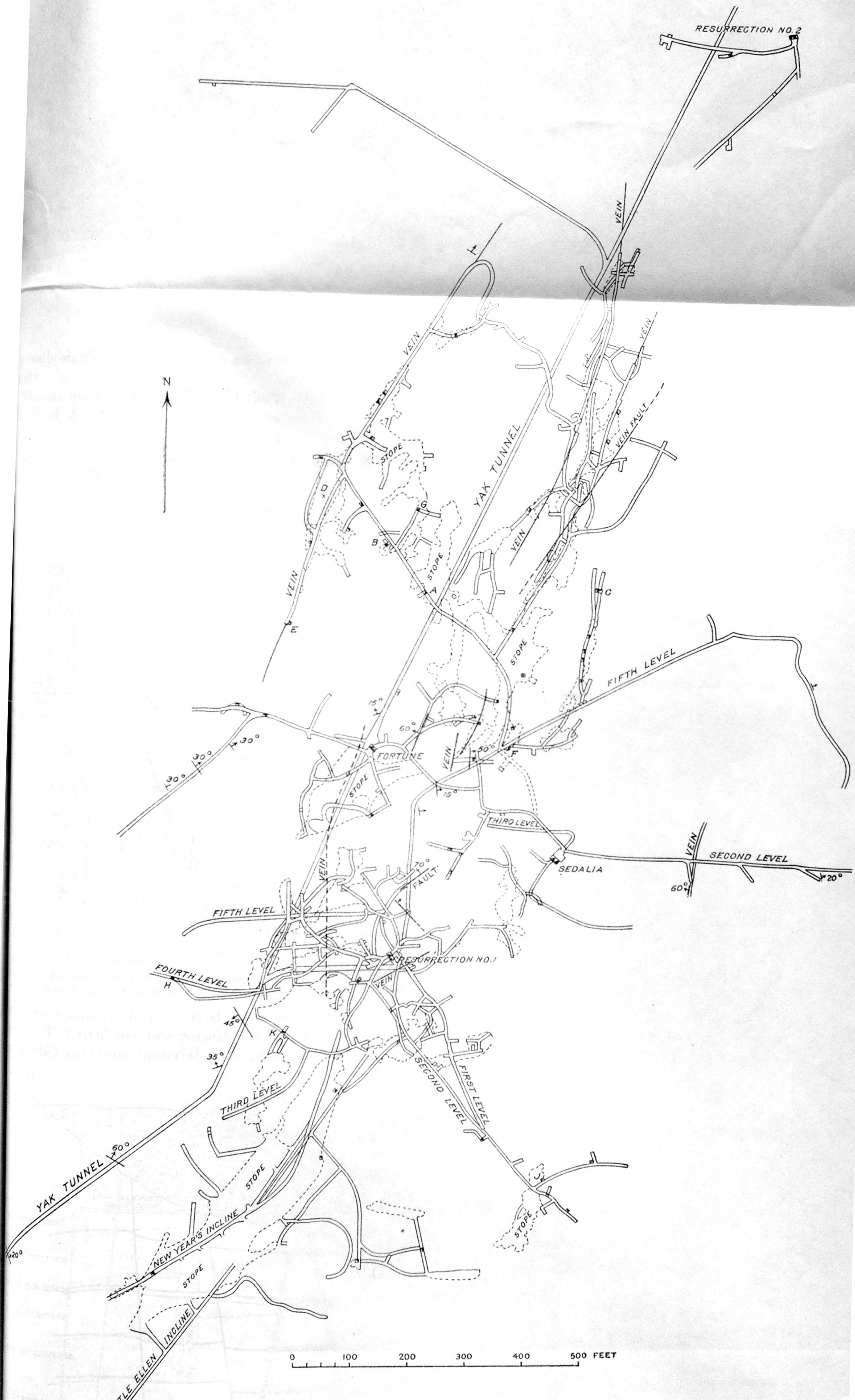


FIGURE 104.—East-west section through Luema shaft. wp, White porphyry; bl, Blue limestone; pq, Parting quartzite; wl, White limestone; €q, Cambrian quartzite gr, granite



PLAN OF WINNIE, LUEMA, AND SILVER SPOON MINES, SHOWING WINNIE-LUEMA LODE AND ASSOCIATED BLANKET ORE BODIES



MAP OF RESURRECTION MINE

by ore both along the main vein and along the branch faults.

The ore above the third level of the Luema and the first level of the Winnie shafts is thoroughly oxidized,

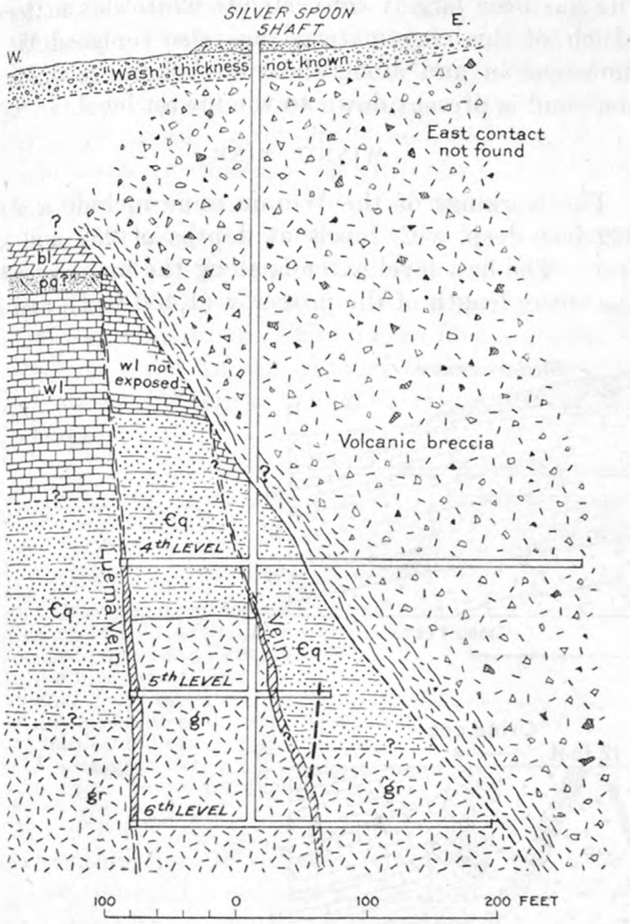


FIGURE 105.—East-west section through Silver Spoon shaft. bl, Blue limestone; pq, Parting quartzite; wl, White limestone; cq, Cambrian quartzite; gr, Granite

and some oxidation has occurred down to the lowest levels. The oxidized ore consists of brown loosely compacted ocherous material with isolated bunches and spots of sericite. The sulphide ore, so far as seen, is a mixture of black zinc blende, pyrite, galena, and chalcopyrite, named in the order of abundance. The general prevalence of zinc blende is also borne out by a large number of assays and smelter returns, but the rich gold-copper ore along the west wall of the main vein in the Winnie ground may have been low in zinc and considerably enriched by chalcocite. In both the Winnie and the Luema-Silver Spoon ore shoots pyrite

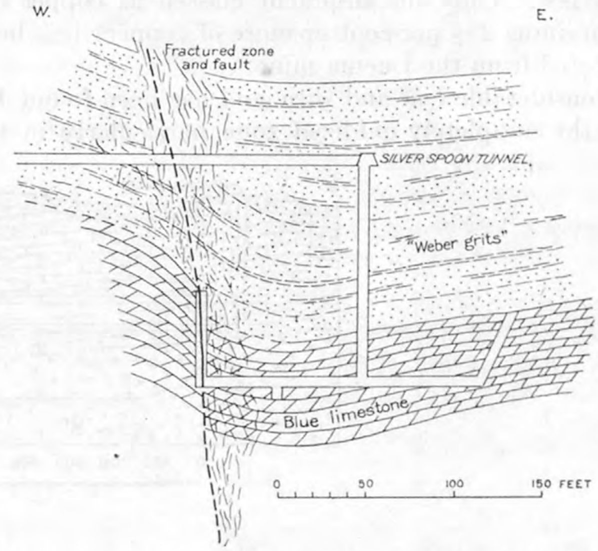


FIGURE 106.—N. 78° E. section at north end of Silver Spoon tunnel, 1,475 feet north-northwest of Silver Spoon shaft

and chalcopyrite are more abundant at the lower levels, where the wall rocks are quartzite and granite, than at higher levels, where limy "transition shales" and White limestone predominate. They are found in irregularly scattered bunches and grains with the blende and galena, and also as comparatively pure streaks; but as a whole they are rather evenly distributed at any one level. Galena is practically absent in some places and relatively abundant in others, especially in

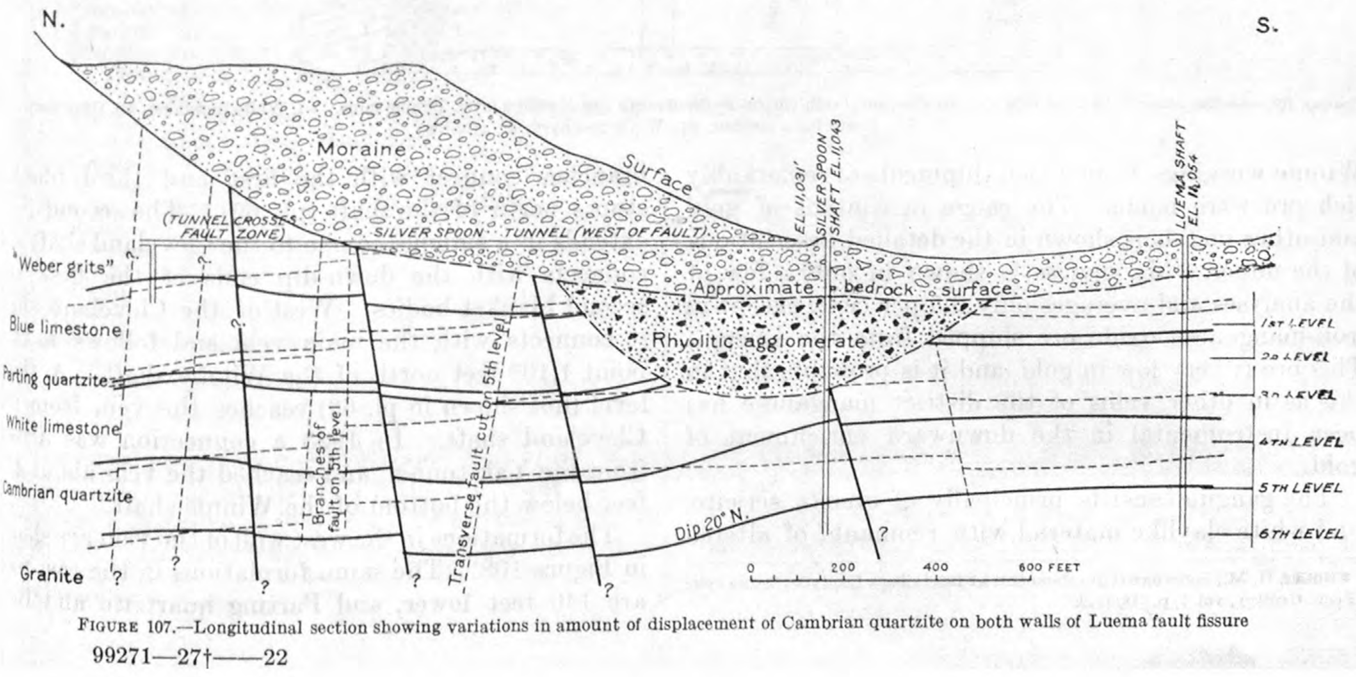


FIGURE 107.—Longitudinal section showing variations in amount of displacement of Cambrian quartzite on both walls of Luema fault fissure

the wider and most thoroughly metallized parts of the main vein and in the adjoining blanket deposits a short distance from the connected branch faults.

Throughout the vein there is considerable black, sooty material, some of which may be the copper oxide tenorite[22] but most of which is chalcocite. It is very conspicuous in places, but available analyses and assays indicate that the copper content of the ore, except along the west wall of the vein in Winnie ground, is very low. Only one shipment classed as copper ore (containing 2½ per cent or more of copper) has been reported from the Luema mine.

Considerable leaf and wire gold has been found below the completely oxidized zone, particularly in the wall rock. Well-crystallized quartz is inconspicuous. Carbonate gangue is rare in the productive parts of the vein, but may be present in and around the associated replacement bodies in White limestone. Sericite has been largely converted to white clay material. Much of this clay material has also replaced White limestone in and along the vein below the oxidized zone and is present down to the lowest level.

WINNIE MINE

The workings of the Winnie mine include a shaft 322 feet deep, with levels at depths of 252 and 322 feet. The first level extends along the main vein for the entire length of the property (1,400 feet), and its

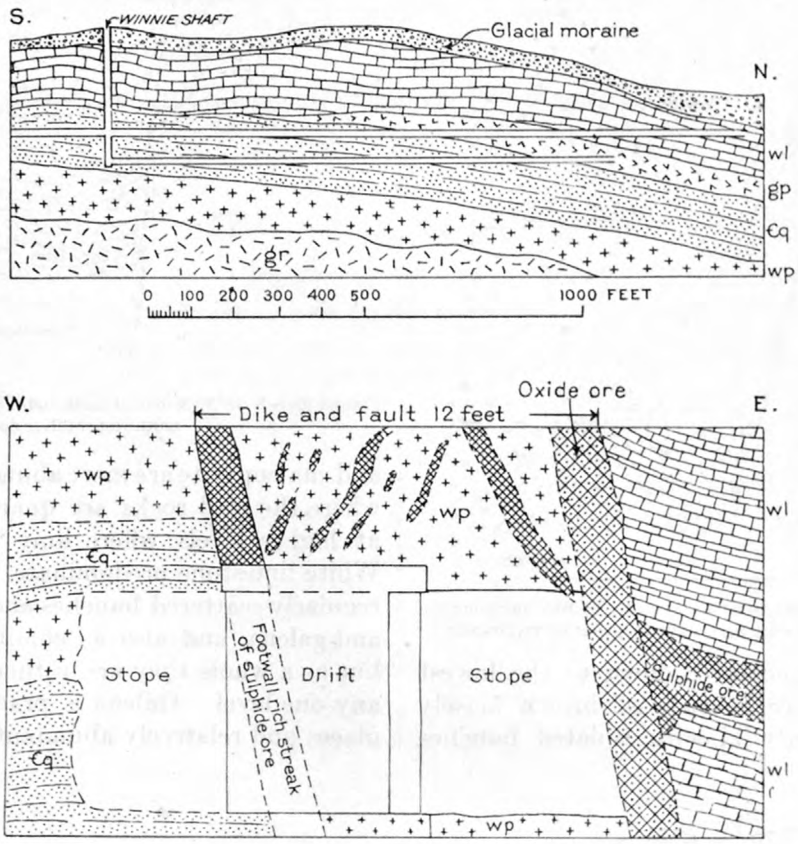


FIGURE 108.—Section along footwall of vein and cross section of vein 140 feet south of north face of second level, Winnie mine. wl, White limestone; gp, Gray porphyry; Єq, Cambrian quartzite; wp, White porphyry; gr, granite

Winnie workings, from which shipments of remarkably rich ore were made. The range in content of gold and other metals is shown in the detailed descriptions of the mines. Manganese is shown in only a few of the analyses and averages only 0.5 per cent, except in iron-manganese oxide ore shipped from the Luema. This ore is very low in gold, and it is probable that in this as in other veins of the district manganese has been instrumental in the downward enrichment of gold.

The gangue consists principally of quartz, sericite, and white claylike material with remnants of altered

[22] Butler, G. M., Some recent developments at Leadville; a Leadville fissure vein: Econ. Geology, vol. 7, p. 318, 1912.

branches connect with the first and third blanket stopes north of the shaft (pl. 69). The second level extends in a sinuous course to the Cleveland shaft and connects with the down-dip ends of the first and second blanket bodies. West of the Cleveland shaft it connects with the main vein and follows it to a point 1,100 feet north of the Winnie shaft. A third level (not shown in pl. 69) reaches the vein from the Cleveland shaft. In 1923 a connection was driven from the Yak tunnel, and reached the vein about 450 feet below the bottom of the Winnie shaft.

The formations in the west wall of the vein are shown in Figure 108. The same formations in the east wall are 140 feet lower, and Parting quartzite and Blue limestone cut by a White porphyry sill are present above the first level for 200 feet northward from the shaft; but White limestone and Cambrian quartzite and the intervening Gray porphyry are the only wall rocks exposed along the two levels. According to Philip Argall,[23] who examined the mine in 1905, the first level follows the footwall of Cambrian quartzite for 700 feet and then passes along the Gray porphyry, which had caved. High-grade enriched sulphide ore was extensively stoped along the footwall. From 220 to 480 feet north of the shaft and 65 feet above the level the ore along the footwall joins a blanket replacement deposit of siliceous oxidized ore in White limestone, which has also been extensively stoped, although a little ore remains in pillars and in places around the edges. It is not known whether the west limit of the stope marks the limit of mineralization or only of high-grade ore.

The sulphide ore on the second level belonged to two classes—rich gold-copper ore and mixed sulphide ore. The gold-copper ore formed a seam 6 inches to 2 feet thick along and near the footwall. Only a few remnants of the footwall vein were left, and crisscrossing stringers of similar ore were present in the middle of the vein (fig. 108).

Samples of ore of this class, collected by Mr. Argall, were assayed, and the results are shown on the first three lines in the following table. The smelter returns on carload lots, listed in the table, were furnished by the owners to Mr. Irving. The contents of gold, silver, and copper in three of them indicate a high degree of enrichment and doubtless very selective mining. Failure to record the copper, lead, and zinc contents in all the assays prevents a thorough comparison of the ore in the main vein with the ore in the connected blanket replacement deposits.

Assays and smelter returns of ore from Winnie mine

	Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)
Along Gray porphyry footwall (1 foot thick)	0.65	3.5	----	----	----
Along quartzite footwall (1.5 feet thick)	3.54	6.1	----	0.7	26.0
Stringer in quartzite hanging wall	2.18	32.0	----	4.6	20.7
Carload lots, main vein:					
First-grade ore	18	180	10.0	----	----
Second-grade ore	7	105	10	----	----
Third-grade ore	3	50	----	----	----
Fourth-grade ore	.9	40	----	----	----
Ore from minor parallel vein	8.40	76.7	11.5	4.5	9.5

The other class of ore was found near the hanging wall of the main vein and in the connected replacement deposits in the White limestone. It is represented by the following assays, in only one of which copper was determined:

Assays of mixed sulphide ore from hanging wall of lode and connected replacement deposits in the Winnie mine

	Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)
1 First replacement body north of Winnie shaft:					
1 carload lot	1.0	(?)	3.0	10.0	----
Samples along north wall—					
Range	0.30–1.32	2.0–13.4	----	0.6–6.8	3.7–31.6
Average	.59	5.0	----	1.7	10.0
2 Hanging wall of lode close by replacement body (average)	.50	5.0	----	6.0	15.0
3 Replacement body at Cleveland shaft:					
Range	.10–.54	2.6–7.0	----	6.3–22.9	7.0–24.5
Average	.289	4.4		12.0	18.7
4 Small shoot near vein west of Cleveland shaft:					
Range	.09–.34	2.1–7.0	----	2.3–12.9	8.3–21.8
Average	.216	3.5		4.4	12.2
5 12 feet below No. 4:					
Range	.25–1.18	2.7–9.4	----	0.7–4.6	5.0–21.9
Average	.638	5.0		1.6	14.1
6 Replacement body at raise No. 18:					
Range	.23–1.18	3.1–6.3	----	1.0–3.8	7.5–25.5
Average	.506	4.7		2.2	17.7

The blanket replacement ore body just north of the Winnie shaft was stoped down the dip from the first level for a distance of 200 feet and an average width of 20 feet. Its height was not recorded, but ore remaining on the north side averaged 2 feet in thickness. When the stope reached the second level the ore body was found too thin to be mined, but it is significant that the trend of this body is about in line with stopes on replacement deposits in Blue limestone near the New

[23] Written communication.

Monarch shaft; the intervening ground is therefore worthy of consideration. The one carload of ore represented in the above table was richer in gold than the ore left along the north wall, and mining was evidently confined to the most enriched ore.

The next replacement deposit to the north was 3.7 feet thick near the Cleveland shaft, and the samples represented in the table were all taken in this vicinity before the bulk of the ore was mined. As they are relatively far from the main vein their lower gold content and high lead content suggest a gradation from the siliceous gold ore of the veins to the mixed sulphide ores of the blanket deposits, but this suggestion can not be emphasized without a study of the ore in place.

The small shoot along the east side of the vein, due west of the Cleveland shaft, is merely a bulging of the vein into the White limestone wall. The ore 12 feet below it, in crushed quartzite or gougy material, averages distinctly higher in gold and lower in lead. The replacement body at raise No. 18, 590 feet north of the shaft, was sampled only close to the vein, before the bulk of it was mined, and here the gold was rather high and the lead low. The northernmost 100 feet of the vein, along the second level, between walls of Gray porphyry, contained ore averaging 0.36 ounce but running up to 1.25 ounces of gold to the ton. Silver averages only 2 ounces to the ton, lead less than 1 per cent, and zinc about 5 per cent. It would not be surprising if a raise to the White limestone should disclose a replacement body at this place. In fact, raises and drifts along all the mineralized branch faults may disclose other replacement bodies in limestone above those already found, and ore may be expected along quartzite walls below the second level. Whether the vein will continue to be productive down into the granite is doubtful. Nothing encouraging has been reported from the Yak tunnel level.

Partial analysis of composite samples from the first and second levels shows, in addition to the metals already tabulated, 16 to 21 per cent of iron, 22 to 29 per cent of silica, and 21 to 25 per cent of sulphur. Rough calculation indicates that about half the iron is present as carbonate or oxide, but no detailed descriptions of the gangue or the amount of oxidation in the commercial sulphide ores are available.

LUEMA MINE

The Luema mine consists of two shafts, the Luema and Silver Spoon, each about 600 feet deep, and six levels about 100 feet apart, as shown in Plate 69. The first level driven from the Luema shaft was inaccessible when the mine was visited in 1913. North of these workings the upper part of the mine is opened by the Silver Spoon tunnel. The vein in the Luema mine has been worked in one continuous ore shoot, which extended for 1,500 feet northward from the Luema shaft (pl. 69 and fig. 109). Farther north low-grade oxidized siliceous ore replacing Blue limestone was found along the vein below the breast of the Silver Spoon tunnel. A parallel vein east of the main lode, near the Silver Spoon shaft, and a vein of northeast trend and a large replacement body in Blue limestone, near the Luema shaft, have also been mined. The ore in the veins was similar to that in the main vein; that in the replacement body was more like the oxidized blanket ores in the western part of the district, but no analyses of it are available.

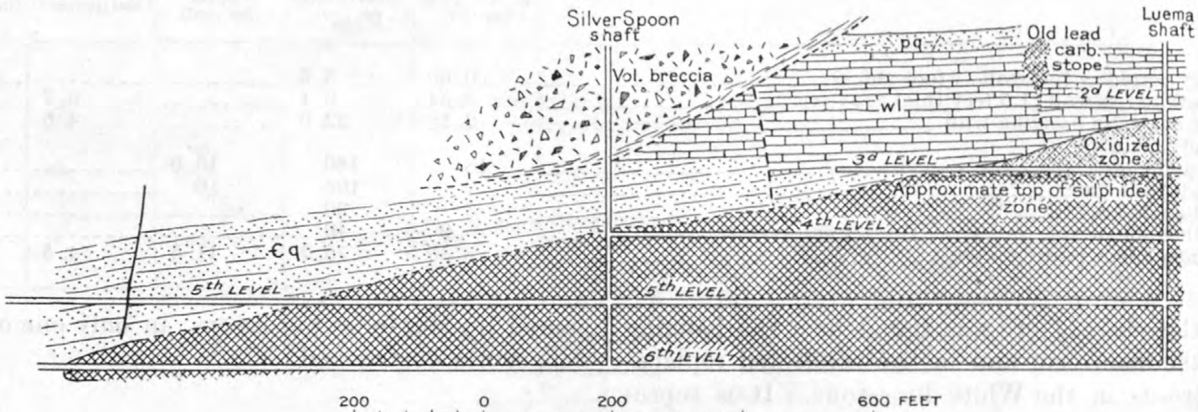


FIGURE 109.—Longitudinal section showing approximate dimensions of Luema ore body and its relations to limestone of east wall. pq, Parting quartzite; wl, White limestone; €q, Cambrian quartzite

The ore shoot in the main vein opposite the Luema shaft extends from a point 25 feet below the second level down about to the sixth level. Above the second level the vein fissure and its walls are thinly impregnated with pyrite. The top of the ore shoot pitches northward at an average angle of 12°, and its bottom extends almost horizontal to the point where the shoot pinches out on the sixth level. Below the fourth level, opposite the Luema shaft, the shoot splits into two branches, one along each wall of the vein, separated by fault material that contains short streaks of ore. The west branch or vein ranged from a few inches to 3 feet in thickness and was mined continuously to the sixth level. The east branch was narrower and less continuous and mostly of too low grade for mining. A series of short lenses lay a short distance east of and parallel to the east branch. Below the shoot on the sixth level the vein contains mainly veinlets 1 or 2 inches thick of typical sulphide ore of good grade but too small and too widely scattered to be mined. About 200 feet southwest of the Silver Spoon shaft, on the fifth level, the ore shoot maintained a width of 12 feet for a distance of 100 feet and contained ore of very high grade.

The ore was thoroughly oxidized down to the third level. It presumably contained little or no zinc, and its tenor in gold was less than that of the underlying sulphide ore, from which, however, as shown on page 318, it did not greatly differ in value per ton.

The north-south vein that parallels the vein on the east near the Silver Spoon (fig. 105) and the northeast vein between the main vein and the Luema shaft (fig. 104) are generally similar to the main vein in character and require little comment. That near the Silver Spoon shaft is cut off at the top by the agglomerate pipe. It was productive where one wall or both walls were of quartzite, but where both walls were of granite there were only small stringers of ore, similar to those below the shoot in the main vein. The vein of northeast trend near the Luema shaft was productive from a point below the second level up to the bedrock surface. This vein had been abandoned when the mine was visited, but so far as known no branch along the beds of White limestone had been found.

The only branch faults connecting with the main vein and corresponding to those in the Winnie mine are intersected by the fifth level 750 feet and more north of the Silver Spoon shaft (pl. 69). They are in Cambrian quartzite which is impregnated with pyrite. No effort has been made to follow them upward into White limestone with the hope of finding blanket replacement deposits.

The large replacement body in Blue limestone near the Luema shaft is capped by White porphyry. Its northern part trends N. 70° E., parallel to the mineralized branch faults of the main vein, but its larger portion trends N. 20° W., about parallel to the main vein, and terminates both northward and southward along steeply dipping fractures. It has not been proved to connect with the main vein or with the northeast vein that passes near the shaft. The stope in this body was inaccessible when the mine was visited. The ore was oxidized above the second level, where it graded into sulphide ore that continued as a narrow shoot trending N. 70° E. beneath the White porphyry. Nearly 200 feet southeast of this narrow shoot a fissure of northeast trend containing oxidized lead ore 1 to 3 feet thick was followed for about 80 feet. Where the second level passed close to the floor of the oxidized shoot small bunches of oxidized zinc ore of good grade were found scattered through low-grade zinc ore, which was stained brown and black by iron and manganese oxides. No oxidized zinc ore in commercial quantity was found.

The northward continuation of the main vein has been explored by the Silver Spoon tunnel (pl. 69), which passes through glacial moraine and "Weber grits," and by drifts from a winze sunk 125 feet below the face of the tunnel into Blue limestone at ground-water level. The vein fissure is there poorly defined and is represented by a broad shattered zone along an eastward-dipping monocline (fig. 106). The Blue limestone has been replaced by jasperoid stained by iron and manganese oxides and containing in places enough lead (5 per cent) to be classed as low-grade siliceous lead ore. This lead ore is said to contain about 0.3 ounce of gold and 10 ounces of silver to the ton, whereas the siliceous iron-manganese oxide ore contains only 0.05 ounce of gold and 10 to 15 ounces of silver to the ton. Shipments classed as iron-manganese oxide ore, evidently from this place, are represented on page 318.

The low grade of the ore, the "feathering out" of the fault, and the northeast dip, which carries the limestone below water level within a short distance, afford little encouragement for prospecting farther northward along the vein. It may be that the small amount of displacement along this part of the fault is due to another change in direction of throw such as occurs somewhere to the south of the Luema shaft, and that the displacement increases again to the northward. The structure in that case may be favorable for another ore shoot, but the cost of determining this question may be at present prohibitive. If the Canterbury Hill tunnel eventually reaches the vicinity and lowers the water level conditions for prospecting the ground beneath the Silver Spoon tunnel will be improved, and the outcome of prospecting there can determine the advisability of extending developments northward.

The Luema, then known as the Valley mine, was operated by lessees in 1891–1893, but no record of production prior to 1908 is at hand. The Luema Mining Co. was incorporated November 25, 1907, after the mine had been idle for at least two years, and its first shipment of ore was made in June, 1908. The average metal contents of annual shipments since then are shown in the accompanying table (p. 318). The ores are all siliceous and are divided into two main classes—"oxide" (in which the sulphur content is less than 10 per cent) and sulphide. These are subdivided according to metal contents. The figures recorded are too incomplete to indicate the mineral composition closely. Sulphur, so far as determined in the oxide ore (in 1908 only), reached a maximum of 2.5 per cent, suggesting that much of the lead was present as galena. Chalcocite may also be present in partly oxidized ore, but the percentage of copper is too little to account for an appreciable amount of sulphur.

Lead in single shipments of oxidized ore amounted to as much as 25 per cent, but on the whole it is no more abundant in the oxidized ore than in the sulphide ore, despite the fact that the leaching of zinc and other soluble materials may have relatively increased the original percentage of lead by as much as one-fifth or one-fourth. The percentage of copper also shows little change from sulphide to oxidized lead ore, although some leaching of the oxidized zone is proved by the films of sooty chalcocite in the sulphide ore below. The one lot of copper sulphide ore shipped in 1916 may be attributed to local enrichment.

Average contents of ores shipped from the Luema and Silver Spoon mines, 1908–1921

Year	Gold (ounce per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)	Silica (per cent)	Iron (per cent)	Manganese (per cent)
Oxide ores[a]								
Siliceous lead ore								
1908	0.328	4.87	(b)	[c]9.99	(b)			0.5
1909	.519	7.42	(b)	[c]11.42	(b)			
1910	.623	8.15	[d]0.648	[c]7.25	(b)			
1911	.174	2.89	[d].099	[c]5.95	1.0	60.0	14.0	.05–.50
1912	.597	7.81	[d].62	[c]6.95	(b)			
1913	.205	3.99	[e].131	[e]7.82	(b)			
1914	.210	5.08	[e].265	[e]9.38	(b)			
1915	.351	5.34	[d].181	[d]15.16	(b)			
1916	.438	7.36	[d].284	[d]15.66	(b)			
1917	.377	6.68	[d].413	[d]13.64	(b)			
1918	.382	6.33	[d].239	[d]14.65	(b)			
1919	.414	5.46	[d].248	[d]11.63	(b)			
1920	.204	4.70	(b)	9.67	(b)			
1921	.403	8.71	(b)	16.15	(b)	48.0	15.0	
Dry siliceous ores								
1913	0.224	4.77	0.189		(b)			
1914	.931	5.88		[e]2.73				
1916	.124	8.8		[d]3.65				
	.660	22.11	[d]2.23	[d]2.38				
1917	.088	7.46		[d]3.56		60.0	9.00	
Iron-manganese ores								
1916	0.029	12.68		1.10				
	.038	13.22		.86		53.8	20.8	18.0
	.035	12.63		.47		58.0	13.7	10.0
Sulphide ores								
Siliceous lead ore								
1910	0.836	8.42	[d]0.695	[c]7.84				
1912	.836	8.43	[d].698	[c]6.27				
1913	.484	6.88	[e].426	[e]8.42				
1914	.420	7.15		[e]15.06				
1915	.374	5.10	[d].288	[d]6.11				
1916	.398	6.53	[d].340	[d]13.85				
1917	.051	2.02		[d]5.90				
	.412	6.55	.298	[d]11.47				
1918	.258	6.37	[d].487	[d]8.08				
Dry siliceous ore								
1911	0.916	11.17	[d]1.66	[c]2.59	10–15	6.0	14	
1913	.864	7.01	[e].78	[e].76				
1914	.744	6.36	[e].54	[e]2.18				
Copper ore								
1916	0.222	27.48	[e]3.38	[d]1.92				
Zinc ore								
1913	0.142	4.27		[d]3.46	14.03			
	.424	6.83	[d]0.207	[d]1.93	24.19			
1914	.435	5.82		[d]2.35	20.03			
1915	.313	5.19		[d]4.91	17.46			
1916	.438	10.14		[d]2.85	23.08			
1917	.351	9.11		[d]2.92	22.39			

[a] The term "oxide ores" in this table implies a content of less than 10 per cent sulphur, whether the ores are appreciably oxidized or not. It is impossible to estimate the degree of oxidation without the determination of the iron, zinc, and sulphur present.
[b] Not determined. [c] Fire assay. [d] Wet assay. [e] Recovered.

Assays of unusually rich ore from the Luema mine

	Gold (ounces per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)	Zinc (per cent)	Manganese (per cent)
Picked specimen, fourth level [a]	8.0	27		29.5	11.1	0.4
Rich ore, fifth level	3.0	18	2	2.0–3.0		
East vein at Silver Spoon shaft, fifth level	2.0	40	3.0–5.0	25.0		

[a] Butler, G. M., Some recent developments at Leadville; a Leadville fissure vein: Econ. Geology, vol. 7, p. 318, 1912.

Zinc is much more prevalent than the partial analyses indicate, and it is likely that some shipments of lead sulphide ore have been penalized for zinc in excess of 12 per cent. The zinc sulphide ore shipped evidently represents lots in which the percentage of lead fell below 5 and is not to be sharply distinguished from the lead and dry ores.

Gold, as usual, varies independently of the other constituents. The highest content recorded, 2.85 ounces to the ton, happened to be in one lot of lead "oxide" ore whose composition can not be even approximately estimated; but on the whole the gold content is distinctly less in the "oxide" than in the sulphide ores, a fact that suggests partial leaching. As several lots of "oxide" ore, which were in fact considerably oxidized, averaged about 0.5 per cent of manganese, it may be inferred that manganese aided in the downward concentration of gold. This inference is strengthened by the extremely low gold content in the iron-manganese oxide ores, which probably came from the northernmost and highest part of the vein, reached by the Silver Spoon tunnel.

Silver averages a little less in the "oxide" than in the sulphide ores, which implies a relatively small amount of downward enrichment on the whole, although highly enriched sulphide ores have been found locally. Single shipments both of lead "oxide" and lead sulphide ore contained as much as 25 ounces of silver to the ton, and the one shipment of copper sulphide ore contained 27.48 ounces to the ton. The presence of maximum silver and copper contents in the same lot of ore suggests that enrichment in both metals has occurred and that chalcocite served as a precipitant of silver, but the ratio of silver to copper in most of the shipments is either not shown or is too variable to indicate that such relation is general.

The predominance of lead ore in the Luema vein may be attributed in part to the influence of White limestone in the walls and within the fault zone, especially along the upper part of the ore shoot; but it appears equally probable that solutions which had already deposited much of their pyrite were unable to escape from gouge-line fault and were obliged to deposit the bulk of their minerals within the fault, regardless of the influence of different wall rocks. This interpretation also implies that the low-grade jasperoid ores found at a higher level below the Silver Spoon tunnel are more remote from the source of supply and consist of such material as was able to make its way through the gougy part of the vein above the main shoot. Such material is likely to be of low grade, except where conditions for enrichment have been unusually favorable.

ORE BODIES EAST OF WINNIE-LUEMA VEIN

The outlines of the blanket ore bodies in Blue limestone between the Winnie and New Monarch shafts were furnished by the persons controlling the property subsequent to Irving's field work, but the former management refused admission to the mine. The workings have been closed during subsequent brief visits to the district, and nothing definite is known of them. Directly north of them ore bodies were worked through the Midnight, Katy, and Valley shafts, but were cut off by the Josie rhyolite pipe, as shown in Figures 13 and 14.

Other blanket bodies were worked in the early days, notably through the Virginius tunnel, where five tons of silver-lead ore is reported to have been produced daily during December, 1879, and in the Cleveland mine. Many large dumps in the vicinity contain mineralized limestone, but no other records of ore bodies have been obtained.

OLLIE REED-SILENT FRIEND GROUP

Another group of blanket deposits in steplike arrangement extends east-northeastward from the pipe of agglomerate south of the Winnie mine. The westernmost of these deposits replaces White limestone in the Ollie Reed mine and is abruptly cut off by the agglomerate (fig. 110). The others are in the Tenderfoot, Favorite, and Silent Friend mines and consist of long, narrow, irregular shoots with an average trend of N. 75° E. They are all in the Blue limestone and are mapped as "first contact" ore bodies, although they lie within the limestone well below the former position of the eroded White porphyry. The ore shoot in the Tenderfoot mine is illustrated in Figures 110 and 111. It extends from the bedrock surface downward with a pitch of 45° to a floor of "flint" or jasperoid about 60 feet above the Parting quartzite. No records showing the contents of its ores have been obtained for comparison with those of the Resurrection group, to the east, and with the blanket deposits underlain by flint in the Iron Hill and Fryer Hill areas. Figure 111 shows a small vein, evidently cut on the south drift, but nothing is known about it or the blanket deposit west of it. There is no record of any work below the Blue limestone.

The blanket ore shoot of the Silent Friend vein was examined by Irving on the Yak tunnel level, where it was found to trend N. 10° W. and dip 70° W. between granite walls and to consist chiefly of pyrite, with some zinc blende and galena. It had been followed upward for some distance and was said to connect with blanket ores, but no connection is indicated in Figure 110.

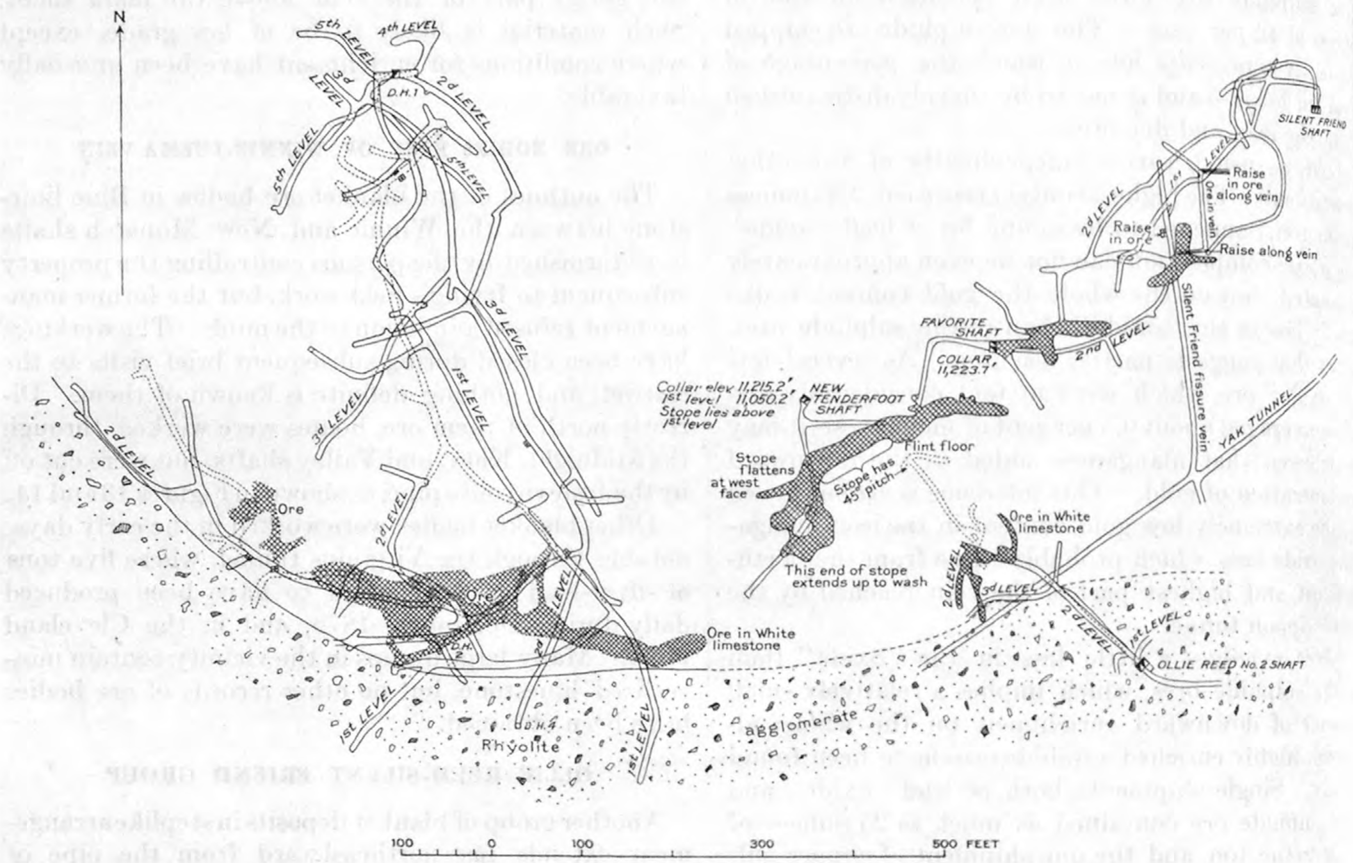


FIGURE 110.—Plan of workings of Ollie Reed, Tenderfoot, Favorite, and Silent Friend mines, showing outlines of ore bodies and edge of great pipe of agglomerate to the south

RESURRECTION GROUP

Nine veins are known in the Resurrection group, and for convenience they have been distinguished by numbers. Four of them—Nos. 1, 2, 7, and 8—have a roughly crescentic form with large radii of curvature. Most of the veins terminate upward in blanket replacement deposits against the layer of the "Weber shales" that commonly lies between the Blue limestone and the overlying White porphyry; some, where the shales were absent, directly underlie the White porphyry. The replacement deposits have been the principal source of ore, and only one of the veins, No. 7, has produced any considerable amount. The relations of blanket replacement deposits and veins are shown in Plates 27 and 70.

The veins were all accidentally discovered by underground workings driven for the purpose of developing the blanket ores, and but little attention has been given to them. Some of them are reported to be connected also with blanket ores belonging to a second or third contact. The spacing of these veins is relatively close, as in the Ibex group. Some of them are cut in the Yak tunnel, nearly 200 feet below their termination against the overlying "Weber shales," but have not been followed on the tunnel level. All the veins belong to the north-northeast system, and they deviate somewhat less from that direction than the veins in the other groups, but the southern part of vein No. 3, which has so far been observed only in the Yak tunnel, assumes a south-southeasterly trend for a distance of 200 feet.

These veins range in width from a few inches to 4 feet. The No. 7 vein, which lies east of the Yak tunnel, is well defined and has been followed downward from the contact for a considerable distance, and it has also been cut on the Yak tunnel level. It has produced a large tonnage of siliceous gold ore, much of which contained galena and zinc blende with subordinate silver. This fissure is vertical as a whole, although locally it hades a little from one side to the other. It is slightly crescentic in form, with its concave surface toward the west. The vein fills a fault fissure, along which a displacement of approximately 40 feet is observable on the lower levels of the Resurrection mine.

Another vein of the same character and attitude fills a fault fissure of slight displacement 100 feet east of the No. 7 vein. It has not been cut on the Yak tunnel level. The vertical vein just west of the Fortune shaft is undoubtedly the same as that cut 500 feet below on the Yak tunnel level. Besides the veins indicated on Plates 27 and 70 others have been reported in workings that could not be examined.

The tops of the blanket deposits pitch generally at an angle of 15° N. 20° E., but some of them have spread in other directions, apparently guided by cross fractures. No further data on these deposits are at hand, and it is not known whether the composition of their ores was generally uniform or changed as distance from the associated veins increased, or whether mining ceased when the ore became low in gold, leaving mixed sulphide ore in the walls. Two classes of ore, siliceous and lead, have been mined in recent years from both the oxidized and the sulphide zones, as shown below; but it is not known from what ore shoots they came. The ores classed as "oxide" include all containing less than 10 per cent of sulphur. The zinc content of the lead sulphide ores is not known.

These replacement bodies are part of a group that extends from the outcrop of Blue limestone on the south side of Little Ellen Hill to the Diamond mine and perhaps farther. Oxidized lead-silver ore was discovered at the outcrop, and as early as 1880 the production amounted to 10 tons a day. The ore lay for the most part just beneath the White porphyry, but at some places it was wholly within the limestone and proved to be a thin blanket of great lateral extent. It was followed in a north-northeast direction by the Little Ellen incline, and its northward continuation, or another shoot in line with it, was reached by the New Years incline, driven from a lower position. Increasing depth northward led to the sinking of the Resurrection No. 1 shaft, on the northwest slope of Little Ellen Hill, which resulted in the discovery of the blankets and connected veins of siliceous pyritic gold ore already described. These ore bodies extended into the Fortune and Sedalia mines. Siliceous pyritic ore was reached through the Resurrection No. 2 shaft, but its metal content was disappointingly low. The

Contents of ores shipped from Resurrection mine, 1915–1918

Class of ore	Year	Gold (ounce per ton)	Silver (ounces per ton)	Copper (per cent)[a]	Lead (per cent)[a]	Zinc (per cent)	Silica (per cent)	Iron (per cent)	Manganese (per cent)
Lead oxide	1915	{0.552	3.17	0.9	5.4		([b])	([b])	
		{.551	1.27	2.0	11.8		([b])	([b])	
Siliceous lead sulphide	1917	.228	5.23	.2	7.4				
Siliceous dry oxide	1917	.374	3.91		9.6		32.0	25.0	
Siliceous dry sulphide	1917	.327	3.02		2.2		44	21	8.0
Siliceous lead sulphide	1918	.305	17.00	.1	34.9				
Lead-iron sulphide	1918	.277	2.33		7.7				

[a] Wet assay. [b] Silica and iron equal, but record not kept.

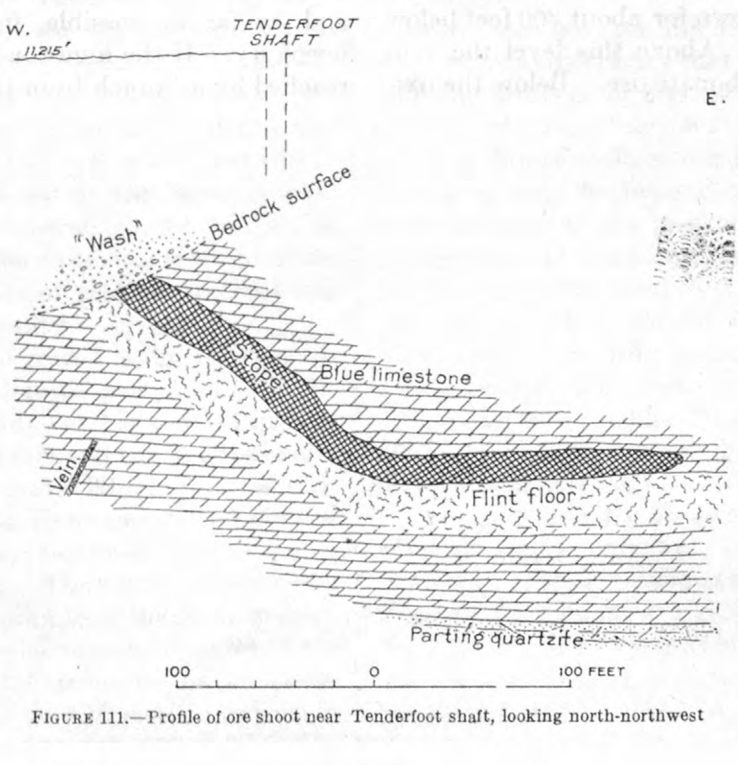


FIGURE 111.—Profile of ore shoot near Tenderfoot shaft, looking north-northwest

northernmost ore bodies found in this group were reached through the Diamond winze, at the end of the Yak tunnel. They are large bodies of low-grade pyritic ore connected with feeding veins, but at the time of Irving's visit, in 1901, no ore of shipping grade had been found, and the mine has been idle for several years.

Blanket bodies similar to those in the Resurrection mine were also found at the "first contact" in the Dolly B. mine and perhaps in the Famous mine. In 1922 an inclined drill hole sunk normal to the bedding from the north drift of the Dolly B. mine cut mineralized rock within the Blue limestone 27 to 50 feet above the Parting quartzite, 0 to 6 feet below the Parting quartzite, in the lower White limestone or the Cambrian "transition shales" 38 to 78 feet above the typical Cambrian quartzite, and in the "transition shales" 19 to 28 and 0 to 5 feet above the quartzite.

SUNDAY VEIN

The Sunday vein is on the west slope of Ball Mountain and is opened by two shafts whose collars have altitudes of 11,921 and 11,929 feet. The vein has also been opened by the Garibaldi tunnel, which extends from the portal, at the head of California Gulch, 2,400 feet northeastward and reaches the vein at a depth of 700 feet.

The vein cuts "Weber grits" with intercalated sills of Gray porphyry. It trends N. 18° E. and dips 88° W. It ranges from 1½ to 8 feet in width and probably averages between 3 and 4 feet. The ore consists of pyrite, galena, small quantities of zinc blende, and chalcopyrite.

The ore was oxidized down for about 300 feet below the collars of the shafts. Above this level the vein was chiefly filled with carbonate ore. Below the oxidized zone a zone of enrichment extended down for at least 400 feet, to the present tunnel level, which is the lower limit of exploration. The value of the enriched ore was still continuing downward at the time of the visit in 1909. Its copper content averaged 6 per cent.

Recent shipments from the Sunday vein are represented below. There were no shipments in 1921 and 1922. Zinc was not recorded.

Contents of ore shipped from Sunday vein, 1917–1920

Class of ore	Year	Gold (ounce per ton)	Silver (ounces per ton)	Copper (per cent)	Lead (per cent)
Siliceous lead sulphide	1917	0. 154	7. 85	0. 6	23. 3
Siliceous lead oxide [a]	1917	. 384	5. 23	------	5. 9
Siliceous lead-copper sulphide	1918	. 161	7. 30	4. 6	18. 7
Siliceous lead sulphide	1918	. 151	3. 53	. 1	5. 5
Siliceous dry oxide [b]	1918	. 160	1. 76	. 01	2. 1
Siliceous lead sulphide	1919	. 083	8. 98	. 8	25. 5
Do	1920	. 080	6. 96	1. 0	19. 3
Iron-lead sulphide	1920	. 098	6. 80	1. 1	17. 6

[a] Silica, 42 per cent; iron, 17 per cent.
[b] Silica, 67. 8 per cent; iron, 10. 3 per cent.

The depth of the Blue limestone below the bottom level of the Sunday mine or elsewhere in the vicinity has never been determined and can not be closely inferred because of the uncertain thickness of the porphyry sills. The depths indicated in sections E–E′ and F–F′ of Plate 15 are only rough approximations. The presence of the Sunday vein and of pronounced mineralization in its vicinity implies that the limestone below may be mineralized. Drilling is therefore justified to determine its depth, degree of mineralization, and, so far as possible, its relations with intrusive porphyry. If the limestone is not too deep it may be reached by a branch from the Yak tunnel.

CHAPTER 14. ORE RESERVES

After a mining district has been a large producer for nearly half a century it must be admitted that there has been considerable opportunity to determine the limits of productive territory by mining and prospecting, and that probably most of the favorable ground within those limits has been thoroughly explored. There are reasons, however, for hoping that the productive area of the Leadville district may still be enlarged and that some good ground heretofore overlooked may be found within the developed area. The relative promise of ground hitherto neglected or inadequately prospected must be gaged by the geologic study of the developed ground, together with a consideration of the cost of exploration. Besides the reserves of promising ground that are believed to exist and the developed and partly developed ore bodies that are minable with profit at present prices, it is reported that large quantities of low-grade material are ready to be mined when higher prices or improvements in metallurgy shall make it profitable to treat them. The following remarks will be confined to promising ground awaiting development and ground shown by development to be discouraging.

The discovery of the large ore shoot that had replaced a limestone inclusion in White porphyry in the Moyer mine suggests that a search for other replaced inclusions would be worth while. They should be expected where the Blue limestone below the White porphyry is abnormally thin. The splitting of the Blue limestone into several slabs inclosed in White porphyry at Fryer Hill, the small aggregate thickness of the slabs, and the general lack of information on the underlying rocks raise the question whether the uppermost part of the Blue limestone has been eroded or whether additional inclusions of it, possibly mineralized, remain to be found. The presence or absence of such inclusions can be determined only by study of geologic sections and mine records, verified by drilling.

A more promising field of search is the prospecting of limestone along reverse faults, particularly in the areas between the Tucson mine and Iron fault in Iron Hill and between the Iron fault and the Wolftone and Greenback mines in Carbonate Hill. Some shafts, including the New Pyrenees, Experiment, and City of Paris, have been sunk in these two areas without penetrating the White porphyry. The Cumberland passed from White porphyry into granite at the Mikado fault and therefore lies between the promising parts of the two areas. The influence of structure on the occurrence of ore in these areas should be similar to that in the mines named. (See pp. 275–276, 287–292.)

As the Tucson fault shows signs of dying out southeast of the Cord mine, the opportunity for deposition of ore at its intersection with fissures below the "first contact" and "second contact" shoots may have been less than in the Cord and Tucson mines; nevertheless, if costs of development in the White limestone are not prohibitive, the ground southeast of the Cord mine is worth prospecting, especially below the great Moyer shoot. The reverse fault that appears to parallel the Tucson fault on its west side (p. 72) may hold similar relations to ore bodies. Very little is known of this fault at present, but it may be feasible to follow the fault to its supposed intersection with the northeastward-trending fissures beneath the known ore shoots.

The continuity of the Moyer shoot with ore shoots in the Blue limestone in Rock Hill raises the question of similar continuity of any ores that may be found in the White limestone. Almost no work in the White limestone has been done there, and knowledge of the local structure is deficient; but the fact that the ore shoots mined have been comparatively narrow and have pinched downward suggests that the solutions that deposited them moved southward along the Blue limestone from the vicinity of the Moyer shoot and did not enter the White limestone. The fact that the little work done in the White limestone in the Oro La Plata and Stevens mines was unproductive supports this suggestion.

In the area between the Moyer shoot and the small stock of Gray porphyry that contains the Printer Boy vein the presence of high terrace gravel conceals any evidence of mineralization at the surface, and the deep burial of the Blue limestone has retarded prospecting. This area may be beyond the southeast end of the Tucson fault, but the presence of ore on both sides of it suggests that it also may be mineralized; nevertheless the structural conditions, though little known, do not appear more favorable here than in the Stevens mine, and prospecting is likely to be expensive and very uncertain of success.

The continuity of the Tucson-Maid fault northwest of the Maid mine has not been proved, although the fault, if it persists so far, should be close to certain of the ore bodies in the Downtown area, as indicated in Plate 18 and on page 75. If projected farther northwestward, with due allowance for offsets along the Pendery fault zone, it should approach the Delante No. 1 shaft; but explorations through that shaft and the Carleton, Seeley, Neptune, and Villa shafts, near by, have failed to find ore, and it must be inferred that no premineral faults or fissures in this vicinity were of sufficient continuity to serve as ore channels. As shown in Figure 10, a drift was driven for nearly 2,000 feet from the Delante No. 1 northward to the Hofer No. 1 shaft, and 14 drill holes were sunk in its vicinity without finding encouraging evidence of mineralization. The only such evidence reported in the vicinity is some low-grade manganese oxide ore carrying 1 to 9 ounces of silver to the ton found in the Jason shaft, and a little low-grade pyrite found in the Sequa shaft and in the Stumpf drill hole, near the Elgin smelter. The whole area is aptly named Poverty Flat, and the limits of appreciable mineralization east and south of it approximately coincide with the boundaries of the Fryer Hill and Carbonate groups of ore bodies indicated in Plate 45.

The limits of minable ground west of the Tucson-Maid fault coincide roughly with the west and southwest limits of the ore bodies of the Carbonate and Iron and Rock Hill groups shown in Plate 45. The western limit of mineralization in the Downtown area has not been closely determined, but all indications point to a gradual decrease in quantity and value of the ores west of the Cloud City fault. Work in this direction has been greatly hindered by excessive amounts of water. The local rocks are very permeable, and the fault has been cut so as to allow water from the east side to flow into the lower ground on the west side. Exploration west of the Cloud City fault has been confined to periods when deep working was in progress east of the fault. Shafts were then sunk to water level, but no attempts were made to go farther, as the cost of pumping for any single enterprise was prohibitive. Drill holes were put down west of the fault by the Western Mining Co. in the more westerly workings of the Coronado, Sixth Street, and Penrose mines, but the quantity and grade of ore found were not very encouraging, and the possibility that the ore-bearing rocks might be eroded within a short distance to the west rendered further development inadvisable.

Toward the south some ore was found in the Valentine mine about 400 feet west of the Cloud City (Valentine) fault, but none in the Home Extension mine, near by. The A. V. mine, 800 feet farther south, produced some manganese ore for a short time during the World War. The Maple Street shaft, west of the Valentine, passed through nearly 500 feet of "wash" and "lake beds" and 50 feet of White porphyry, reaching the top of the Blue limestone at a depth of 548 feet. A 5-foot thickness of iron oxide with very low content of silver or lead was cut there, but it proved to be discontinuous, and this result, together with the difficulty of handling the water, discouraged further prospecting. In short, the available evidence, though scattered, all points to the dying out of mineralization westward and to the improbability that there are any ore bodies west of the Cloud City fault of sufficiently high grade to justify the high cost of prospecting for them.

Only a few ore bodies have been found in the southern part of Carbonate Hill, and none have been found south of California Gulch and west of the Iron fault, although these areas have been considerably prospected. In southern Carbonate Hill extensive exploration of the Blue limestone has been conducted through the Toledo Avenue, Modest Girl, and California Gulch shafts without finding any large ore bodies, though a small one was found in the Modest Girl. Another small ore body was found in 1894 in the Thespian mine, but with this exception the mine was devoid of mineralization. To the north a large ore body was found in the Evelyn mine at the second or Gray porphyry contact, and it may have connected with the large ore shoots of the Wolftone and Castle View mines; but no maps of the Evelyn and Castle View mines have been available.

In the Toledo Avenue mine the usual "contact matter" between White porphyry and Blue limestone was found, but no ore. The Rose Emmett shaft, south of the Thespian, when examined in 1901 was 780 feet deep and had penetrated the first and second contacts of the Blue limestone, and drifts on the 475-foot level extended along the first contact for 176 feet westward, 190 feet southward, and 415 feet northward, but no ore was found. According to Emmons,[1] the Prospect incline and the Rosebud and Deadbroke tunnels, on the north side of California Gulch, and the Jordan and Swamp Angel tunnels, on the south side, followed the "first contact" and exposed "contact matter" but no valuable ore bodies.

The nearest ore to the east is the shoot in the Satellite and Star of the West mines, which is a down-faulted continuation of the North Iron ore shoot. To the south of the ore bodies in the Reindeer and Bessie Wilgus shafts is a westward down-faulted continuation of the shoot worked through the Dome incline and the Rock No. 1 and No. 2 shafts. Between these two down-faulted ore bodies extensive explorations have been conducted west of the Iron fault, through the Little Delaware, Hope, Zulu King, Commercial Drummer No. 2, Switzerland, Hawkes, Moffat, Coon Valley, Ontario, and McKeon shafts. A small amount of ore was found in the Hope ground, just southeast of the Little Delaware, but no other noteworthy discoveries were made. Either the southwestward-trending ore channels or fissures of the Iron Hill group, except the two noted above, died out to the east of this ground, or the solutions deposited their metals before reaching it. To the south the Blue limestone has been largely removed by preglacial erosion.

The great group of ore bodies that spreads from the Tucson-Maid fault zone in Carbonate Hill is

[1] U. S. Geol. Survey Mon. 12, p. 412, 1886.

known to be connected in some places with the Fryer Hill group, and the old workings beneath Stray Horse Ridge, were they now accessible, would probably supply evidence of other connections. As stated on page 208, ore-forming solutions may have traveled northward along the bedding from Carbonate Hill to Fryer Hill, although there is some reason for suspecting a local deep-seated source of the ore at Fryer Hill and East Fryer Hill. No large mineralized fissures have been found there, however, and the meager amount of exploration in the White limestone has been very disappointing. Any undiscovered local trunk channels were evidently not seriously obstructed by the Parting quartzite, and the solutions reached the Blue limestone before being impounded and forced to deposit their metals. There has been less exploration of the White limestone at Fryer Hill than at East Fryer Hill, and the available data are too few to warrant a definite opinion as to the possible presence of ore. If the dikes in these areas are of deep-seated origin and not offshoots of a sill, the fissures along which they rose may have been reopened and served as ore channels, as suggested by J. E. Spurr,[2] but there are no strong indications that the White limestone contains valuable ore bodies. The conditions at Fryer Hill and East Fryer Hill may be similar to those at Rock Hill, where continuous though narrow ore shoots were found in the Blue limestone but the White limestone contains little or no ore.

North of Fryer Hill, in the vicinity of Little Evans Gulch, there are outcrops of silicified limestone, and it is reported that considerable oxidized silver ore was mined there before the decline in the price of silver in 1893. This area was not studied closely during the resurvey, and it remains for future study to determine the factors controlling the occurrence of this ore and whether or not it is of commercial value below the zone of oxidation. Farther north the Roseville mine, on Canterbury Hill, is said to have produced silver ore in the early days, but exploration of this mine in 1924 and of the Minneapolis mine in 1926 through the Canterbury Hill tunnel was a disappointment. A low-grade ore body was cut by the tunnel 2,700 feet from the portal in 1925.

East of the Carbonate Hill group there may have been a local trunk channel in the vicinity of the Adelaide mine, but the almost total lack of data regarding mines in the Adelaide group, in spite of the large amount of work done, makes it unsafe to offer any suggestions for further developments. North of the Adelaide group and east of the Fryer Hill group explorations in the Yankee Hill area have been disappointing.

The Adelaide and Iron Hill groups are bounded on the east by a stocklike mass of pyritic porphyry, in which small veins may be found; but the amount of unproductive work already done shows that the chances of success in prospecting are relatively small. Only the enriched parts of the veins are likely to be of commercial value, and the zones of oxidation and sulphide enrichment are shallower here than elsewhere in the district. The only limestone inclusions found within this porphyry have been replaced by silicates and magnetite, and the prospects of finding deposits of commercial value in them are small.

East of this stock the much faulted and fissured Ibex area has been intensively but thus far not exhaustively explored. Structural conditions north of the Ibex No. 4 vein and west of the Little Vinnie shaft are favorable for the presence of several small veins and connected blankets of siliceous ore similar to those mined in the Golden Eagle mine. The junctions of such veins, if present, and the Colorado Prince reverse fault should be favorable places for ore. It is a curious fact that the Colorado Prince fault has thus far been cut only where its walls are siliceous rocks, and the most favorable ground—limestone at the junctions of the fault with mineralized fissures of northward trend has not been touched, so far as available records show. The junction of the Blue limestone and the Colorado Prince fault has been entirely removed by erosion, although the blanket ore bodies in the Little Jonny mine are not far from its former position. The junction of the White limestone and the Colorado Prince fault is also removed near the Modoc vein and near the Weston fault, but it is well worth prospecting in the intervening ground.

The possible continuation of the Colorado Prince fault west of the Weston fault, mentioned on page 76, can be determined only by systematic drilling, as structural evidence is concealed by porphyry and glacial débris. If its continuation is established, its junctions with veins cutting the limestones should be favorable locations for ore. The little information available about the Great Hope and neighboring properties on the slope south of Evansville indicates that this area has received less attention than it deserves, largely because of the shallow water level. The fissures through which ore in this area was introduced should continue northward as far as the suggested continuation of the Colorado Prince fault. Although these structural relations are promising, the ore horizons are beneath Evans Gulch, where ground water is doubtless abundant and the zone of oxidation shallow, owing to its partial removal by glacial erosion. The proportion of enriched ore may therefore be relatively small, and it is a question whether or not the grade of the primary ore may be encouraging. The interpretation of concealed geologic structure commends this area for consideration, and it remains for systematic drilling to determine whether further development

[2] Written communications.

work is justified. If plans to drive the Canterbury Hill tunnel into this area are realized, the drainage problems may be largely solved.

Further continuation of the Colorado Prince fault would bring it near the Mammoth Placer shaft, which is said to have cut some low-grade ore—a result which encourages the hope that favorable conditions similar to those just considered may exist there also; but a fault of the size and character of the Colorado Prince fault can not persist indefinitely, and not much interest in this vicinity is justified until favorable results have been obtained from prospecting at Evansville.

Another block of ground where structural conditions appear favorable for the presence of ore is that south of the Modoc vein and east of the Garbutt vein, where faulting has carried the Blue limestone below the levels that have been productive in the Ibex mine. The position of the limestone can not be accurately calculated, owing to imperfect knowledge of the local structure and to the indefinite thickness of the overlying Weber (?) formation and porphyry sills; presumably, however, it could be located by systematic drilling from the surface or by drifting to the east of the Garbutt vein. This ground is presumably most fissured and therefore most mineralized near its northwest corner, just beyond which a number of veins have been found in the Ibex mine, as shown in Plate 57. The rocks at the surface here are considerably silicified, and it would not be surprising if ore bodies were found replacing the limestones for some distance east of the Garbutt vein.

The mineralization at the surface continues southward and southeastward beyond the Sunday vein, and it is reasonable to expect other veins between the Garbutt and Sunday veins, but structural details have been so obscured by "wash" that the veins, if present, can be found only by very close study of the débris, followed by trenching. The limestones in the vicinity of the Sunday vein are deeply buried, probably below the level of the Yak tunnel, and prospecting of them would necessarily be expensive.

Northeast of the Colorado Prince fault there may be additional blanket deposits branching from the west as well as from the east side of the Winnie-Luema vein; but prospecting, especially on the west side, is largely a hit-or-miss undertaking. Extensions of the blanket ore bodies in Blue limestone may exist, and other similar bodies may be found between those shown on Plate 45; but here as elsewhere in the district ore shoots of which there is no record may have been exhausted in the early days.

The northernmost workings in the Winnie-Luema vein indicate that the limit of ore deposition has been reached and that only low-grade jasperoid is likely to be found farther north. The low grade of the ore in the Diamond mine, together with the increasing depth of the Blue limestone, toward the northeast gives little encouragement for development any farther in that direction.

No systematic study of the territory beyond the limits of the Leadville district has been made during the resurvey. This territory includes a few mines that have been notable producers but are handicapped by lack of transportation facilities. No appraisal of this outlying territory can be made here, but it is hoped that the information presented in this report will serve as a basis for more extended studies by those who are interested.

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PRODUCTION FROM DIFFERENT CLASSES OF ORE, 1895-1912

NOTE.—After this paper was in page proof the following table, compiled from the annual review editions of the Leadville Herald-Democrat, was received from Mr. C. W. Henderson. It is given to supplement from 1895 to 1908 the other tables in this report (pp. 126-133) and to compare from 1909 to 1912 the Government's exacting tabulation and the Herald-Democrat's hastily collected New Year's tabulation. This comparison shows that the Herald-Democrat's efforts are of much merit, and for that reason its figures for 1895-1908 are considered a valuable contribution to this report.

Leadville Herald-Democrat classification of Leadville ore, 1895-1912, in short tons

Year	Lead carbonate	Iron-silver oxide and iron-manganese-silver oxide	Sulphide	Siliceous	Zinc sulphide	Zinc carbonate	Total
1895	70, 429	86, 243	116, 975	57, 286			330, 933
1896[a]	60, 000	50, 000	110, 000	60, 000			280, 000
1897[a]	70, 000	100, 000	200, 000	60, 000			430, 000
1898	82, 650	150, 980	206, 555	60, 170			500, 355
1899	32, 050	123, 787	238, 514	105, 025	10, 690		510, 066
1900	102, 761	231, 144	297, 421	78, 919	59, 926		770, 171
1901	27, 483	256, 153	338, 041	94, 021	23, 261		738, 959
1902	22, 930	285, 494	281, 558	72, 215	85, 699		747, 896
1903[a]	20, 000	210, 000	300, 000	80, 000	160, 000		770, 000
1904	56, 109	147, 953	339, 745	88, 668	105, 300		737, 775
1905	86, 174	127, 170	297, 909	154, 370	159, 747		825, 370
1906	102, 412	163, 760	276, 109	107, 875	228, 565		878, 721
1907	39, 617	123, 443	233, 482	119, 023	136, 015		651, 580
1908	33, 127	117, 423	162, 188	92, 187	70, 197		475, 122
1909	29, 811	81, 360	308, 604	32, 192	88, 545		540, 512
1910	14, 369	73, 745	273, 829	34, 008	82, 608	10, 135	488, 694
1911	10, 950	26, 770	197, 955	41, 758	82, 820	79, 475	439, 728
1912	18, 194	94, 979	127, 834	25, 049	38, 619	160, 779	465, 454
	879, 066	2, 450, 404	4, 306, 719	1, 362, 766	1, 331, 992	250, 389	10, 581, 336

[a] Interpolated by Charles W. Henderson.

Appendix.—MINING CLAIMS IN LAKE COUNTY

In Leadville as in other mining districts mines have changed hands from time to time. Old companies have been reorganized under new names or consolidated and operated by new companies. New mines have been opened, and old mines have been abandoned and relocated. The names of patented claims and their survey numbers, however, do not change, and even the names of unpatented but productive claims are likely to be permanent. A list of mining companies, therefore, must be subject to frequent revision, whereas a list of claim names accompanied by survey and entry numbers and description of location is of permanent value, especially in an old district like Leadville.

The accompanying list, compiled from records in the surveyor general's office at Denver, is in two parts, the first arranged alphabetically and the second by survey numbers. It includes claims surveyed for patent as late as July 15, 1925, not only in the Leadville (California) district but in the following small neighboring districts: Alicante, Birds Eye, Buckeye, Chalk Ranch, Dewey, Empire Gulch, English Gulch, French Gulch, Granite, Half Moon, Homestake, Hope, Independence, Lackawanna, Lake Creek, Mosquito, Red Mountain, St. Kevin, Sugar Loaf, Tenmile Creek, Tennessee Park, Thompson Gulch, Twin Lakes, Two Bit Gulch, Union Gulch, and Willow Creek. The claims within the area covered by detailed geologic study are shown on Plate 13. Nearly all of these, as well as the claims immediately to the northeast and south of them, are shown on a map published by C. F. Saunders in 1901.

In the lists of mining claims the following abbreviations are used: a., lode; am., amended; b., mill site; l. subd., legal subdivision. Absence of a mineral entry number means that the land was not bought from the Government, therefore there was no patent. Claims that form a group are listed under their respective names. To save space, locations are given in the form "19—8—78," meaning sec. 19, T. 8 S., R. 78 W.

Alphabetic list of mining claims in Lake County, Colo.

	Survey No.
A. & F.	3530
A. B.	2887
"A" et al	11052
A. L. S.	14310
Al Wilder et al	9422
A. M. Thomas et al	6758 a. b.
A. P. Willard	1066
A. V. B. & Valentine	6391
A. V. H. et al	10844
A. W. D.	4081
A. Y.	790
Abandoned	4563
Abe Lincoln	2994
Abe Lincoln	3124
Abel	5848
Abraham Lincoln et al	7725
Acacia	13520
Accident	2496
Accidental	2917
Accountias	724
Acme	2918
Acme et al	9248
Acme et al (9 and 3 mill site)	19357 a. b.
Across the Ocean	909 am.
Adams	3165
Addie Smith	3078
Adelinde et al	14514
Adelphia	1125
Adirondack	18136
Adlaide	254
Aetna	403
Aetna et al	13304
Aetna et al	14291
Agassiz	316
Aid de Camp	4537
Ajax	1015
Ajax et al	9512
Aladin	1565
Alaska	12198
Albatross et al	10183
Albert A. Blow's placer	l. subd.
Albert et al	9286
Albion	4391
Alexander placer	10127
Alhambra placer	2361
Alicante	948
Alice	494
Alice	4011
Alice	17437
Alice & Marjory	6379
Alice et al	9443
Alice Mason	4403
Alice placer	396
Alice R.	5436
Alice S.	7997
Alleghany	1966
Alleghany No. 2 et al	4743
Alleghany placer	2187
Allice	505
Allie G. et al	9372
Allison et al	6173
All Right	431
Alma	1619
Alma Mater	2565
Almeda	3604
Almena	18932
Almon placer	l. subd.
Alpha	1685
Alphia	2659
Alpine	11657
Alps	4330
Alps No. 1	1952
Alps No. 2	1953 am.
Alta	295
Alta No. 1	2424
Alta No. 2	2425
Alta No. 3	2426
Alta No. 4	2427
Alta No. 5	2428
Altamont et al	9894
Altamont et al	13691
Altoona	736
Amazon & Honduras	4769 am.
Amelia	654
Amelia	3205
American	9379
American Eagle	693
American Eagle	14192
American Eagle and mill site	360 a. b.
American Liberty	3160
American Smelter Co.'s placer	414
Amie	351
Amity	2028
Ancher	13173
Andora placer	1640 am.
Andy Johnson	528
Anglesity et al	12176
Angora placer	9377
Anita	888
Anita et al	12176
Annie C. et al	9119
Annie et al	6173
Annie G., Griffin No. 2, and Hilder	19848
Annie Leonard	1011
Annie Merrill et al	15599
Antelope	834
Antelope	1481
Antioch	1627
Antonetta	9324
Apex	19149
Arabi Bey	5296
Arcadia	1263
Arapahoe	456
Archer	689
Arcturus	3453
Ardath et al	12101
Argentine	2850
Argentum et al	8979
Argo	447
Argo	798
Argonaut	9509
Arizona placer	1497
Arkansas & Lucky placer	l. subd.
Arkansas et al	4379
Arkansas placer	423
Arkansas River placer	108
Arlington	1366
Arlington et al	5209
Arrietta	2849
Artic	349
Arty	4500
Ashley	708
Aspen Mammoth	1617 am.
Asteroid placer	l. subd.
Atlas	20086
Atlas et al	9010
Augusta	690
Augusta D. et al	7180
Augusta et al	11265
Augusta No. 2	6333
Aurora et al	12859
Aurum	18710
Australasian	3361
Australian	2712 am.
Autocrat	4386
Avalon	6728
Aztec	532
Aztec et al	9010
"B" et al	11052
B. M. et al	16128
B. W. S. et al	7314
Baby	2510
Baby	4337
Baby	5201
Badger	4193
Badger State	619
Badger State et al	12167
Bailey et al	16352
Bald Mountain	722 am.
Ballarat placer	l. subd.
Ballard	589
Ball placer	l. subd.
Baltimore	979
Baltimore	9387
Bangkok	1488
Bank	4724
Banker	910
Banker	4063
Bank placer	8361
Bank Statement et al	10448
Banner	2952

Alphabetic list of mining claims in Lake County, Colo.—Continued

	Survey No.
Banner	3988
Banner	14841
Banner et al	9422
Barrium	4459
Bartlett et al	12867
Basin	7620
Bates placer	l. subd.
Bayswater et al	4653
Bazoo	849
Beecher	1460
Beech et al	6210
Belcher	256
Belgian	372
Bell	3038
Belle	3363
Belle Grant	2121
Belle of Colorado	302
Belle of Colorado No. 2	1555
Belle of Granite	8536
Belle of Granite mill site	15880
Belle of Kentucky	2286
Belle of the West	1251
Belle of the West et al	9448
Belle placer	2778 am.
Belle Vermont	1693
Ben Burb	938
Bengal Tiger et al	7557
Benjamin	4822
Benjamin Franklin	485
Benjamin Franklin	1389
Benson et al	14295
Berdell & Witherell placer	1269
Berlin et al	9935
Berlin et al	12065
Bertha	11296
Bertha et al	7998
Bertha et al	15297
Beryl et al	9353
Bess	4460
Bessie	3099
Bessie	5134
Bessie H. and Brother (2)	19365
Bessie Steward	4229
Bessie Wilgus	1918
Best Hope	2745
Beulah et al	10844
Bevis	468
Big	3984
Big Chief	835 am.
Big Chief et al	12176
Big Evans et al	4554
Big Four et al	12167
Big Jim et al	17248
Big Johnnie et al	15743
Big Minnesota	1188
Big Missouri	9292
Big Six	1616 am.
Bill et al	9995
Billy Stevens	3098
Bill Sykes	3100
Bi-Metallic et al	6464
Bi-Metallic et al	9939
Birdella et al	7899
Birdie C	9510
Birdie R	4567
Birdie Trimble	871
Birds Eye et al	13427
Birds Nest	2537
Birthday	1473
Bismark	748
Bismark et al	14514
Black	917
Black Cat	1494
Black Cloud	903
Black Cloud	6462
Black Diamond	2896
Blackhawk	878
Black Hawk	6884
Black Iron	3182
Black Prince	643
Black Swan et al	6020
Blanch et al	6931
Blanche	4499
Blanche	17412
Blanche et al	10771
Blanche Morris et al	9177
Bland et al	16454
Blind Tom	791
Bloomington	1596
Blue Belle et al	11121
Blue Bird	480
Blue Bird	3325
Blue Bird et al	16708
Blue Jay et al	5650
Blue Mountain	2666
Blue Ribbon et al	5405
Blue Ribbon et al	10448
Bo	14079
Boa	14268
Board of Trade et al	12167
Board of Trade et al	13002
Bob Ingersol	3155
Bob Ingersoll et al	11622
Bob Sheppard et al	5740
Bohen	1564
Bohn & Lane et al	13840
Bonanza	188
Bonanza	1088 am.
Bonnie Bell	16193
Bonnie Kate	688
Bon Ton	4949
Bonton et al	17089
Bonus	1089 am.
Boss	4058
Bottcher No. 2	994
Boulder	694
Boulder	4083
Boulder City	2871
Boulder Nest No. 2	3574
Boulder Slide et al	7142
Boutwell	176
Bow	11777
Bowron et al	16267
Boyd	2960
Bradford Belle	5170
Bradshaw	1755
Brian Barau	564
Brick Pomeroy	420
Bright Days et al	9294
Brink Clark et al	5786
Broadway	1487
Brodax	1498 am.
Broncho et al	7197
Brookland	536 am.
Brown	4426
Brown	9581
Brown placer	11771 am.
Brown Queen	1909
Bryan et al	16897
Bryant et al	3222
Buckeye	235
Buckeye	653
Buckeye Belle	3697
Buckeye State	3693
Buckskin et al	7572
Budweiser	847
Buelo et al	7314
Buffalo et al	7306
Buffalo Girl	2354
Bug et al	13716
Buglet	13228
Bull Dog	20066
Bulldozer	3822
Bullion	387
Bullion	7210
Bulls Eye	232
Bully of the Woods	546
Buncombe	884
Bunker Hill et al	15817
Burkey	3913
Burlington et al	10183
Burnice	15040
Burton placer	l. subd.
Bush	1236
Butcher Boy	1189
Butcher Boy	4176
Butterfly et al	17268
C. & S. et al	14677
"C" et al	11052
C. H. S. et al. (4)	19139
C. I. Thomson	4687
C. K. et al	11715
C. M. fraction	11501
C. S. placer	l. subd.
C. T. L	12713
C. W. et al	15169
Cable	16245
Cache et al	4668
Caledonia	1377
California	48
California	15965
California Gulch	1086
California Rose	2464
Campbell	1550
Camp Bird	237
Camp Bird et al	16708
Camp Bird No. 1 et al	15439
Camp Bird No. 3 et al	15440
Can	12077
Canestota	19273
Cape Town et al	15453
Capital placer	977
Capitol	1326
Capitol et al	6965
Carbonate	279
Carbonate King	6843
Carboniferous	326
Cargo	509
Caribou	6091
Carleton	3007
Carleton	3696
Carleton	3897
Carleton et al	9301
Carlton	1912
Carondelet	2746
Carpenter	1256
Carr	5541
Carrie F	3732
Cascopedia et al	9432
Cashier	4062
Cash placer	1099
Castle	957
Castle et al	6965
Castle View	760
Cataba	811
Catalpa	1475
Catalpa No. 2	1680
Catheleen	4458
Cayuga placer	11770
Cecil et al	13850
Ceder Rapids	575
Celia et al	9372
Centennial	6760
Centre	2925
Cerlew & Flamingo placer	1. subd.
Cerusite et al	12176
Challance et al	6729
Champion	739
Champion	1485
Champion	3556
Champion	3868
Chapman et al	9292
Chapman placer	2364
Chapman placer	1. subd.
Charles B	2291
Charles et al	5786
Chas. G. Arnold placer	947
Chas. G. Arnold placer	1036
Charlestown	284
Charlestown et al	4554
Chautauquan	12882
Chemango et al	4743
Chemita	13098
Chemung	901
Chestnut	713
Chestnut Burr et al	5405
Chicago	1295
Chicago	3039
Chicago Boy	1868
Chicago placer	787
Chicago Reduction Works placer	930
Chicago Reduction Works placer	931
Chicago Reduction Works placer	932
Chicopee et al	4743
Chicora et al	9396
Chieftain	978
Chieftain	9537
Chieftain	12046
Chihuahua	2862
Chloride	9039
Chloride placer	1447
Christmas	763
Christmas Gift	663
Chrysolite	288
Chrysolite No. 2	3930
Cincinnata	239
Circulator et al	10448
City	1253
Clara	2792
Clara Burbank	2224
Clara Dell	844
Claremount	11998
Clarence	4167 am.
Clarendon placer	809
Clark et al	6764
Clark et al	11934
Claum Counell	3080
Clayton et al	16352
Clear Grit	1536
Cleaves placer	11396
Clencoe et al	16267
Cleora	989
Cleveland	477
Cleveland	4051
Cleveland	9649
Cleveland No. 2 et al	11682
Cliff	2794
Cliff	11443
Cliff	19909
Climax	343
Climax	14336
Climax et al	5548
Climax No. 2	19976
Clinetop	4055
Clint placer	1. subd.
Clipper	11329
Clipper et al	6965
Clontarf	1327
Cloth of Gold et al	16604
Cloud City	5406
Clover Leaf	14436
Clover	12747 am.
Club	8457
Clyde	4241 am.
Clyde	5692
Clydesdale	1092
Codfish Balls	767
Coffee	2463
Coleman	9747
Colima	20156
Collateral	1033
Collier & Lewis	6180
Collin Campbell	12054
Collin Campbell No. 2	12090
Colonel Duggan	19847
Colonel Sellers	2334
Colorado Belle placer	5563
Colorado Boy et al	5740
Colorado Chief	450
Colorado Gulch placer	1293
Colorado No. 1 et al	9443
Colorado No. 2	1040
Colorado Princes	565
Colorado Princess	1300
Col. Sellers	2495
Columbia	572
Columbia	594
Columbia et al	12176
Columbia placer	4329
Columbine	10009
Columbus	1955 am.
Comadore et al	9372
Comet	4184
Comet placer	1. subd.
Commercial Drummer	1246
Commet	1851

Alphabetic list of mining claims in Lake County, Colo.—Continued

	Survey No.
Commet et al	11238
Compromise	1047
Comstock	822
Comstock	1542
Comstock	3613
Comstock et al	7306
Comstock et al	7875
Comstock et al. (8)	18045
Comstock No. 1	425
Comstock No. 1 et al. (8)	19248
Cone	744
Confidence	754
Confidence et al. (3 and mill site)	18227 a. b.
Confident	1610 am.
Confident et al	13717
Congress et al	6965
Connecting Link et al	5405
Connection	7256
Consolidated Capt. Kirby placer	4562
Consolidated Virginia	3067
Constance	3398
Constance	13097
Contact et al	7314
Content et al	9373 am.
Continental	344
Continental	788
Continental	902 am.
Continental Chief	3497
Conundrum	3242
Coon Valley	1243
Cooper et al	4743
Cop et al	13850
Copper King	4052
Copper Prince	15548
Cora	1024 am.
Cora Bell	644
Cora Bell	3919 am.
Cordelia Edmonson	674
Cord et al	13698
Cornelium	5711 am.
Cornfield	15173
Corner	819
Cornucopia	1503
Cornucopia	11492
Cosmopolitan et al	12101
Cosmopolitan et al	16604
County Line	11359
Cowcumber	13047
Coyote	18415
Crescentia	939
Croppy Boy et al	17927
Crouse et al	5786 am.
Crown Point	1091 am.
Crown Point	3241
Crown Point	5640
Crown Point	12675
Crown Point et al	9177
Crystal Lake placer	4078
Cucumber	390
Cucumber	390 am.
Cullen	1821
Curley placer	357
Curran	449
Cute Mc placer	l. subd.
Cyclops	1567
Czar placer	814
Crytogram	6880
D. & A. No. 5 et al (5)	18975
D. and R. G. et al	7572
D. H. Elder	2039
D. H. Moffat	4546
D. P. R.	862
Daisey	751
Daisy	2883
Daisy	16788
Daisy No. 2	2884
Dania	506
Daniel O'Connell	3141
Dante's Inferno	3413
Dauntless	579
Dauntless et al. (2)	19518
Davis	2886
Davis	3264
Davis	9300
Daylight et al	9512
Dead Broke	445
Dearborn et al	7180
Debuque	1376
Decagon placer	l. subd.
Deer	1907
Deer et al	9995
Deer Foot	939
Deer Lodge	321
Defiance	1450
Defiance et al	9316
Defiance No. 5	9468
Del Monte	530
Delphian & Isthmian	18429
Delta	1005
De Mary placer	2082 am.
Dennis	18944
Denver	16167
Denver City	726
Dessery	3119
Detroit	2953
Detroit et al	7759
Detroit placer	l. subd.
Devlin	1579
Dewey et al	14321
Dexter et al	11421
Diamond A. et al	12079
Diamond & Harrison	5652
Diamond B. et al	12079

	Survey No.
Diamond C. et al	12079
Diamond D. et al	12079
Diamond E. et al	12079
Diamond et al	11446
Diamond Field	6920
Diamond S. et al	12079
Diamond State	2851
Diana	2455
Dick Bland et al	9362
Dickson placer	413
Dick Turpin et al	4598
Dillon	486
Dimmick	1052
Dinero	2593
Dinero placer	l. subd.
Dipper placer	l. subd.
Dirk	1459
Dispute	12310
Ditch placer	416
Dives	294
Dives et al	9278 am.
Divide et al	5548
Dodo et al	8891
Dolomite	4980
Dolphin	719
Dome	236
Dominion et al	17256
Don Hunter et al	10844
Don No. 1 et al	13887
Donovan	732
Doris	566
Double Decker	354
Dresure et al	7180
Duchess et al	6932
Duffie	1084
Dunboy	5089
Dundaff	16743
Dundee	16278
Dunkin	297
Dwight L. Dow	2810
Dwyer	6173
Dyer	1321
E. A. C	18689
E. C	11353
E. C. B	1334
E. E. Beach et al	16352
E. Plumbus Union et al	12176
E. R. H. et al	10844
Eagle	1006
Eagle	2027
Eagle et al	4728
Eagle et al	16378
Eagle Horn	3796
Eastern Rose	3483
East Lynn Placer	1495
Easton et al	11741
Eavensville et al	12896 am.
Echo	652
Echo	836
Eclip	471
Eclipse	2077
Eclipse	9530
Eclipse et al	11567
Eddie et al	12071
Ed. et al	10230
Edison et al	7306
Edith	586
Edith	3962
Edith Tangent	3437
Edna Dolloff	6834
Edna M.	19314
Edna M. et al	9512
Edna placer	l. subd.
Edward E. et al	11479
Effa Harris	752
Eighteen Ninety Two	4623 am.
Eighty Eight	5665
Elbert	4163
Elbert placer	5701
Eldorado	4110
Electric et al	17012
Eleventh Hour et al	16417
Eliza	457
Eliza	5037
Elk	1654
Elk	2881
Elk et al	9275
Elk Horn	2073
Ella	17155
Ella Beeler	1778
Ella et al	10389
Ellen	1683
Ellen Morgan	3162 am.
Elmira placer	6339
Elmore	636
El Paso	1822
Elsie Francis et al	7180
Elva Elma	2688
Embolite	13400
Emeral	17925
Emerald et al	9292
Emily	1119
Emma	577
Emma	626
Emma	756
Emma	4536
Emma & Mable placer	l. subd.
Emma D. et al	7180
Emma et al	9274
Emma et al	9894
Emma et al	13340
Emma et al	16267
Emma Sophia et al	4379

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Emmett	148
Emmet et al. (3)	18444
Empire	1442
Empire	1854
Empire et al	9286
Empire placer	2267
Ennerdale et al	4728
Enterprise	591
Equator	1500
Equator	6454
Equator et al	9585
Equitable et al	5405
Equitable et al	5405 am.
Erie	731
Erin	4045
Erin et al	9512
Esperanza	1072
Essie et al	10098
Esther	14614
Ethel	2882
Eugene	4573
Eugenia Texas	2466
Eulolia et al	9234
Eunice Blake et al	4711
Euphenia Ducin Collins	3369
Eureka	2050
Eureka	4992
Eureka et al	6076
Eurydice	908
Eva	2911
Evans et al	5420
Evansville et al	9010
Eva Wilson et al	7180
Eveline Walsh et al	9371
Evening Star	405
Evening Star	8232
Everett	498 am.
Everett placer	2283
Evin	15507
Excelsior	3052
Exchange No. 1 et al. (4)	18132
Exile et al	9512
Expansion	19660
Expansion et al	15560
Experimental	1551
Express et al	15509
Extended Hope	11809
Extension Copper King	6518
Extra	15721
F. B.	3549
F. D. placer	l. subd.
F M. C.	5263
F. X. O.	18112
Fain et al	10183
Faint Hope	252
Fairmount	954
Fairplay	597
Fair Play	3544
Fairplay	7581
Fairplay et al	7899
Fairview	430
Fairview	3262
Fairview	9743
Fairview et al	5242
Fairy Ethel et al	9716
Fairy et al	12167
Famous et al	4554
Fannie Gage	1426
Fanny	922
Fanny	3438
Fanny Rawlings	461
Farragut	4194
Farrish mill site	4660 b.
Father Ryan	4455
Favorite et al	10771
Fawn	15107
Fickle	7230
Field et al	9422
Finbach et al	11485
Findland et al	4380 am.
Finland	2744
Finnis et al	5242
First Chance	1908
First Chance	4414
First National	753
First National	1277
First National	1934
Fitz Hugh	1207
Five Per Cent et al	12305
Five Twenty	1900
Flagstaff	348
Flint	3661
Florence	701
Florence	759
Florence	772
Florence et al	10345
Florence Rust et al	6932
Florida et al	7314
Fluddin	2730
Fonchon placer	660
Forest City No. 2	890
Forest Queen	3008
Forest Rose	1003
Forest Rose	2682 am.
Forfeit	895
Forrest City	319
Forrester et al	6020
Fortuna	2041
Fortune	2309
Foster et al	9422
Foundling et al	9739
Four Per Cent	9664
Fourth of July	1023

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Fourth of July	6490
Fourth of July et al	11237
Fox mill site	19978
Fraction et al	6164
Fraction et al	7303
Fraction et al	16708
Francenia	1147
Frank	681
Frank	4253
Frank	6466
Frank et al	12076
Frankfort et al	9443
Frankin	19634
Frank placer	l. subd.
Free America No. 2	1177
Free Coinage	13167
Free Coinage et al	6464
Free Coinage et al	7759
Free Coinage et al	7875
Free Gold	46
French Gulch placer	2207
Frenchman	692
Friday	18023
Friday et al	9995
Frisholm	4006
Fryer Hill et al	5786
Fuerstien placer	l. subd.
Fulton et al	6076
G. F. Daily mill site	371
G. L. N	11341
G. M. Favorite	799
G. R. Follet et al	16352
G. T. M	13448
Galbolinsky	6459
Galemite et al	12176
Galesburg	2570
Gallileo et al	14321
Gambeta	298
Gamecock et al	12076
Garbutt	459
Garden City	1427
Gardiner	443 am.
Garfield	2384
Garnet et al	8613
Gates	3263
Gaw placer	4080
General Cadwallader	487
General Grant	4244 am.
General Grant et al	11297
General Hancock et al	13741
General Lawton	16266
General Lee	4384
General Logan et al	13741
General Sheridan	1141
General Sheridan et al	112[illegible]7
General Sheridan et al	13741
General Sherman	4667
General Shields	831
General Shields	1384
Genesee	800
Geneva	762
Geneva et al	7579
Genevieve	18877
George Diamond et al	16352
George F. et al	12101
Geo. F. Monahan et al. (2)	18189
George H. placer	l. subd.
Georgia	3474
Georgia	3961
Georgia et al	5548
Gerald Griffin	3896
Gerini et al	6057
German Bank	2777
Germania placer	389
Gertrude	15871
Gertrude	17619
Gill & Martin mill site	927
Gilt Edge	490
Gipsey Carbonate	3606
Gipsey et al	13850
Glacier et al	9894
Glacier placer	3866
Glengary	716
Globe	765
Gloucester et al	13717
Goff Mining Co. placer	116
Golconda	3690
Gold Belt et al	9373
Gold Belt et al	11264
Gold Buckle et al	10171
Gold Bug et al	6932
Gold Bug et al	9294
Gold Chief	8724
Gold Claim et al	12026
Gold Coin et al	16734
Gold Crown	1984
Gold Cup et al	9443
Gold Edge	8991
Golden Calf et al	10171
Golden Casket	1301
Golden Curry	848
Golden Eagle	936
Golden Eagle	2376
Golden Eagle	9413
Golden Eagle et al	10230
Golden Eagle et al	16318
Golden et al	13698
Golden Fleece	3859
Golden Fleece	15437
Golden Gate	3500
Golden Gate	3500
Golden Gate	3852
Golden Gate	19193

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Golden Gate No. 2 et al. (3)	18013
Golden Key et al. (5)	18497
Golden Ledge et al	4653
Golden Rod	9441
Golden Rule	1492
Golden Rule	3324
Golden Treasure	3076
Golden Wonder et al	4653
Gold et al	9352
Gold Excitement et al	9562
Goldfield	2437
Gold Hill	18048
Gold Leaf and mill site	356 a. b.
Gold Leaf et al	16454
Gold Plate No. 1 et al	19184
Goldsmith	4456
Goldsmith et al	8554
Gold Spoon et al	11555
Gold Sulphide No. 1 et al. (10)	18436
Gonabrod	552
Goodell	443 am.
Goodell placer	2333
Goodsell placer	2345
Good Times et al	9497
Goodwill et al	6020
Gordon et al	7557
Governor	13778
Governor Waite et al	9318
Grace	806
Grace	15218
Grace	17154
Grace et al	11682
Grace Gracewood	2130
Grafton	384
Graham placer	563
Grand Prize	473 am.
Grand Prize	1292
Grand View	621
Grand View	6334
Granite	1352
Gray Eagle	1090 am.
Gray Eagle et al	15817
Great Eastern	3268
Great Eastern	3367
Great Eastern et al	17743
Greater New York "A" et al	13942
Greater New York B	16064
Greater New York D	19318
Great Hope	489
Great Hope et al	14333
Great Northern et al	15105
Great O'Sullivan	1618
Great O'Sullivan	17948
Great Republic	2692
Great Republic and Pitcher (2)	19297
Great Southern et al	15105
Great Western	374
Great Western	1937
Great Western	3366
Great Wyoming et al	9482
Greenback	1043
Greenback	1071
Green Mountain	1190
Greenwood	630
Griffin et al	9277
Griffin No. 2. (See Annie G.)	
Grindrod	3332
Ground Dog No. 1 et al. (2)	19268
Ground Hog	4475
Ground Hog et al	6774
Ground Hog et al	12663
Grover Cleveland	8982
Grover Cleveland	11698
Grubstake placer	l. subd.
Guildersleve	1373
Gulch et al	7579
Gunnison	2943
Guome	1010
Gurnee	1729
Gwendoline	3358
H. A. (See Olga No. 2.)	
H. Alexander	15121
H. A. M. et al	9294
H. A. T. placer	1162
H. D	278
H. E. et al	7725
H. F	4249 am.
H. M. L	598
H. M. L. et al	7197
Hamburg	880
Hamburg	8469
Hamilton Gold	980
Hand Saw	18590
Hannah	648
Hap Hazard et al	12656
Happy New Year	3968
Hard Cash	628
Hard Cash et al	9443
Hard Chance et al	9702
Hard Luck et al	9739
Hard Times et al	9497
Harmes	4626 am.
Harrisonael	12370
Harris et alt	8658
Harry Colvin	629
Harry D et al	7180
Harry Earl	4133
Harry Steele et al	5740
Hartford	783
Hartford	919
Harvard	3449
Hattie Clark No. 2 et al	5299
Hattie et al	10389

	Survey No.
Hattie Jane	45
Hattie K	6664
Hawk et al	5405
Hawkeye	625 am.
Hawkeye	920
Hawkeye Belle	2854
Hawk Nos. 1 et al. (24)	19732
Hawthorne	1320
Hazel et al	12658
Hazelholm et al	4728
Hazzard	607
Hector	2129
Hector placer	5919
Helen	3069
Helena	4033 am.
Helen et al	7125
Helen Frances et al	12257
Helen Gould. (See Roosevelt.)	
Hellen et al	9177
Helvetia	1954
Hemitite	1142
Hennessy	11721
Henriett	365
Henry et al	8201
Henry George et al	11622
Henry M. Teller et al	7759
Heomina et al	10844
Hercules	614
Hermann et al	8201
Herman placer	l. subd.
Heytrossar	1844 am.
Hexagon placer	l. subd.
Hiawassee et al	10844
Hiawatha	4263
Hiawatha placer	l. subd.
Hibernia	446
Hibschle placer	399
Hibschle placer	400
Hidden Treasure	599
Hidden Treasure	5596
Highland Chief	429 am.
Highland Mary	539
Highland Mary	656
High Line placer	12885
Hildegrade et al	6765
Hilder. (See Annie G.)	
Hill	5356
Himmala	1869
Hog Eye	1543
Hokitika	9208
Holden	1340
Holy Cross	4048
Homer placer	970
Homestake	124
Homestake	514
Homestake	1540
Homestake et al	16318
Homestake No. 1	520
Homestake No. 2	519
Honest Dollar	11206
Honest John et al	11701
Honey Comb	905
Hoodoo	651
Hoosier	1264
Hoosier Boy et al	13599
Hoosier Girl	1404
Hoosier Girl	2860
Hoover	3157
Hope	460
Hope	832
Hope	7269
Hope et al	9512
Hopkins	2149
Hopkins et al	5786
Horace et al	8201
Horse Shoe	1493
Horse Shoe et al	92[illegible]2
Horse Shoe Prince	6022
Hortense No. 2 et al	15313
Hotel et al	16352
Hot Spur	16790
Houlton Placer	5843
Houston	1857
Howard et al	8201
Howard M. Holden	1137
Howell	3409
Hubert	11286
Huckleberry	6042
Hucksel	2113
Hudson	18829
Hugh	14338
Hugh et al	8201
Humboldt	749
Humboldt	1455
Humboldt	4501
Humbug	19526
Hummer No. 1	16802
Hunkidori	4462 am.
Hunter's Last Chance	1592
Hurricane	2658
Ice Palace et al	10884
Idaho	667
Idaho	7018
Ida & Alice	3169
Ida et al	9286
Ida Nyce	313
Idlewild et al. (3)	18153
Ihrie	2297
Illinois	1094
Illinois	1979
Imes	363
Immo et al	8891
Imogene	2733

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Imperial et al	15560
Independence	510
Independence et al	5558
Independent	467
Indiana	605
Indus placer	l. subd.
Inez	15864
Inez	19838
Inez No. 1	15865
Ingersol placer	2658
Ingomar et al	8891
Inspector	6826
Intermural	12343
International	3501
Iola	1004
Iowa	474
Iowa	3140
Iowa et al	17521
Irene	668
Iron	233
Iron	6357
Iron Chief et al	12176
Iron Duke	2132
Iron Duke	5307
Iron Hat	277
Iron Hat	5229
Iron Mask	2020
Iron Mask	5594
Iron Queen	720
Iron Rock	969
Iron Rose et al	17160
Iron Safe	1628
Isabel	4272
Isabella	1728
Isabelle et al	14968
Ishpeming	1018
Island	4261
Issard	604
Ivo et al	8891
J. A. C. K.	14769
J. B. Grant	879
J. B. Hall placer	224
J. C.	12091
J. D. Dana	253
J. D. Dana et al	6758
J. D. Loker	282
J. D. placer	l. subd.
J. D. Ward	933
J. F. W.	15176
J. G. fraction	13251
J. G. M.	4973
J. H. & P. C.	8300
J. H. W.	1490
J. I. M.	14769
J. K.	19317
J. M. C.	4227
J. N. Murphy	2316
J. Q. S.	1316
J. R.	3004
J. Silk et al	9443
Jack	7233
Jack et al	9995
Jack Whacker	11480
Jacob D. et al	7180
Jacobson placer	380
James	9347
James	12067
James placer	1098
Jamie Lee	472
Jane Eugene	3391
Jane Horner et al	13717
Janet	17998
January et al	9424
Jason	6676
Jay	3665
Jay Bird	723
Jay Bird	12740
Jeannetta	2888
Jefferson et al	8658
Jenny June	17968
Jessie	709
Jessie Clark	549
Jessie Gray et al	9448
Jew	7141
Jim Blaine	6503
Jim Fisk	1812
Jimmie Swisher	3860 am
Joe et al	12076
Joe No. 3	10084
John A. Logan	11942
John B. Raymond mill site	458
John J. et al	11051
John Lawrence	11614
John Leary placer No. 2	592
John Mitchell	743
John placer	1096
John Reed et al	11682 a. b
John Schaffer	4209
John Tompson placer	341
John Wannamaker et al	6729
Joiner et al	9099
Jonny et al	9424
Joplin	1093
Josephine	3226
Josephine et al	9292
Joseph S. et al	7180
Josie	3605
Josie et al	4554
Judge Bowen	976
Judge Pendery	428
Julia et al	5650
Julia V	11390
Juniatta	1483
Junior	2005
Juno	4739
Jupiter	3134
Jupiter et al	12101
K. C. et al	13969
K. R. L	4299
Kankakee	956
Kannoshia	665
Kansas & Inez	4703
Kansas Boy	10512
Kathleen	996
Katie	3969
Katie	13218
Katie et al	10389
Katie H	11889
Katie Ross	16267
Katy	567
Katy D. et al	9292
Kauffman	9415
Kayserine	2715
Kearsage et al	7875
Kemble	3410
Kennebec	684
Keno	1682
Kent	1017
Kentuckian	4059
Kentuckian No. 2	4590
Kentucky	3057
Kerr	1143
Key	704
Key placer	l. subd.
Keystone	238
Keystone	292
Keystone	1375
Keystone	6087
Keystone	16267
Keystone et al	7725
Kierscey	696
Kildare	4271
Kilkenny Boy	3950
Killarney et al	15509
Kingan Consolidated	889
King Soloman	769
Kinny Side	3798
Kinston et al	10183
Kismet	4461 am.
Kit Carson	432
Kittie	1287
Kittie D	20261
Klondyke	12264
Knickerbocker	4608
Kohinoor	635
Kokomo	892
Kosciusko	4091
Kyle et al	4528
L. C. et al	8658
L. C. et al	9372
L. M.	3092
L. W. & F. W. fractions	13905
Lackawanna Belle et al	12765
Lackawanna placer	1083
Lac La Belle	828
Lady Adele	2163
Lady Alice	966
Lady Alice	15908
Lady Crawford	1870
Lady Elgin	2553
Lady Gay et al	7197
Lady Jane	491
Lady Loftin	3234
Lady Margaret	19299
Lady May	2070
Lafayette et al	10840
La Jaunita	10210
Lake County	618
Lake County	664
Lake placer	2358
Lake View et al	12867
Lalla Rookh	915
Lanphier No. 1 et al. (17)	19287
Lanphier Nos. 8, 19, 20 (3)	19287 am.
Laplander et al	4397
La Plata Blanco	1397
La Plata et al	7259
Larkin	9293
Last Batch	7071
Last Chance	353
Last Chance	1322
Last Chance	1531
Last Chance	1541
Last Chance	9512
Last Chance	18688
Last Chance et al. (2)	19231
Last Chance No. 1 et al. (7)	18067
Last Chip	478
Last Rose	15438
Last Rose of Summer	3502
Latch	3633
Laundry	11878
Laura	3439
Laura & Daisy placer	l. subd.
Laura P.	9443
Laurel	789
Laurel W.	4254
Law	314
Law placer	4752
Lawrence	1257
Leadville	6 9
Leadville	2973
Leadville et al	7759
Leadville et al	9918
Leadville et al	13702
Leander	3079
Leaser & Goldsmith	1136
Leavenworth	1549
Lecompton	4497
Lenora	12739
Lenox et al	4743
Leo	3487
Leo D. et al	7180
Leonard	2894
Leopard	801
Le Roy	562
Leviathan	1585
Lewis	4691
Liberty	4159
Liberty B	19979
Liberty et al	9373
Lickscumdidricks	1042 am.
Lida	2155
Lida	2155 am.
Liddia	9254
Lillian et al. (2)	19544
Lillie	916
Lillie	3217
Lime	216
Lime et al	9443
Lincoln	2658
Lincoln	6855
Lincoln et al	9099
Linda et al	7725
Linden et al	6210
Lingula	560
Little Addie	3676
Little Albion	16789
Little Alex	15436
Little Alice	542
Little Alice	2400
Little Alice	8249
Little Allie	1447
Little Allie et al	4711 am.
Little Andy et al	6020
Little Angie	3743
Little Anna	4818
Little Annie	601
Little Annie	14248
Little Arthur et al	11622
Little Aurora	5018
Little Bentley et al	14685
Little Bertha	504
Little Bertie et al	6076
Little Blonde	703
Little Bob	11436
Little Canada	2292
Little Champion	682
Little Champion	757
Little Charlie et al	5558
Little Chief	358
Little Chippewa	655
Little Clara	1079
Little Cole	3756
Little Comstock	935
Little Comstock	1123
Little Comstock	6804
Little Corinne	1029
Little Daisy	1532
Little Debeque	3575
Little Delaware	2137 a.
Little Diamond	755
Little Dot	9444
Little Doubtful	3850
Little Ed	12657
Little Edenburg	620
Little Ed. et al	9372
Little Ella et al	7197
Little Ellen	550
Little Eva	367
Little Eva et al	7355
Little Flora et al	10807
Little Floy	4305
Little Forepaugh	463
Little Fraction	2423
Little Fraction	3212
Little Fred	4727
Little Galesburg	1176
Little Giant	1861
Little Giant	1862
Little Harry	2248
Little Hatie	1124
Little Hope	2552
Little Hugh	3934
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Little Joe	8040
Little Joe mill site	13754
Little Jonny	518
Little Jose	2734
Little Julia	1811
Little Keystone	1254
Little Keystone	19115
Little Lena	1056
Little Lillie	1333
Little Link	5271
Little Lou	3485
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Little Mary	2732
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Little Maude	18336
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Little May	10087
Little Miami	509
Little Mollie et al	10183
Little Monia	7226
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Little Nancy	14099
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Little Nellie	1501
Little Nellie	3113
Little Nellie et al	7344
Little Nellie placer	5561
Little Pet	1477
Little Pittsburgh	293
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Little Prince	551
Little Ralph	2773
Little Rex	2796
Little Rische	412
Little Scott	914
Little Sharron	906
Little Sister placer	l. subd.
Little Sliver	421
Little Stella	545 am.
Little Stella	1467
Little Sugar Loaf placer	1744
Little Todd	706
Little Tom	8817
Little Troubador	1248
Little Troy	5199
Little Twins	2932
Little Vinnie	596
Little Willie	2748
Little Winnie	535
Lock	2205
Logan	730
Logan	5006
Logan	19581
London Extension et al	15491
Lone Hand	7926
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Lone Star et al	6579
Lone Star et al. (3)	19295
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Lone Tree	764
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Lonney C. et al	11479
Lora Lynn	588
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Loretie et al	9286
Lorraine Gibson	15863
Lost Mine et al	12167
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Lottie	4195
Louise	4477
Louise D'Or et al	12101
Louisiana	1335
Louis Stell	2467
Louisville	417
Lovejoy	1044
Loveland	727
Lower Printer Boy	347
Lowland Chief	818
Lucinda	3225
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Lucknow	853
Lucky Baldwin	18121
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Lucos	2206
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Lulu B. et al	14604
Lumsden et al	5786
Luna placer	1523
Lupe	3901
Luzerne	9918
Lyons	3186
Lyons placer	2561
M. A. P	5995
M. E. C	9769
M. N	18417
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Mabel	15320
Mac Gregor	1865
Macomb et al	12718
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Maggie et al	10389
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Maggie Ross	16267
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Malvina	5152
Mamie Ross et al	16267
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Mammoth	1127
Mammoth	5289
Mammoth	5531
Mammoth	14891
Mammoth et al	16318
Mammoth Extension et al	16318
Mammoth placer	2817
Mandelle	1802
Manhattan et al	9281
Manhattan et al	9292
Manhattan et al	12718
Manhattan et al	16352
Manilla placer	l. subd.
Mansfield	953
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Maple et al	6210
Margaret	8036
Margarite et al	16358
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Marion Virginia	1829
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Mars et al	12101
Marshall	9319
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Martha	17542
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Mary	740
Mary	4586
Mary	10872
Mary	16106
Mary Alsberg	1164
Mary Ann	2389
Mary C.	2897
Mary C. et al	7998
Mary C. et al	12443
Mary E.	721
Mary et al	9353
Mary et al	10389
Mary et al	14923
Mary Jane	2390
Mary Jane	19941
Maryland	700
Mary Murphy	8052
Mascotte	3994
Mason	1686
Massive placer	5697
Matchless	470
Mater et al	8999
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Maude F.	14277
Maude S. et al	13717
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Mayflower et al	5953
Mayflower et al	9432
Mayflower et al	12071
Mayflower extension et al	9432
Mayo et al	9612
May placer	13195
May Queen	448
May Queen	1314
May Queen	6900
May Queen	9583
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McKenzie placer	1014
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Miagera et al	11622
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Michigamme	8060
Michigan	15373
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Mickey Joys	9303
Midland	6260
Midland	6918
Midland et al	16708
Midnight	4532
Mikado	8015
Mike	441
Mike placer	2263

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Miller	13951
Milton	3161
Mineral et al	9470
Mineral Farm	1359
Miner Boy	553
Miner et al	16352
Miner's College	3280
Miner's Dream and Gold King (2)	19910
Miners Hope	1612
Minneapolis	2878
Minneapolis	5005
Minneapolis et al	4314
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Minnehaha placer	l. subd.
Minnesota	2651
Minnesota et al	4314
Minnesota et al	10807
Minnetonomah	8515
Minnie	975
Minnie	2840
Minnie et al	7316
Minnie et al	12071
Minnie Lee	1350
Minnie placer	6971
Minnie S	16313
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Missing Link et al	6164
Mobile	2452
Modest Girl and mill site	377 a. b.
Modoc	813
Moler et al	8999
Mollie Stark placer	523
Molly et al	6173
Molly Kelly	1716
Monarch	3742
Monarch	9073
Monarch	10987
Monitor	2299
Monitor et al	5347
Monte Christo	534
Monte Christo	913
Monte Christo	9566
Montezuma	865
Montgomery	410
Montreal	2249
Moonstone	2406
Morena	2574
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Morning Glory	361
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Morning Star	3070 am.
Morning Star et al	6579
Morning Star et al	9512
Mosquito	4542
Mosul	12126
Mountain Boy	465
Mountain Boy	466
Mountain Boy	1085
Mountain Gem	188
Mountain King	3735
Mountain Lake placer	3884
Mountan Lion	805
Mountain Lion	1051
Mountain Lion et al	8835
Mountain Lion et al	16358
Mountain Maid et al	16318
Mountain Queen	3482
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Mount Elbert placer	l. subd.
Mount Massive placer	666
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My Day	4624
Myron	2150
Mystic	1850
N. Rollins	3156
Nancy L	1013
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Nanticoke et al	12663
Napperville	2848
National	4660 a.
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National Union placer	l. subd.
Nautilus	493
Navarra et al	9362
Ned et al	9995
Negro Infant	795
Neil & Mertens placer	l. subd.
Nellie	1312
Nellie B. et al	9372
Nellie C. et al	4485
Nellie et al	14685
Nellie Fay	9405
Nellie G. et al	6232

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eptune	9865
estegg	9725
estor	1160
ettie L	3111
ettie Morgan	929 am.
ettie S	3184
ettie S. placer	14636
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evada	16452
ew Buffalo et al	9301
ew Delta	3231
ew Discovery	286
ew Discovery	4276
ew Foundland	642
ewhall	8595
ew Hampshire	4100
ew Klondyke	15401
ew Orleans	1448 am.
ew Orleans	15224
ewport	2287
ews Boy	15991
ew Tenderfoot et al	14604
ewton	2470
ew Year	496
ew Year	4450 am.
ew Year	8779
ew York	1294
ew York placer	l. subd.
ezahualcoyotyl	3918
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ightingale	3086
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iles	691
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onie	1502
ora	995
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ormanna	3270
orthern	16178
orthern Spy	3829
orth Side	3723 am.
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orway	8728
ow or Never	3322
oyes	2383
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D. & F. Co. placer	158
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M. D. & F. Co. placer	283
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ean	854
ean Wave	768 am.
ean Wave	1161
ean Wave	6670
'Connell et al	15509
ctober	5664
'Donnovan Rossa	3091
hio	584
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klahoma et al	7142
lathe placer	1095
ld Bullion placer	l. subd.
ld Dan, Old Dan Nos. 2 and 3, and Sunnyside (4)	18814
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ga	492 am.
ga No. 2, Silver King, and H. A. (3)	19289
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ive	617
ive Branch	2235
ive Branch	4098 am.
ive Branch et al	14341
llie Reed	3112
lson placer	2719
maha	3040
'Malley et al	12498
mega	8881
mego et al	9916
ne Hundred & Halcyon (2)	18428
'Neil et al	5136
nly Chance	1563
nondago	3244
nondago	11187
nota	1282
nota No. 2	8466
ntario	617

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Ontario	3162
Ontario	4310
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Ophir	3654
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Orange Blossom	3951
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Oregon Gulch placer	l. subd.
Oriental	587
Orinoco	3701
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Orion	742
Orion placer	l. subd.
Oro	846
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Oro City	937
Oro La Plata	327
Oro Nogo	4482
Oro placer	424
Orphan	16127
Orphant Boy	4425
Oscar placer	2362
Oscar placer	l. subd.
Oshkosh Boy et al	12167
Oskaloosa	7392
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Ottawa	1594
Ottawa	2916
Our Louise	1012
Ovens	8597
Overland	2919
Overlooked	8650
Oxford et al	4743
Ozark No. 3 et al. (2)	19835
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Pacific	3840
Palisade mill site	5937 b.
Palmer	9936
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Panama & Mason	6649
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Paragon placer	l. subd.
Parallogram	2665
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Park	4686
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Pauline	3166
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Pauline et al	7180
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Pay Rock et al	9277
Peabody	2542
Peak	5997 a.
Pease placer	624 am.
Peerless	2079
Peggy McCallum	6397
Peminah	8996
Penfield	2308
Pennacle	259 am.
Pennsylvania	613
Pennsylvania	718
Penrose	4311
Peoria Boy	784
Percival	3486
Pharmacist et al	11617
Phat Purse	1593
Phenix	7868
Philadelphia	486
Philadelphia	3010
Philadelphia	3687
Philip et al	15736
Phoebe Grace et al	7180
Pickaway et al	7899
Pickwick	1217
Picton Star et al	13246
Pilgrim	7248
Pilot	1268
Pilot et al	11323
Pinafore	2254
Pine	287
Pine Forest	1121
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Pioneer	8328
Pittsburgh	422
Plattner	401
Plattsburgh	2052
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Pocahontas	796
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Pontiac	17385
Poor Boy	4131
Populist et al	11622
Porphyry	375
Porphyry	3075
Porter J. placer	l. subd.
Portland	1732
Portland et al	12127
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Power	4017
Power No. 2	4018
President	3895
President	8942
President et al	7306
Preston	4297
Pride of the Hills	3963
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Prince Albert	3639 am.
Prince Albert	4496
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Prince of Iowa et al	6164
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Prince Rudolf	15054
Princess Louise et al	12101
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Printer Boy	49
Printer Girl	761 am.
Pritchard	5135
Prosperine et al	5214
Prospect	531
Prospect placer	4549 am.
Providence et al	16634
Ptarmigan et al	5644
Pueblo et al	12718
Pugnacious et al	12101
Puritan	5044
Pussy et al	9424
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Puzzler et al	9470
Pyrenees	1537
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Q. D. et al	5682
Quadrilateral	2352 am.
Quadrilateral et al	15210
Quaker	16210
Quaker et al	5405
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Queen City	9074
Queen of Clubs	1681
Queen of Diamonds	3821
Queen of May et al	15210
Queen of Sheba	856
Queen of the Hills	391
Quig placer	l. subd.
R. A. M	1566
R. J. F. Bartlett	4023
Rachael	6528
Ralph	13761
Ranchero	337
Randell placer	2188
Rankin	14482
Ranson & Irvin Brick Field placer	1223
Rare Metal Nos. 12-17	19980
Rarrus	574
Rassus	2518
Rattler	12249
Rattling Jack	1772
Raven	17212
Ravenna	1444
Ready Cash	304
Ready Cash et al	9422
Rebel	2717
Reconstruction	1866
Red Bird	867
Red Cap	6069
Red Cloud	499
Redheaded Mary	697
Red Hood	1319
Red Hook et al	4485
Redick	3041
Red Porphyry	3630
Red Raven	1069
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Reed	4659
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Riffle	7005
Right Angle	1480
Rita M. Willow. (See Roosevelt.)	

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Robinson	1743
Robinson placer	378
Rock	218
Rockafellow	2289
Rock Creek placer	2083 am.
Rockefeller et al	13304
Rock Island	2081
Rockland	4457
Rocky & Snow Flake	5038
Rogers	2885
Roosevelt, Helen Gould, Rita M. Willow (4)	19199
Rosa	1311
Rosa Henrietta	1642
Rose Bud et al	10230
Rose et al	9539
Rose et al	9551
Rose et al	10389
Rose placer	9111
Rose placer	l. subd.
Roseville	2385
Rosuna et al	9274
Rothschild	946
Rothschild	1396
Rothschild	3448
Roudebush & Moynahan placer	868
Rough and Ready	964
Rough and Ready	4108
Rough and Ready No. 2	4959
Roy et al	5282
Royal	1120
Royal	18878
Royal K. placer	2135
Royal Oak et al	4653
Rubie	845
Ruby	1028
Ruby	6211
Ruby	11947 am.
Rummel et al	16352
Rustler	9440
Ruth et al	9539
Ryan	2026
S. C. B	6380
S. D. & Q. D	5682
S. Small & M. S	362 ab.
S. S. S	3582
S. T. X	2633
Saginaw City	8621
Saginaw Valley et al	10090
Sailing Cissy et al	11121
St. Ann	4640
St. Bernard et al	9286
St. Clair et al	13304
St. Crispen	1281
St. Jo	6885 am.
St. John	20296
St. John et al	9292
St. Joseph	746
St. Joseph	1325 am.
St. Julian	2568
St. Julien	9533
St. Kevin	3364
St. Louis	558 am.
St. Mary et al	15010
St. Mary et al	15110
St. Mary et al	16246
St. Mary's	2247
St. Paul et al	4314
St. Teresa	1271
Saline et al	5786
Salley Jane	3148
Sampson placer	1097
San Francisco	8215
Sangamon	771
Sangamon fraction and Quarto (2)	19333
Sangre	4362
San Jose	543 am.
San Juan placer	l. subd.
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Santiago	17972
Sappho	330
Satellite	3168
Satellite	6190
Saturday	17884
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Schulherr	5067
Scofield	807
Scooper	529
Scotia	4781
Scraps	8512
Seabright placer	16336
Seabright placer	17449
Searl placer	435
Searl placer	436
Searl placer	12993
Secundus	13540
Security	3181
Sedalia	659
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Seranac	992
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Seven Thirty et al	9585
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Shale et al	11121
Shamrock	280
Shamrock	19868
Shamus O'Brien	512
Shelby	2791
Shenango	3368
Sheridan	8727
Sheridan et al	5740
Sherman et al	7572
Shiawassee et al	10090
Shiloh	3330
Siberia	1554
Sidney & Melburn	5802
Sidney et al	5558
Sierra Nevada	554
Sifter et al	4591
Silent Friend	595
Silurian	3647
Silver Anchor	7124
Silver Basin	923
Silver Cave et al	5786
Silver Chain	
Silver Champion et al	4775
Silver Chief	5357
Silver Chief et al	7998
Silver Cliff	6508
Silver Cloud	1016
Silver Cord	988
Silver Crown	4866
Silver Dale	3269
Silver Dollar	4654
Silver Dollar et al	5423
Silver Dollar et al	7998
Silver et al	9443
Silver Falls placer	1206
Silver Flagon	2100
Silver Issue et al	6949
Silver King	606
Silver King	4095
Silver King	4701
Silver King. (See Olga No. 2.)	
Silver King et al	7142 am.
Silver Moon	4692
Silver Nest	3085
Silver Nugget	1030
Silver Point	1172
Silver Queen	3671
Silver Queen et al	7142
Silver Spoon et al	5405
Silver Spray	1539
Silver Standard et al	7759
Silver Star et al	12718
Silver Wave	671
Silver Wave et al	5764
Silver Wheel et al	6232
Simon D. et al	7180
Sir Edward et al	9294
16 to 1	18337
Sizer placer	388
Slide	2619
Slide	6455
Slide et al	9739
Small Hope	2300
Smasher	1928
Smasher	2296
Smith mill site	382
Smuggler	6663
Smuggler	16320
Smuggler et al	9958
Smuggler et al	16318
Snow	4161
Snow	4481
Snow	6651
Snow Bird et al	16708
Snow Flake et al	5038
Snow Storm	404
Solux Tiyee	47
Sonora	2861
Sonoro	4486 am.
Soudan et al	5644
South Down et al	14741
South Eagle	4153
South Fork	623
Sovereign	955
Spar	7294
Spar et al	9448
Spokane et al	16318
Spot Cash	9261
Springfield	4413
Spruce	2963
St.	3581
Stanton et al	11375
Stark & Heron placer	l. subd.
Stark County	4315
Starlight	2069
Starlight placer	l. subd.
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Starry Flag	3218
Starr placer	255
Steamboat	928
Steam Boat et al	11323
Steel Spring	1461
Steen	3583
Sterling	4264
Sterling et al	15076
Steuben	680
Stevens & Leiter placer	271
Stevens & Leiter placer	275
Stillings	15399
Stinson placer	661
Stone	217
Stormbole et al	10807
Storm Cloud et al	9177
Storm King	7003
Stormy	2233
Stormy	5052
Stormy Petrel	17342
Stray Horse	301
Streeter placer	2021
Strike	12064
Strip	411
Stromboli et al	13717
Stumpf placer	398
Suakin et al	5644
Sulphide No. 1 et al	5143
Sultan	1568
Sumac	6759
Summer Girl et al	10183
Summit et al	15210
Summit No. 2 et al	6590
Sunday	1266
Sundown	1434
Sunflower	5953
Sunnyside	585
Sunnyside. (See Old Dan.)	
Sunnyside No. 1 et al. (4)	18277
Sunset	3123
Sunshine et al	14604
Superior	728
Superior et al	4715
Supervisor et al	6478
Surprise	18969
Susquehanna	3820
Swamp Angel	475
Sweet Home	2420
Switzerland	1992
Sylvanite	1583
T. L. Welsh	885
T. M. Molybdenite Nos. 1, 2, and 5	20065
T. O. M	14769
T. P. M	5494
Tabor	1202
Talisman No. 2	1933
Tankerstown	508
Tarter	15926
Taylor et al	6188
Teddy Roosevelt	19017
Teller et al	9177
Temptation	3702
Tenderfoot	580
Tenderfoot	1557
Tenderfoot placer	l. subd.
Ten Per Cent	3876
Terrible	299
Terrible et al	8990
Texas	19804
Texas Boy	2080
Texas Star	7014
Thatcher	1200
Thatcher placer	2189
The Boy	4357
Theodolite No. 1 placer	8509
Theodolite No. 3 placer	8512
Theodolite No. 8 et al	4598
Theodolite No. 9 et al	8576 a. b.
Theresa	1145
Thespian	2112
Thistle and mill site	376 a. b.
Thistle et al	6757
Thomas & Anthony mill site et al	6758
Thos. Corlyle et al	11622
Thos. L. Derby et al	l. subd.
Thos. McMicheals placer	l. subd.
Thomas Starr	442
Thunderboldt	872 am.
Ticket Broker et al	11873
Ticonic	965
Tiger	1301
Tiger	1365
Tiger	2053
Tillie H	4985
Tilton	1595
Tingle Tangle	6404
Tip Top	364
Tip Top	1026
Tip Top	2531
Titan	544 am.
Titus	2795
Tokio	9923
Tom et al	14294
Tom Graham placer	3229
Tom Hamilton	1449
Tonawanda	2876
Tontine	5996

Alphabetic list of mining claims in Lake County, Colo.—Continued

	Survey No
tal Eclipse	3045
wn Talk	673
yama	3608
iner	2315
ns-Atlantic	2624
ns-Atlantic	3209
surer	5252
sure Vault	569
angle	4893
angle	5631
angle placer	l.subd.
bune	516
bune placer	1938
nidad et al	9292
o.	863
poli et al	5644
mph	883
e Discovery et al	7314
quois et al	8613
scon	842
n Brothers	16912
inkle	2234
o Bit	15803
o Brothers et al.	5691
o Lauras	3110
rant	9304
ca & Superior	4715
ter	918
ter	2678
le Sam	455
le Sam et al	12176
corn et al	9361
on	3565
on	11126
on	15094
on Bank et al	5786
on Emma	747
on et al	6232
on et al	9422
on placer	2022
on Rebel	861
tah placer	2407
ted et al	5405
S. Mint	555
S. Senate	3213
known et al	6164
er Arkansas placer	1939
h	750
	1985
R.	4230
	13046
ey	2751
derbilt	19797
s et al	9112
ture	1903
ture	14278
ture et al	16604
us	3084
us	3135
us et al	17250
mont	1692
mont	4099
tibule et al	10448
via et al	14291
vius	229
vius	17156
et al	10807
et al	10844
or et al	16318
or Hugo	4119
oria	2054
ory	1469
of Leadville et al	10389
et al	9248
ng	1588

	Survey No.
Virginia	16593
Virginia Dare et al	1135 am.
Virginius	495
Virginius	511
Volcan	4208
Volunteer	13238
Vulture	419
W. A. Anthony et al	6758
W. F. Ilgenfritz	3412
W. G. et al	9702
W. G. Reid	1050
W. J. Bryan	11668
W. J. Bryan	14534
W. J. Bryan No. 2	17243
W. S. Hancock	3233
Wade Hampton	1538
Wahl et al	7180
Walker et al	14321
Wall Street	687
Wall Street	1000
Walnut	713
Walrus et al	11485
Walsh No. 1 et al. (3)	20058
Walter Scott et al	8658
Wandering Refugee	10511
War Eagle	600
Warren B. Fitzgerald et al	9448
Warsaw	650
Washburn	1405
Washington	482
Washington	841
Washington Gulch placer	159
Washoe et al	12176
Wasicakin	4111
Water Jacket	5036
Waterloo	452
Waterloo	483
Water Wheel placer	l. subd.
Waverlite et al	10844
Wax	4463
Way Up et al	11052
Webster	12600
Wedge et al	16320
Wednesday	794
Weil	4971
Weldon	1035 am.
Wellington	5178
Wells & Alexander placer	1388
Wells & Moyer placer	281
West Fraction	19621
Weston et al	11741
West Point	4352 am.
Weyand	1936
Whale	9864
Whale et al	11485
What is Left	4970
Wheeler	20197
Whetiker et al	14321
Whip	9522
Whipple	951
White Cap	893
White Cloud	1315
White House	4650
White Prince	4356 am.
White Quail et al	6931
White Rabbit	612
Whiteside	1267
White Star	2618
Whittelsey	4246
Whyte et al	13850
Wide Awake	1057
Wild Cat	502
Wilder	3529
Wilkesbarre No. 1	3979
Wilkesbarre No. 2	3980

	Survey No.
Wilkesbarre No. 3	» 3981
Willard et al	17501
William	725
Wm. Byrd Pages' placer	l. subd.
Wm. Moyer placer	ıL 300
Wm. N. Loker placer	303
William Pauper	3465
William Penn	484
William Reddick	559
Williams	685
William Wallace	773
Willie S. et al	7355
Wilmot	1468
Wilson	683
Wilson	1428
Wilson	3672
Winan	3096
Windsor et al	4653
Winnemuch No. 2	622
Winner	14727
Winona	2317
Winter	427
Winter	896
Wintry	5649
Wisconsin	5228
Wolcott et al	7759
Wolftone	533
Woodbine	13940
Woodbury	707
Woodland et al	6020
Woodruff	729
Wootten placer	l. subd.
Wren et al	13850
X. 10 U. S	1027
X. Y. T.	4162
Xmas	6279
Yale	3216
Yalu	9489
Yalu No. 2	10382
Yamagata	17923
Yankee	13021
Yankee Blade	3029
Yankee Boy	4454
Yankee Doodle	825
Yankee Fraction	1351
Yankee Girl et al	10183
Yaqua et al	11468
Yates	802
Yellow Chief	4245
Yellow Jacket	1491
Yellow Jacket	4496
Yellow Jacket	6140
Yellow Jacket	9309
Yosemite	44
Young America	285
Young American et al. (2)	18338
Young America placer	l. subd.
Young Canadian	1893
Young Caribou	573
Ypsilante	662
Ypsilante No. 2	7928
Ypsilanti No. 2	1499
Yuma	9846
Zanzibar et al	12389
Zebra	9552
Zeolite	5729
Zillar et al	9894
Zion et al	16910
Zion No. 3	13776
Zoo	10412
Zulu	1455
Zulu King	1146
Zuni placer	4436

Placer claims in legal subdivisions in Lake County, Colo.

Name	Mineral entry No.	Location	Area (acres)	Mining district	Name	Mineral entry No.	Location	Area (acres)	Mining district
Albert A. Blows	361	29, 20, 21—9—80	160.000	California.	Little Sister	849	34—9—80	160.000	California.
Almon	335	22—9—80	160.000	Do.	Manilla	4514	13—9—80	6.140	Do.
Arkansas & Lucky	4527	14, 15—9—80	120.860	Do.	Meteor	2261	23—11—80	100.000	Hope.
Aspen	01392	5—11—80	160.000	Box Creek.	Mike	844½	35—9—80	156.070	California.
Asteroid	2250	23, 24—11—80	160.000	Hope.	Minnehaha	2892	36—9—80	160.000	Do.
Ballarat	3271	15—9—80	60.000	California.	Mount Elbert	2163	5—11—80	40.000	Box Creek
Bates	847	34—9—80	160.000	Do.	National & Union	4526	33, 34—9—80	317.600	California.
Burton	333	28—9—80	160.000	Do.	Neil Mertens	5128	13—11—80	30.000	Hope.
C. S	350	23—9—80	40.000	Do.	Nellie Hayden	01351	3—11—80	40.000	Box Creek
Cerlew & Flamingo	2282	27—11—80	80.000	Hope.	New York	336	15, 22—9—80	160.000	California.
Chapman	811	25—9—80	144.960	California.	Old Bullion (2)	3898	6, 7—10—79	320.000	Union Gulch.
Clint	332	15—9—80	160.000	Do.	Oregon Gulch	482	26, 27—11—80	158.860	Hope.
Comet	2249	25—11—80	160.690	Hope.	Orion	2256	25—11—80	151.99	Do.
Cute Mc	845	35—9—80	160.000	California.	Oscar	812	36—9—80	114.000	California.
Decagon	2252	21—80—25, 16	151.000	Hope.	Paragon	2254	26—11—80	159.030	Hope.
Derry	01392	6—11—80	144.55	Box Creek.	Parson	846	35—9—80	160.000	California.
Detroit	334	22—9—80	160.000	California.	Percheron	01392	4—5—11—80	160.000	Box Creek.
Dinero	2967	19—9—80	40.000	Sugar Loaf.	Perley	01392	5—11—80	40.000	Do.
Dipper	2255	12, 13—11—89	100.000	Hope.	Polygon	2248	26—11—80	20.000	Hope.
Edna	291	14—9—80	160.000	California.	Porter J.	814	34—9—80	160.000	California.
Emma & Mable	1869	23—8—80	160.000	St. Kevin.	Quig	848	35—9—80	160.000	Do.
F. B	01123	4—11—80	40.000	Box Creek.	Rhododendrom	308	21—9—80	160.000	Do.
F. D	351	14, 23—9—80	120.000	California.	Rose	741	16, 21—9—80	160.000	Do.
Frank	813	36—9—80	160.000	Do.	Rupert	0732	21—8—80	40.000	Do.
Fuerstien	384	12—9—30	40.000	Do.	San Jaun	4439	14—9—80	54.850	Do.
George H.	815	36—9—80	160.000	Do.	Stark and Heron	2247	3, 10—11—80	120.000	Hayden.
Gold Belt	5215	3—10—80	162.18	Do.	Starlight	2257	13, 14—11—80	130.000	Hope.
Granite	01392	4—11—80	40.000	Box Creek.	Tenderfoot	2259	24, 25—11—80	155.230	Do.
Grubstake	2245	24, 25—11—80	150.060	Hope.	Thos. L. Derby	360	16—9—80	160.000	California.
Hermann	743	27—9—80	160.000	California.	Thos. McMicheals	359	15, 16—9—80	160.000	Do.
Hexagon	2262	25, 26—11—80	153.080	Hope.	Triangle	3991	26—9—80	19.160	Do.
Hiawatha	3915	1—10—80	79.830	California.	Water Wheel	4519	1, 2—10—80	119.23	Do.
Hutchinson	01206	26—11—81	100.000	Lake Creek.	Wm. Byrd Pages	359	16, 21—9—80	160.000	Do.
Indus	3933	27—11—80	70.000	Hope.	Wootten	742	28—9—80	160.000	Do.
J. D	290	22—9—80	160.000	California.	Young America	2251	13, 24—11—80	160.000	Hope.
Key	3064	23, 24—11—80	100.000	Hope.	Zion No. 1 and No. 2	5017	32—8—79	295.96	California.
Laura and Daisy	949	21—9—80	160.000	California.					

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925

[From records of U. S. General Land Office]

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
44	Yosemity	6	29—11—79	4.810	Hope.
45	Hattie Jane	7	29—11—79	3.440	Do.
46	Free Gold	8	29—11—79	3.440	Do.
47	Solux Tiyee	9	29—11—79	3.440	Do.
48	California	[a] 10	19, 30—11—79	3.440	Do.
49	Printer Boy	11	32—9—79	2.350	California.
100	Magenta	71	29, 30—11—79	1.830	Hope.
108	Arkansas River placer		24, 25—11—80	19.420	Do.
116	Goff Mining Co. placer	83	24, 25, 26—11—80	79.840	Do.
124	Homestake		8—81	3.440	Homestake.
158	O. D. & F. Co. placer	133	26—9—80	255.560	California.
159	Washington Gulch placer	95			
176	Boutwell		29—11—79	3.300	Hope.
178	Mountain Gem		29—11—79		Do.
188	Bonanza	100	29—11—79	9.820	Do.
216	Lime	114	30—9—79	10.300	California.
217	Stone	120	30—9—79	9.180	Do.
218	Rock	115	30, 31—9—79	10.300	Do.
224	J. B. Hill placer	123	33—9—80	20.000	Willow Creek.
229	Vesuvius	124	27—11—81	1.830	Twin Lakes.
232	Bulls Eye	126	30—9—79	9.180	California.
233	Iron	125	30—9—79	9.700	Do.
235	Buckeye				
236	Dome	127	31—9—79	10.330	Do.
237	Camp Bird	130	19, 30—9—79	7.303	Do.
238	Keystone				
239	Cincinnati	144	35, 36—9—79	10.33	Do.
252	Faint Hope	145	32—9—79	9.73	Do.
253	J. D. Dana	146	32—9—79	9.73	Do.
254	Adlaide	1097	19—9—79	10.227	Do.
255	Starr placer	182	25—9—80	164.610	Do.
256	Belcher	148	32—9—79	9.230	Do.
259 am	Pinnacle	1835	31—9—79	8.280	Do.
271	Stevens & Leiter placer	154	23—9—80	298.32	Do.
274	Seventy Six	158	30—9—79	6.400	Do.
275	Stevens & Leiter placer		30—9—79	119.24	Do.
277	Iron Hat	220	30—9—79	9.70	Do.
278	H. D	205	30, 31—9—79	10.19	Do.
279	Carbonate	151	24, 25—9—80	10.33	Do.
280	Shamrock	152	24, 25—9—80	10.28	Do.
281	T. S. Wells & Wm. Moyer placer	155	29, 30, 31, 32—9—79	193.43	Do.
282	J. R. Loker	779	24—9—80	10.26	Do.
283	O. M. D. & F. Co. placer	165	26—9—80	140.98	Do.
284	Charlestown	164	19, 30—9—79	4.31	Do.
285	Young America	159	19—9—79	8.21	Do.
286	New Discovery	156	24—9—80	10.17	Do.
287	Pine	157½	19, 30—9—79	4.06	Do.
288	Chrysolite	179	24—9—80	10.25	Do.
292	Keystone	195	19—9—79	9.05	Do.
293	Little Pittsburgh	167	24—9—80	9.72	Do.
294	Dives	181	24—9—80	1.06	Do.
295	Alta	233	28, 33—9—79	10.310	Do.
297	Dunkin	190	19—9—79	6.40	Do.
298	Gambetta	2945	24—9—80	7.867	Do.
299	Terrible	1341	19—9—79	7.276	Do.
300	Wm. Moyer placer	180	30—9—79	56.69	Do.

[a] Canceled; no patent.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
[illegible]	Stray Horse	509	24—9—80	7.94	California.
[illegible]	Belle of Colorado	3026	19, 30—9—79	7.198	Do.
[illegible]	Wm. N. Loker placer				
[illegible]	Ready Cash	166	33—9—79	10.33	Do.
[illegible]	Ida Nyce	3368	24—9—80	.94	Do.
[illegible]	Law				
[illegible]	Robert E. Lee	170	19—9—79	4.77	Do.
[illegible]	Agassiz	186	19—9—79	8.55	Do.
[illegible]	Robert Emmet	684	19—9—79	10.33	Do.
[illegible]	Result	685	19—9—79	10.33	Do.
[illegible]	Forrest City	683	19—9—79	9.23	Do.
[illegible]	Carboniferous	184	24—9—80	6.80	Do.
[illegible]	Oro La Plata	212	30, 31—9—79	6.57	Do.
[illegible]	Sappho	515	19—9—79	10.33	Do.
[illegible]	Ranchero	1012	19—9—79	.58	Do.
[illegible]	John Thompson placer	274	25—9—80	11.52	Do.
[illegible]	Climax	3226	24—9—80	6.84	Do.
[illegible]	Continental	3737	32—9—79	10.33	Do.
[illegible]	Lower Printer Boy	289	29—9—79	6.84	Do.
[illegible]	Flagstaff	980	19, 30—9—79	10.27	Do.
[illegible]	Artic	791	30—9—79	5.380	Do.
[illegible]	Nevada	208	21, 28—9—79	10.33	Do.
[illegible]	Amie	2973	24—9—80	7.67	Do.
[illegible]	Last Chance	225	19—9—79	8.61	Do.
[illegible]	Double Decker	3785	19—9—79	7.569	Do.
[illegible] a. b.	Gold Leaf and mill site	[a] 1794	24—9—80	4.873	Do.
[illegible]	Curley placer				
[illegible]	Little Chief	778	24—9—80	6.988	Do.
[illegible]	American Eagle and mill site	[b] 1005	24—9—80	6.889	Do.
[illegible]	Morning Glory	1111	19, 20—9—79	7.11	Do.
[illegible] a. b.	S. Small and mill site	1510	24—9—80	11.697	Do.
[illegible]	Imes	875	30—9—79	8.504	Do.
[illegible]	Tip Top	2511	19—9—79	2.419	Do.
[illegible]	Henriett	213	24—9—80	9.95	Do.
[illegible]	Little Eva	193	24—9—80	10.33	Do.
[illegible]	G. F. Daily mill site	191	24—9—80	City lots.	Do.
[illegible]	Belgian	4569	19, 30—9—79	8.28	Do.
[illegible]	Great Western	202	30—9—79	10.33	Do.
[illegible]	Porphyry	196	32—9—79	7.49	Do.
[illegible] a. b.	Thistle and mill site	888	25—9—80	10.33	Do.
[illegible] a. b.	Modest Girl and mill site	1764	25—9—80	8.804	Do.
[illegible]	Robinson placer	217	25, 26—9—80	172.12	Do.
[illegible]	Jacobson placer	239	13, 14—9—80	77.37	Do.
[illegible]	Meyer placer	206	23—9—80	2.60	Do.
[illegible]	Smith mill site	[a] 243	13—9—80	2.14	Do.
[illegible]	Grafton	[a] 1832	24—9—80	4.315	Do.
[illegible]	Bullion	2951	24—9—80	5.21	Do.
[illegible]	Sizer placer	565	23, 24—9—80	62.07	Do.
[illegible]	Germania placer	219	27—9—80	19.13	Do.
[illegible]	Cucumber	3997	25—9—80	5.164	Do.
[illegible] am	Part of Cucumber	2968	25—9—80	2.539	Do.
[illegible]	Queen of the Hills				
[illegible]	Malta placer	216	33—9—80	48.80	Do.
[illegible]	Martha placer				
[illegible]	Alice placer	3538	24—9—80	17.89	Do.
[illegible]	Stumpf placer	246	13—9—80	19.04	Do.
[illegible]	Hibschle placer	357	11, 12, 13, 14—9—80	160.00	Do.
[illegible]	do	356	1, 12—9—80	160.00	Do.
[illegible]	Plattner	223	32, 33—9—79	7.55	Do.
[illegible]	Magnolia placer				
[illegible]	Aetna	215	24, 25—9—80	10.33	Do.
[illegible]	Snow Storm	1039	19—9—79	2.793	Do.
[illegible]	Evening Star	207	24—9—80	4.85	Do.
[illegible]	Montgomery	222	30—9—79	8.79	Do.
[illegible]	Strip	224	32, 33—9—79	5.99	Do.
[illegible]	Little Rische	2100	21—9—79	9.71	Do.
[illegible]	Dickson placer				
[illegible]	American Smelter Co.'s placer	500	27—9—80	18.99	Do.
[illegible]	Neusitz placer	295	23—9—80	38.59	Do.
[illegible]	Ditch placer	557	11, 12, 13, 14—9—80	145.43	Do.
[illegible]	Louisville	238	30—9—79	10.33	Do.
[illegible]	Vulture	210	24—9—80	8.07	Do.
[illegible]	Brick Pomeroy	229	24—11—81	10.33	Twin Lakes.
[illegible]	Little Sliver	234	19—9—79	6.57	California.
[illegible]	Pittsburg	2278	24—9—80	8.43	Do.
[illegible]	Arkansas placer	561	6, 7—9—79; 1, 12—9—80	155.58	Do.
[illegible]	Oro placer				Do.
[illegible]	Comstock No. 1	884	29—9—79	9.78	Do.
[illegible]	Pandora	211	24—9—80	4.75	Do.
[illegible]	Winter				Do.
[illegible]	Judge Pendery	1789	24, 25—9—80	9.666	Do.
[illegible] am	Highland Chief	3832	20—9—79	2.208	Do.
[illegible]	Fairview	2276	24—9—80	7.907	Do.
[illegible]	All Right	1864	24—9—80	6.200	Do.
[illegible]	Kit Carson	1865	24—9—80	4.13	Do.
[illegible]	Searl placer				Do.
[illegible]	do	284	13, 14, 23, 24—9—80	158.00	Do.
[illegible]	Mike	353	29—9—79	10.33	Do.
[illegible]	Thomas Starr	352	29, 30—9—79	10.26	Do.
[illegible] am	Goodell	5284		1.72	Do.
[illegible] am	Gardiner	5283		1.72	Do.
[illegible]	Dead Broke	2281	25—9—80	5.095	Do.
[illegible]	Hibernia	410	19—9—79	4.48	Do.
[illegible]	Argo	302	13—9—80	10.34	Do.
[illegible]	May Queen	2747	19—9—79; 24—9—80	4.254	Do.
[illegible]	Curran	3868	20—9—79	8.80	Do.
[illegible]	Colorado Chief	218	24—9—80	1.39	Do.
[illegible]	Morning Star	249	24—9—80	5.83	Do.
[illegible]	Waterloo				Do.
[illegible]	Maud Hicks	751	28—9—79	10.83	Do.
[illegible]	Uncle Sam	871	21—9—79	13.10	Do.
[illegible]	Arapahoe	303	9—9—79	39.58	Do.

[a] Canceled; no patent. [b] Mill site canceled.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
457	Eliza	883	20—9—79	10.33	California.
458	John B. Raymond mill site	[a] 435	13—9—80	4.53	Do.
459	Garbutt	221	28—9—79	10.33	Do.
460	Hope	244	25—9—80	7.74	Do.
461	Fanny Rawlings	1983	21—9—79	10.33	Do.
463	Little Forepaugh	709, 2782	19—9—79	4.56	Do.
465	Mountain Boy				Do.
466	Mountain Boy No. 2				Do.
467	Independent	230	20—9—79	7.89	Do.
468	Bevis	2840	20—9—79	9.235	Do.
469 am	Quartzite	2401	25—9—80	7.02	Do.
470	Matchless	282	19—9—79	4.43	Do.
471	Eclip	1536	20, 21—9—79	7.67	Do.
472	Jamie Lee	2478	18, 19—9—79	9.76	Do.
473 am	Grand Prize	3886	20—9—79	4.51	Do.
474	Iowa				Do.
475	Swamp Angel	245	25—9—80	10.33	Do.
477	Cleveland	1911	21—9—79	10.33	Do.
478	Last Chip	3319	24—9—80	10.031	Do.
480	Blue Bird	524	27—9—79	9.38	Do.
481	Emmett	232	25—9—80	8.69	Do.
482	Washington	231	25—9—80	10.33	Do.
483	Waterloo	248	24—9—80	8.57	Do.
484	William Penn	251	20—9—79	8.90	Do.
485	Benjamin Franklin	250	20—9—79	9.50	Do.
486	Philadelphia	1336	20—9—79	9.03	Do.
487	General Cadwallader	252	20—9—79	9.50	Do.
488	Dillon	226	24—9—80	5.86	Do.
489	Great Hope	2637	20—9—79	10.34	Do.
490	Gilt Edge	492	30—9—79	3.79	Do.
491	Lady Jane	2966	20—9—79	8.504	Do.
492 am	Olga	2305	24—9—80	3.426	Do.
493	Nautilus				
494	Alice	237	28—9—79	9.17	Do.
495	Virginius	1304	18, 19—9—79	8.59	Do.
496	New Year	1318	21—9—79	9.30	Do.
498 am	Everett	1754	25—9—80	4.042	Do.
499	Red Cloud	301	20—9—79	7.33	Do.
502	Wild Cat	555	24—9—80	4.12	Do.
504	Little Bertha	1757	20—9—79	8.922	Do.
505	Allice				
506	Dania	919	19—9—79	9.48	Do.
507	Congo	1433	19—9—79	9.23	Do.
508	Tankerstown	1197	29—9—79	10.33	Do.
509	Little Miami	827	19—9—79	6.919	Do.
510	Independence				
511	Virginius	3176	21—9—79	7.967	Do.
512	Shamus O'Brien	2957	19—9—79	8.83	Do.
514	Homestake	851	4—10—79	8.15	Empire Gulch
516	Tribune	1454	29—9—79	10.33	California.
517	Little Mack				
518	Little Jonny	1633	21—9—79	10.33	Do.
519	Homestake No. 2	562	14—8—81	10.33	Homestake.
520	Homestake No. 1	563	14—8—81	10.33	Do.
522	Ohio & Missouri Smelter Works mill site				
523	Mollie Stark placer	304	26—9—80	47.11	California.
528	Andy Johnson	2199	20—9—79	9.605	Do.
529	Scooper	794	19—9—79	10.33	Do.
530	Del Monte	2965	19—9—79	8.18	Do.
531	Prospect	1846	25—9—80	6.368	Do.
532	Aztec	1043	19—9—79	5.632	Do.
533	Wolftone	299	24, 19—9—79	10.33	Do.
534	Monte Christo	2094	19, 24—9—79	5.028	Do.
535	Little Winnie	3191	21—9—79	5.328	Do.
536	Brookland	5270	24—9—80	1.852	Do.
538	Robert Burns	1695	20—9—79	9.859	Do.
539	Highland Mary	311	20—9—79	6.60	Do.
542	Little Alice	2322	20—9—79	4.09	Do.
543 am	San Jose	3736	21—9—79	6.084	Do.
545 am	Titan	3738	28—9—79	6.88	Do.
544 am	Little Stella	3734	21—9—79	6.677	Do.
546	Bully of the Woods	292	20—9—79	5.48	Do.
549	Jessie Clark	3393	21—9—79	2.71	Do.
550	Little Ellen	601	21—9—79	10.140	Do.
551 am	Little Prince	2865	20—9—79	7.083	Do.
552	Gonabrod	1013	19—9—79	9.089	Do.
553	Miner Boy				
554	Sierra Nevada	430	30—9—79	2.51	Do.
555	U. S. Mint				
558 am	St. Louis	3665	21—9—79	8.03	Do.
559	William Reddick	346	30—9—79	2.82	Do.
560	Lingula	1671	30—9—79	5.32	Do.
561	Maria	280	29, 30—9—79	10.33	Do.
562	Le Roy	306	18—9—79	10.33	Do.
563 am	Graham placer	1250	30—9—79	8.21	Do.
564	Brian Barau	3830	32—9—79	7.067	Do.
565	Colorado Princess				
566	Doris	270	32, 33—9—79	10.29	Do.
567	Katy	1374	21—9—79	10.042	Do.
568	Maid of Erin	834	24—9—80	6.07	Do.
569	Treasure Vault	2569	21—9—79	5.248	Do.
572	Columbia	[a] 872			
573	Young Caribou	2983	19—9—79	3.37	Do.
574	Rarrus	2417	19—9—79	7.115	Do.
575	Cedar Rapids	266	13—8—80	10.33	Do.
576	P. O. S	1390	24—9—80	5.63	Do.
577	Emma	255	27, 28—9—79	10.33	Do.
578	Pocahontas	858	18—9—79	9.348	Do.
579	Dauntless	313	21, 22—9—79	10.33	Do.
580	Tenderfoot	3989	21—9—79	8.653	Do.
584	Ohio	287	20, 29—9—79	10.31	Do.
585	Sunnyside	670	32—9—79	9.414	Do.
586	Edith	966	20—9—79	7.975	Do.

[a] Canceled; no patent.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
587	Oriental				
588	Lora Lynn				
589	Ballard	1376	20—9—79	3.24	California.
590	Pride of the West	516	18—9—79	9.68	Do.
591	Enterprise	398	28—9—79	9.58	Do.
592	John Leary placer claim No. 2	273	25—9—80	2.280	Do.
594	Columbia	254	30—9—79	10.02	Do.
595	Silent Friend	1333	21—9—79	4.65	Do.
596	Little Vinnie	862	21, 28, 29—9—79	4.748	Do.
597	Fairplay	297	8—10—79	10.32	Do.
598	H. M. L	[a]2389	20—9—79	7.14	Do.
599	Hidden Treasure	2839	19, 20—9—79	8.44	Do.
600	War Eagle	2158	29—9—79	10.33	Do.
601	Little Annie	316	21—9—79	10.33	Do.
604	Iszard	554	21—9—79	6.84	Do.
605	Indiana	1963	19—9—79	0.63	Do.
606	Silver King	3044	19—9—79	5.088	Do.
607	Hazzard				
608	Nisi Prius	407	31—9—79	6.96	Do.
612	White Rabbit	2013	19—9—79	10.33	Do.
613	Pennsylvania	1349	32—9—79	9.19	Do.
614	Hercules				
617	Ontario	882	32—9—79	10.15	Do.
618	Lake County	275	32—9—79	6.88	Do.
619	Badger State	1588, 1020	29—9—79	7.90	Do.
620	Little Edenburg	448	20, 21—9—79	8.42	Do.
621	Grand View	2170	21—9—79	2.47	Do.
622	Winnemuch No. 2				
623	South Fork	1989	21—9—79	10.16	Do.
624 am	Pease placer	1003	31—9—79	48.226	Do.
625 am	Hawkeye	3748	28—9—72	5.224	Do.
626	Emma	508	24—9—80	.87	Do.
628	Hard Cash	737	19—9—79	10.226	Do.
629	Harry Colvin	[a]439			
630	Greenwood	271	19—9—79	10.17	Do.
635	Kohinoor	3015	21—9—79	7.05	Do.
636	Elmore	2015	21—9—79	10.20	Do.
642	New Foundland	2642	28—9—79	10.33	Do.
643	Black Prince	3790	20, 21—9—79	10.09	Do.
644	Cora Bell	2554	19—9—79	5.529	Do.
647	Olive	307	28—9—79	10.33	Do.
648	Hannah	472	16, 17—9—79	10.33	Do.
649	Muchachinoch				
650	Warsaw	948	22—9—79	9.99	Do.
651	Hoodoo	907	6—10—79; 31—9—79	10.33	Do.
652	Echo	906	6—10—79; 31—9—79	10.33	Do.
653	Buckeye	1871	13, 24—9—80	9.20	Do.
654	Amelia				
655	Little Chippewa	641	20, 29—9—79	9.92	Do.
656	Highland Mary	2559	19—9—79	3.92	Do.
657	Luck	347	26—11—81	10.32	Lake Creek.
658	Mahala	318	19—9—79	9.43	California.
659	Sedalia	298	21—9—79	10.33	St. Kevin.
660	Fanchon placer	286	13—9—81	118.92	Sugar Loaf.
661	Stinson placer	285	12, 13—9—81	124.25	California.
662	Ypsilanti	4024	24—9—80	1.04	Do.
663	Christmas Gift	330	30—9—79	4.03	Do.
664	Lake County	536	13—9—79; 18—9—80	7.42	Do.
665	Kannoshia	272	5—10—79	10.16	Do.
666	Mount Massive placer	449	25—9—81	99.68	Do.
667	Idaho				
668	Irene	3447	28—9—79	4.116	Do.
669	Leadville	[a]1985			
671	Silver Wave	433	30—9—79	5.77	Do.
673	Town Talk	1418	35—9—79	10.33	Do.
674	Cordelia Edmonson	3259	19—9—79	3.604	Do.
680	Steuben	337	7—9—79	7.90	Do.
681	Frank	785	29—9—79	10.33	Do.
682	Little Champion	281	18—9—79	7.70	Do.
683	Wilson				
684	Kennebec	1177	19—9—79	7.47	Do.
685	Williams	2582	32—9—79	5.89	Do.
687	Wall Street				
688	Bonnie Kate				
689	Archer	3735	21—9—79	2.316	Do.
690	Augusta	982	24—9—80	2.42	Do.
691	Niles	983	24—9—80	1.67	Do.
692	Frenchman	588	19, 30—9—79	5.91	Do.
693	American Eagle	735	29—9—79	10.33	Do.
694	Boulder	366	20—9—79	10.29	Do.
696	Kierscey	2048	28—9—79	9.11	Do.
697	Redheaded Mary	[a]1995	19—9—79	1.653	Do.
700	Maryland	329	18—9—79	10.33	Do.
701	Florence	2853	29—9—79	8.756	Do.
702	Princeton	818	18—9—79	10.34	Do.
703	Little Blonde	819	18—9—79	6.65	Do.
704	Key	820	18—9—79	6.10	Do.
706	Little Todd	1456	16—9—79	5.04	Do.
707	Woodbury	325	16—9—79	10.32	Do.
708	Ashley	324	16—9—79	10.32	Do.
709	Jessie	1990	18—9—79	10.330	Do.
712	Chestnut	857	30—9—79	9.38	Do.
713	Walnut	856	30—9—79	4.72	Do.
716	Glengary	944	20, 29—9—79	4.00	Do.
718	Pennsylvania				
719	Dolphin	586	24—9—80	1.99	Do.
720	Iron Queen	859	30—9—79	4.335	Do.
721	Mary E.	868	28—9—79	10.34	Do.
722 am	Bald Mountain	1118	28—9—79	10.34	Do.
723	Jay Bird	3666	29—9—79	8.243	Do.
724	Accountias	288	18—9—79	7.69	Do.
725	William	[a]734			

[a] Canceled; no patent.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
726	Denver City	310	19—9—79	6.62	California.
727	Loveland	2765	19—9—79	7.77	Do.
728	Superior	2766	20—9—79	10.33	Do.
729	Woodruff	850	19—9—79	6.259	Do.
730	Logan	905	19—9—79	4.933	Do.
731	Erie	378	20—9—79	4.32	Do.
732	Donovan	537	21—9—79	5.25	Do.
735	McDermith placer	1067	29, 32—9—79	23.930	Do.
736	Altoona	892	32—9—79	9.98	Do.
737	Minnehaha	893	32—9—79	9.98	Do.
738	Ohio	891	28—9—79	6.665	Do.
739	Champion	925	32—9—79	5.92	Do.
740	Mary	1373	21—9—79	8.89	Do.
741	Resurrection	1380	21, 22—9—79	8.89	Do.
742	Orion	2231	24—9—80	4.637	Do.
743	John Mitchell	798	28—9—79	7.941	Do.
744	Cone	926	32—9—79	6.836	Do.
746	St. Joseph	890	32—9—79	5.188	Do.
747	Union Emma				
748	Bismark	1170	24—9—80	4.28	Do.
749	Humboldt	2101	25—9—80	6.687	Do.
750	Utah	396	25—9—80	4.34	Do.
751	Daisey				
752	Effa Harris	417	5—10—79	10.33	Empire Gulch.
753	First National	416	5—10—79	10.33	Do.
754	Confidence				
755	Little Diamond				
756	Emma	342	29—9—79	8.26	California.
757	Little Champion	[a] 5028	19, 20—9—79	3.73	Do.
758	Little Maud	2625	19, 20—9—79	4.86	Do.
759	Florence	1855	24—9—81	9.12	St. Kevin.
760	Castle View	475	24, 25—9—80	7.10	California.
761 am	Printer Girl	3629	29—9—79	8.278	Do.
762	Geneva	300	20—9—79	7.48	Do.
763	Christmas	405	21—9—79	5.12	Do.
764	Lone Tree				
765	Globe				
767	Codfish Balls	1266	30—9—79	2.63	Do.
768 am	Ocean Wave	1451	30—9—79	4.653	Do.
769	King Soloman	343	28—9—79	6.19	Do.
771	Sangamon				
772	Florence	1598	32—9—79	9.52	Do.
773	William Wallace	1912	24, 25—9—80	9.087	Do.
783	Hartford	339	29—9—79	9.17	Do.
784	Peoria Boy	340	29—9—79	6.78	Do.
787	Chicago placer				
788	Continental				
789	Laurel	427	19—9—79	7.48	Do.
790	A. Y	314, 1327	30—9—79	10.27	Do.
791	Blind Tom	512	30—9—79	10.33	Do.
794	Wednesday	305	28—9—79	10.33	Do.
795	Negro Infant	338	28, 29—9—79	4.94	Do.
796	Pocahontas	578	24—9—80	4.151	Do.
797	Palmetto & American Flag	873	28—9—79	7.892	Do.
798	Argo				
799	G. M. Favorite	975	32—9—79	9.072	Do.
800	Genesee	2746	18, 19—9—79	5.93	Do.
801	Leopard	1977	28, 33—9—79	3.29	Do.
802	Yates	854	20, 21—9—79	7.621	Do.
805	Mountain Lion	679	28—9—79	9.68	Do.
806	Grace	415	4, 5—10—79	7.58	Empire Gulch.
807	Scofield				
809	Clarendon placer				
811	Cataba	860	18—9—79	9.54	California.
813	Modoc	1031	25—9—80	9.225	Do.
814	Czar placer	[a] 312	13, 14—9—80	147.33	Do.
818	Lowland Chief				
819	Corner				
822	Comstock				
823	Mahanoy	1558	21—9—79	2.50	Do.
825	Yankee Doodle	328	24—9—80	8.02	Do.
828	Lac La Belle				
831	General Shields	399	24—9—81	10.33	Sugar Loaf.
832	Hope	2956	24—9—80	8.32	California.
833	Prince of Orleans	[a] 3793	19—9—79	3.155	Do.
834	Antelope				
835 am	Big Chief	4240	24, 30—9—79	4.364	Do.
836	Echo	422	19—9—79	6.34	Do.
838	Park	474	19, 20—9—79	10.33	Do.
841	Washington	309	29—9—79	8.29	Do.
842	Tucson	412	30—9—79	8.11	Do.
844	Clara Dell	1138	19—9—79	7.514	Do.
845	Rubie	369	30—9—79	7.36	Do.
846	Oro	391	30—9—79	8.20	Do.
847	Budweiser				
848	Golden Curry	832	24—9—81	10.33	Sugar Loaf.
849	Bazoo	425	29—9—79	10.18	Do.
850	Old Stonewall	572	19—9—79	3.24	Do.
852	Norcom	319	18—9—79	4.89	Do.
853	Lucknow	320	18—9—79	9.04	Do.
854	Ocean	402	21—9—79	10.33	Do.
856	Queen of Sheba				
859	Little Monitor	2031	19—9—79	3.31	Do.
860	Seneca	1487	21—9—79	5.308	Do.
861	Union Rebel	575	28—9—79	9.01	Do.
862	D. P. R.	2239	19—9—79	3.10	Do.
863	Trio	513	30—9—79	8.34	Do.
865	Montezuma				
866	Mammoth	899	28—9—79	7.88	Do.
867	Red Bird	1425	28—9—79	7.83	Do.
868	Roudebush & Moynahan placer	[a] 947	23—9—80	95.568	Do.
870	Maudy	845	28—9—79	3.76	Do.
871	Birdie Tribble	3196	19—9—79	.39	Do.

[a] Canceled; no patent.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
872 am	Thunderbolt	1710	29—9—79	8.362	Sugar Loaf.
878	Blackhawk	910	27—9—79	10.33	Do.
879	J. B. Grant	1997	19—9—79	4.172	Do.
880	Hamburg	[a] 600			
883	Triumph	921	28—9—79	6.44	Do.
884	Buncombe				
885	T. L. Welsh	341	24—9—81	10.33	Do.
887	Moynahan				
888	Anita	885	20—9—79	.307	California.
889	Kingan Consolidated				
890	Forest City No. 2	1446	21—9—79	10.00	Do.
892	Kokomo	1421	21—9—79	8.211	Do.
893	White Cap	1434	30—9—79	3.827	Do.
894	Pacific	660	18—9—79	10.19	Do.
895	Forfeit	1572	30—9—79	2.40	Do.
896	Winter	681	20—9—79	2.536	Do.
897	Park No. 2	688	20—9—79	9.684	Do.
901	Chemung	[a] 3869			
902 am	Continental	1428	33—9—79	9.157	Do.
903	Black Cloud	1966	33—9—79	10.33	Do.
905	Honey Comb	878	29—9—79	8.97	Do.
906	Little Charron	[a] 576			
908	Eurydice				
909 am	Across the Ocean	2857, 3412	20—9—79	6.222	Do.
910 am	Banker	2673	29—9—79	9.673	Do.
913	Monte Christo	345	21—9—79	7.30	Do.
914	Little Scott	358	22—9—79	10.33	Do.
915	Lalla Rookh	844	21—9—79	5.365	Do.
916	Lillie	2665	29, 30—9—79	2.23	Do.
917	Black	519	25—9—80	10.14	Do.
918	Ulster	520	25—9—80	10.13	Do.
919	Hartford	331	8—9—79	9.76	Do.
922	Fanny	1649	32—9—79	7.16	Do.
923	Silver Basin	1687	19—9—79	7.61	Do.
924	Hawkeye	367	19—9—79	7.01	Do.
927	Gill & Martin's mill site				
928	Steamboat	568	16—9—79	10.30	Do.
929 am	Nettie Morgan	2864	20—9—79	4.29	Do.
930	Chicago Reduction Works placer	363	26, 27—9—80	5.00	Do.
931	do	364	26, 27—9—80	5.00	Do.
932	do	365	26, 27—9—80	5.00	Do.
933	J. D. Ward	1766	32—9—79	3.00	Do.
935	Little Comstock	355	34—9—79	10.33	Do.
936	Golden Eagle	580	20, 29—9—79	4.39	Do.
937	Oro City	803	30—9—79	9.08	Do.
938	Ben Burb	409	30—9—79	8.63	Do.
939	Crescentia	2891	30—9—79	8.42	Do.
940	Robert Emmett	408	30—9—79	10.33	Do.
946	Rothschild	2154	19—9—79	6.136	Do.
947	Chas. G. Arnold's placer	843	25—9—80	3.04	Do.
948	Alicante	777	13—8—79	10.33	Alicante.
951	Whipple	354	15—9—79	10.33	California.
952 am	Ontario	2604	33—9—79	2.502	Do.
953	Mansfield	922	32—9—79	9.33	Do.
954	Fairmount	2838	20—9—79	7.17	Do.
955	Sovereign	2834	19—9—79	9.31	Do.
956	Kankakee	920	32—9—79	8.52	Do.
957	Castle	923	32—9—79	8.48	Do.
964	Rough and Ready				
965	Ticonic	447	22—9—79	10.33	Do.
966	Lady Alice	371	20, 29—9—79	7.50	Do.
969	Iron Rock	895	25—9—80	7.763	Do.
970	Homer placer	661	22, 23, 26, 27—9—80	154.70	Do.
975	Minnie	406	30—9—79	10.14	Do.
976	Judge Bowen	593	21—9—79	7.65	Do.
977	Capital placer	403	14, 23, 24—9—80	107.29	Do.
978	Chieftain	789, 2422	19—9—79	8.557	Do.
979	Baltimore	2570	19—9—79	3.68	Do.
980	Hamilton Gold	372	34—9—79	10.13	Do.
988	Silver Cord	1054	30—9—79	8.278	Do.
989	Cleora	656	30—9—79	8.93	Do.
991	Merry Monarch	911	32—9—79	10.11	Do.
992	Seranac	912	32—9—79	10.32	Do.
994	Bottcher No. 2	1359	18—9—79	8.61	Do.
995	Nora	2366	20—9—79	4.72	Do.
996	Kathleen	730	20—9—79	7.233	Do.
1000	Wall Street	2700	21—9—79	3.06	Do.
1003	Forest Rose				
1004	Iola	[c] 577			
1005	Delta	1052	30—9—79	5.347	Do.
1006	Eagle	1053	30—9—79	4.206	Do.
1010	Guome	2850	21—9—79	2.92	Do.
1011	Annie Leonard	[a] 3638	13—9—80	7.94	Do.
1012	Our Louise	373	17—9—79	9.88	Do.
1013	Nancy L	898	28—9—79	2.511	Do.
1014	McKenzie placer	444	31—9—79	160.00	Do.
1015	Ajax	1669	28—9—79	7.71	Do.
1016	Silver Cloud	1703	20—9—79	4.901	Do.
1017	Kent	[d] 1702			
1018	Ishpeming	1701	20—9—79	8.252	Do.
1023	Fourth of July	1391	28—9—79	9.49	Do.
1024 am	Cora	370	28—9—79	10.30	Do.
1026	Tip Top	908	25—9—80	6.787	Do.
1027	X. 10 U. S.	909	25—9—80	9.218	Do.
1028	Ruby	744	29—9—79	2.580	Do.
1029	Little Corinne	400	2—9—79	10.050	Do.
1030	Silver Nugget	383	28—9—79	5.160	Do.
1032	Martha	808	21—9—79	2.950	Do.
1033	Collateral				
1035 am	Weldon	2682	24—9—80	4.640	Do.
1036	Chas. G. Arnold placer	914	25—9—80	16.050	Do.
1040	Colorado No. 2	717	30—9—79	7.479	Do.

[a] Canceled; no patent. [c] Canceled Dec. 15, 1882. [d] Canceled Mar. 12, 1886

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
1042 am	Lickscumdidricks	3062	19—9—79	3.730	California.
1043	Greenback	491	19—9—79	3.980	Do.
1044	Lovejoy	3505	32—9—79	9.147	Do.
1047	Compromise	984	19—9—79	1.388	Do.
1050	W. G. Reid	468	28—9—79	8.900	Do.
1051	Mountain Lion	395	18—9—79	9.270	Do.
1052	Dimmick	426	19—9—79	1.620	Do.
1056	Little Lena				
1057	Wide Awake	452	4—10—79	4.010	Empire.
1066	A. P. Willard	657	30—9—79	4.470	California.
1069	Red Rover	[a] 2229	2—9—79	8.390	Mosquito.
1070	Mouse	504	7—9—79	10.320	California.
1071	Greenback	505	7—9—79	10.010	Do.
1072	Esperanza	429	18, 19—9—79	9.890	Do.
1079	Little Clara	707	27—9—79	10.000	Do.
1083	Lackawana placer				
1084	Duffie	521	19—9—79	1.430	Do.
1085	Mountain Boy	3115	20—9—79	2.680	Do.
1086	California Gulch	3123	20—9—79	.381	Do.
1088 am	Bonanza	3081	20—9—79	5.915	Do.
1089 am	Bonus	2807	24—9—80	2.933	Do.
1090 am	Gray Eagle	2419	24—9—80	6.859	Do.
1091 am	Crown Point	2800	24—9—80	3.299	Do.
1092	Clydesdale	1948	22—9—79	10.290	Do.
1093	Joplin				
1094	Illinois				
1095	Olathe placer	283	13, 24—9—80	62.760	Do.
1096	John placer	558	5, 6, 7—9—79	159.160	Do.
1097	Samson placer	559	5, 6, 7—9—79	158.210	Do.
1098	James placer	560	5, 6, 7—9—79	158.150	Do.
1099	Cass placer	556	7—9—79; 12—9—80	157.140	Do.
1115	Moyamensing	3924	19—9—79	2.802	Do.
1119	Emily	924	31—9—79	10.330	Do.
1120	Royal	525	29—9—79	8.260	Do.
1121	Pine Forest	763	33—9—79	10.330	Do.
1122	Old Mariner	411	33—9—79	10.330	Do.
1123	Little Comstock				
1124	Little Hattie	1257	29—9—79	6.553	Do.
1125	Adelphia	517	29—9—79	2.050	Do.
1127	Mammoth	486	32, 33—9—79	9.350	Do.
1136	Leaser & Goldsmith				
1137	Howard M. Holden	637	28—9—79	5.600	Do.
1141	General Sheridan	461	2—10—79	10.330	Empire Gulch.
1142	Hemitite	459	11—10—79	10.330	Thompson Gulch.
1143	Kerr	460	12—10—79	10.300	California.
1144	Maggie	528	28—9—79	7.250	Do.
1145	Theresa	3114	20—9—79	2.700	Do.
1146	Zulu King	3697	30—9—79	7.576	Do.
1147	Francenia	432	28, 33—9—79	7.920	Do.
1160	Nestor	633	32—9—79	4.350	Do.
1161	Ocean Wave	1484	21—9—79	10.314	Do.
1162	H. A. T. placer	[a]1028			Do.
1164	Mary Alsberg	526	28—9—79	1.340	Do.
1166	Little Nell	686	25—9—80	3.250	Do.
1172	Silver Point	445	26—9—79	10.330	Do.
1176	Little Galesburg	721	20—9—79	5.991	Do.
1177	Free America No. 2	1361	20—9—79	4.213	Do.
1188	Big Minnesota				
1189	Butcher Boy	1500	27—9—79	8.870	Do.
1190	Green Mountain	1788	28—9—79	8.953	Do.
1200	Thatcher	592	28—9—79	8.950	Do.
1201	Oolyte	463	13—9—80	9.450	Do.
1202	Tabor	464	13—9—80	9.440	Do.
1205	Semilunar placer				
1206	Silver Falls placer				
1207	Fitz Hugh	569	19—9—79	6.490	Do.
1217	Pickwick	1378	32—9—79	4.240	Do.
1225	Seek No Further	725	32—9—79	9.000	Do.
1236	Bush	1321	13—9—80	9.674	Do.
1243	Coon Valley	1831	31—9—79	9.320	Do.
1246	Commercial Drummer	602	30—9—79	4.740	Do.
1247	Revenue	613	26—9—79	6.720	Do.
1248	Little Troubador	479	33—9—79	10.330	Do.
1251	Belle of the West	1384	24—9—81	10.330	Sugar Loaf.
1253	City	606	29—9—79	10.310	California.
1254	Little Keystone				
1255	Reveille	727	29, 32—9—79	7.155	Do.
1256	Carpenter	1522	31—9—79	10.320	Do.
1257	Lawrence	753	28—9—79	9.745	Do.
1263	Arcadia				
1264	Hoosier	720	33—9—79	10.330	Do.
1266	Sunday	752	28—9—79	9.240	Do.
1267	Whiteside	2025	28—9—79	10.330	Do.
1268	Pilot	659	29, 32—9—79	2.450	Do.
1269	Berdell and Witherell placer				
1271	St. Teresa	1055	30—9—79	1.980	Do.
1277	First National	473	31—9—79; 36—9—80	10.330	Do.
1281	St. Crispen	587	28—9—79	1.120	Do.
1283	Onota	619	20—9—79	5.080	Do.
1287	Kittie	881	32—9—79	6.090	Do.
1292	Grand prize	729	32, 33—9—79	6.550	Do.
1293	Colorado Gulch placer	1866	24—9—81; 30—9—80	106.610	Do.
1294	New York	928	22—9—79	10.140	Do.
1295	Chicago	930	23—9—79	10.020	Do.
1300	Colorado Princess	1149	28—9—79	1.300	Do.
1301	Golden Casket	1150	28—9—79	1.300	Do.
1310	Tiger	2685	33—9—79	9.650	Do.
1311	Rosa	654	33—9—79	1.700	Do.
1312	Nellie	2308	28—9—79	.470	Do.
1314	May Queen	2404	25—9—80	7.057	Do.
1315	White Cloud	1934	20—9—79	6.800	Do.
1316	J. Q. S	1148	28—9—79	6.518	Do.
1319	Red Head	627	30, 31—9—79	.279	Do.

[a] Canceled; no patent.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
1320	Hawthorne	977	26—9—79	5.888	California.
1321	Dyer	976	26—9—79	10.248	Do.
1322	Last Chance	653	33—9—79	1.030	Do.
1323 am	St. Joseph	1544	28—9—79	6.506	Do.
1326	Capitol	646	29—9—79	6.880	Do.
1327	Clontarf	2321	24—9—80	4.800	Do.
1333	Little Lillie	518	21, 22—9—79	8.790	Do.
1334	E. C. B	1119	28—9—79	2.500	Do.
1335	Louisiana	1099	21, 28—9—79	4.180	Do.
1340	Holden	761	19—9—79	1.813	Do.
1350	Minnie Lee	696	30—9—79	5.050	Do.
1351	Yankee fraction	[e] 649			
1352	Granite	929	23—9—79	10.330	Do.
1359	Mineral Farm	1114	19, 20—9—79	9.060	Do.
1365	Tiger	532	24—9—81	10.330	Do.
1366	Arlington	723	22—9—79	10.330	Sugar Loaf.
1373	Guildersleve	599	33—9—79	9.820	California.
1375	Keystone	3122	20—9—79	3.380	Do.
1376	Dubuque	3074	20—9—79	2.030	Do.
1377	Caledonia				
1384	General Shields	574	8—9—79	9.880	Do.
1388	Wells and Alexander placer	1833	29, 32—9—79	11.830	Do.
1389	Ben Franklin	2266	29, 32—9—79	3.748	Do.
1396	Rothschild	535	11—9—79	7.420	Birdseye.
1397	La Plata Blanco	2400	20—9—79	6.130	California.
1404	Hoosier Girl				
1405	Washburn				
1426	Fannie Gage	1424	28, 33—9—79	4.479	Do.
1427	Garden City	1939	30—9—79	10.330	Do.
1428	Wilson	931	28—9—79	5.184	Do.
1434	Sundown	748	24—9—81	10.330	Sugar Loaf.
1442	Empire	690	4—10—79	10.051	Empire Gulch.
1444	Ravenna	603	29—9—79	9.110	California.
1447	Little Allie	876	20—9—79	9.680	Do.
1448 am	New Orleans	2104	33—9—79	4.383	Do.
1449	Tom Hamilton	538	22—9—79	9.130	Do.
1450	Defiance	680	24—9—81	5.780	Sugar Loaf.
1451	Mabel	672	28—9—79	5.330	California.
1452	Nil Desperandum	530	31—9—79; 36—9—80	9.820	Do.
1453	Zulu				
1455	Humboldt	1117	28—9—79	1.140	Do.
1459	Dirk	665	4—10—79	10.330	Empire Gulch.
1460	Beecher	597	34—9—79	10.160	California.
1461	Steel Spring	3913	29, 32—9—79	10.300	Do.
1467	Little Stella				
1468	Wilmot	1106	28—9—79	7.050	Do.
1469	Victory	1105	28—9—79	7.780	Do.
1473	Birthday	1542	28—9—79	9.777	Do.
1474	Chloride placer	728	19—9—79	2.100	Do.
1475	Catalpa	747	24—9—80	4.890	Do.
1477	Little Pet	[a] 986			
1478	North Star	655	33—9—79	7.990	Do.
1480	Right Angle	913	19—9—79	3.280	Do.
1481	Antelope	1486	21, 28—9—79	4.540	Do.
1483	Juniatta	783	13—9—81	10.330	Sugar Loaf.
1485	Champion	1385	29—9—79	7.880	California.
1487	Broadway				
1488	Bangkok	1591	19—9—79	5.740	Do.
1490	J. H. W	648	7—9—79	10.330	Do.
1491	Yellow Jacket	1386	29—9—79	7.010	Do.
1492	Golden Rule				
1493	Horse Shoe	2111	30—9—79	5.480	Do.
1494	Black Cat	589	31—9—79	7.540	Do.
1495	East Lynn placer	691	34—9—79	38.920	Do.
1497	Arizona placer	669	4—10—79	160.000	Empire Gulch.
1498 am	Broadax				
1499	Ypsilanti No. 2				
1500	Equator	689	33—9—79	6.370	California.
1501	Little Nellie	782	29—9—79	4.090	Do.
1502	Nonie	2557	28, 29—9—79	5.660	Do.
1503	Cornucopia	788	36—9—80	10.330	Do.
1523	Luna placer	933	24—11—80	50.057	Granite.
1531	Last Chance	861	33—9—79	8.070	California.
1532	Little Daisy	2608	30—9—79	0.516	Do.
1536	Clear Grit	616	33—9—79	5.000	Do.
1537	Pyrenees	713	19—9—79	6.804	Do.
1538	Wade Hampton	643	20, 29—9—79	6.050	Do.
1539	Silver Spray	642	20, 29—9—79	2.047	Do.
1540	Homestake	644	29—9—79	7.601	Do.
1541	Last Chance	[a] 3916	9—9—79	2.080	Do.
1542	Comstock	1204	20—9—79	3.470	Do.
1543	Hog Eye	2200	30—9—79	5.240	Do.
1549	Leavenworth				
1550	Campbell	722	33—9—79	9.940	Do.
1551	Experiment	673	30—9—79	6.940	Do.
1552	Star of the West	889	30—9—79	7.970	Do.
1553	Old King Cole	1206	29—9—79	9.950	Do.
1554	Siberia	1582	32—9—79	7.877	Do.
1555	Belle of Colorado No. 2				
1557	Tenderfoot	755	28—9—79	4.470	Do.
1563	Only Chance				
1564	Bohen	1523	28—9—79	4.680	Do.
1565	Aladin	1464	28—9—79	7.360	Do.
1566	R. A. M	1449	19—9—79	5.920	Do.
1567	Cyclops	1448	19—9—79	8.700	Do.
1568	Sultan	1870	13—8—79	10.330	Do.
1579	Devlin	1447	19—9—79	7.640	Do.
1583	Sylvanite				
1584	Sequin	4262	31—9—79	1.000	Do.
1585	Leviathan	2466	32—9—79	6.120	Do.
1588	Vining	4116	30—9—79	7.400	Do.
1592	Hunter's Last Chance				
1593	Phat Purse	900	28—9—79	7.000	Do.
1594	Ottawa	617	30—9—79	.780	Do.

[a] Canceled; no patent.

[e] Canceled Apr. 2, 1886.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued.

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
1595	Tilton	664	34—9—79	7.490	California.
1596	Bloomington	2011	33—9—79	5.615	Do.
1610 am	Confident	4124	30—9—79	3.712	Do.
1612	Miners Hope	840	29, 32—9—79	6.815	Do.
1616 am	Big Six	1411	20—9—79	3.700	Do.
1617 am	Aspen Mammoth				
1618	Great O'Sullivan	[a] 4941	30, 31—9—79	4.591	Do.
1619	Alma	1335	30—9—79	2.704	Do.
1627	Antioch	647	29—9—79	7.220	Do.
1628	Iron Safe	663	34—9—79	10.330	Do.
1639	Makeshift	682	34—9—79	9.930	Do.
1640 am	Andora placer	[a] 990			
1642	Rosa Henrietta	918	28, 33—9—79	4.480	Do.
1654	Elk	1329	21—9—79	9.290	Do.
1674 am	Lucy B. Hussy	2140	24—9—80	1.920	Do.
1680	Catalpa No. 2	822	24—9—80	.390	Do.
1681	Queen of Clubs	2032	19—9—79	8.490	Do.
1682	Keno	1483	30, 31—9—79	5.433	Do.
1683	Ellen	[a] 1513			
1685	Alpha	[a] 708			
1686	Mason				
1692	Vermont	2110	32—9—79	4.540	Do.
1693	Belle Vermont	1045	32—9—79	5.980	Do.
1716	Molly Kelly	816	5—9—79	10.330	Do.
1728	Isabella	1996	32—9—79	6.650	Do.
1729	Gurnee				
1732	Portland	1672	24—9—80	1.410	Do.
1743	Robinson	1540	25—9—79	8.053	Do.
1744	Little Sugar Loaf placer	793	19—9—80; 23—9—81	76.332	Sugar Loaf.
1755	Bradshaw	2026	32—9—79	3.530	California.
1772	Rattling Jack	4029	21—9—79	1.520	Do.
1778	Ella Beeler	2092	33—9—79	9.731	Do.
1802	Maudelle				
1803	Oriole	927	29—9—79	3.630	Do.
1811	Little Julia	2386	33—9—79	5.342	Do.
1812	Jim Fisk	2412	33—9—79	4.920	Do.
1821	Cullen				
1822	El Paso	3045	19—9—79	4.649	Do.
1829	Marion Virginia				
1844 am	Heytrossar	2952	24—9—80	1.155	Do.
1850	Mystic	1094	13—9—80	9.310	Do.
1851	Comment	[a] 1093	13—9—80	2.970	Do.
1854	Empire	874	32—9—79	1.560	Do.
1857	Houston	1302	33—9—79	9.378	Do.
1861	Little Giant	2105	25—9—80	3.720	Do.
1862	Little Giant	2106	24, 25—9—80	2.580	Do.
1865	MacGregor	853	25, 36—9—80	10.320	Do.
1866	Reconstruction	833	36—9—80	10.330	Do.
1868	Chicago Boy	1379	18—9—79	8.940	Do.
1869	Himmala	1001	5—10—79	10.270	Empire Gluch.
1870	Lady Crawford	1697	28—9—79	7.580	California.
1893	Young Canadian	1617	17—9—79	10.330	Do.
1900	Five Twenty	1492	29, 32—9—79	1.170	Do.
1903	Venture	4460	24—9—81	10.330	Sugar Loaf.
1907	Deer	1485	21—9—79	5.161	California.
1908	First Chance				
1909	Brown Queen	1087	22—10—79	10.330	Empire Gulch.
1912	Carleton	1120	30—9—79	2.740	California.
1918	Bessie Wilgus	1987	31—9—79	3.098	Do.
1919	Lucy L.	3663	23—8—80	10.330	Homestake.
1924	Michigan Boy	1350	24—9—81	9.050	Sugar Loaf.
1928	Smasher	1889	25—9—80; 30—9—79	10.330	California.
1933	Talisman No. 2	1878	28—9—79	6.590	Do.
1934	First National	1247	33—9—79	9.360	Do.
1935	Revenue Cutter	1030	21, 28—9—79	7.510	Do.
1936	Weyand	1410	33—9—79	9.777	Do.
1937	Great Western	1041	13—8—79	10.330	Alicante.
1938	Tribune placer				
1939	Upper Arkansas placer				
1952	Alps No. 1	1496	27—9—79	8.160	California.
1953 am	Alps No. 2	[a] 1497	27—9—79	9.510	Do.
1954	Helvetia	1494	27—9—79	10.320	Do.
1955 am	Columbus	1498	27—9—79	7.480	Do.
1966	Alleghany	4214	19—9—79	.881	Do.
1979	Illinois	1133	27—9—79	8.310	Do.
1984	Gold Crown	1392	25—8—79	10.330	French Gulch.
1985	Ute	1006	2—10—79	10.330	Empire Gulch.
1992	Switzerland	1559	31—9—79; 36—9—80	7.360	California.
2005	Junior				
2020	Iron Mask	1366	9—10—79	9.960	Empire Gulch.
2021	Streeter placer				
2022	Union placer				
2026	Ryan	1433	6—9—80	10.330	St. Kevin.
2027	Eagle	2638	6—9—80	10.330	Do.
2028	Amity	1537	6—9—80	10.330	Do.
2039	D. H. Elder	1027	10—11—82	10.330	Lackawanna.
2041	Fortuna	1744	33—9—79	8.000	California.
2049	Saturday Night	3025	11—81	10.330	Twin Lakes.
2050	Eureka	2669	11—81	10.090	Do.
2052	Plattsburgh				
2053	Tiger	2191	11—81	10.330	Do.
2054	Victoria	1538	36—8—81	10.330	St. Kevin.
2069	Starlight	[a] 1503			
2070	Lady May	2615	23, 24—9—81	10.270	Sugar Loaf.
2073	Elk Horn	1062	26—8—80	9.740	French Gulch.
2077	Eclipse	1499	21, 28—9—79	10.250	California.
2078	Lone Star	[a] 3020	30—9—80	10.330	Sugar Loaf.
2079	Peerless	2640	6—9—80	10.331	St. Kevin.
2080	Texas Boy	2639	6—9—80	10.300	Do.
2081	Rock Island	1539	6—9—80	10.330	Do.
2082 am	De Mary placer	3302	36—9—81	83.190	Sugar Loaf.
2083 am	Rock Creek placer				

[a] Canceled; no patent.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No	Name	Mineral entry No.	Location	Area (acres)	District or place
2100	Silver Flagon	1171	27—9—79	7.970	California.
2112	Thespian	1334	25—9—80	5.850	Do.
2113	Huckel				
2121	Belle Grant				
2129	Hector	1080	34—9—79	7.680	Do.
2130	Grace Greenwood	1079	34—9—79	7.410	Do.
2132	Iron Duke	2893	7—11—81	10.330	Twin Lakes.
2135	Royal K. placer				
2137 a. b	Little Delaware & McAllister mill site	1297	25—9—80	12.350	California.
2149	Hopkins	2729	2—10—79	10.330	Empire Gulch.
2150	Myron	1468	22, 23—8—79	10.330	Alicante.
2155 am	Part of Lida	1752	13, 24—9—80	2.080	California.
2155 am	Lida		13, 24—9—80	6.630	Do.
2163	Lady Adele	1056	29—9—79	9.000	Do.
2187	Alleghany placer	1095	2, 3, 10, 11—10—79	160.000	Empire.
2188	Randell placer	1096	3, 10—10—79	160.000	Do.
2189	Thatcher placer	3985	2, 3—10—79	160.000	Do.
2205	Lock	1969	34—9—79	9.868	California.
2206	Lucas				
2207	French Gulch placer				
2224	Clara Burbank	1169	35—9—79	10.330	Do.
2233	Stormy	3116	2—10—79	10.330	Empire.
2234	Twinkle	1541	2—10—79	10.330	Do.
2235	Olive Branch	1553	13—8—79	9.000	Alicante.
2247	St. Mary's	1082	24—9—81	7.470	Sugar Loaf.
2248	Little Harry	1081	24—9—81	8.660	Do.
2249	Montreal	1213	33—9—79	5.730	California.
2254	Pinafore	1970	34—9—79	10.330	Do.
2267	Empire placer				
2283	Everett placer				
2286	Belle of Kentucky	1342	23, 26—9—79	10.331	Do.
2287	Newport	1343	23, 26—9—79	10.330	Do.
2289	Rockafellow				
2290	Resumption				
2291	Charles B	2029	29—9—79	4.097	Do.
2292	Little Canada				
2293	Mount Carbon				
2296	Smasher	2540	30—9—79	7.220	Do.
2297	Ihrie				
2298	Long View				
2299	Monitor				
2300	Small Hope	1137	21—8—79	10.250	English Gulch.
2308	Penfield	3159	21—9—79	3.413	California.
2309	Fortune	3160	21—9—79	4.727	Do.
2314	P. J. C	1166	27—9—79	7.850	Do.
2315	Trainer	1165	27—9—79	6.860	Do.
2316	J. N. Murphy	[a] 1164			
2317	Winona	1423	13—8—79	5.050	Alicante.
2333	Goodell placer				
2334	Colonel Sellers	1656	29—9—79	8.400	California.
2345	Goodsell placer	4013	6—9—79	36.630	Do.
2352 am	Quadrilateral	4215	19—9—79	1.760	Do.
2354	Buffalo Girl	1167	27—9—79	9.080	Do.
2358	Lake placer	1753	36—9—81	79.800	St. Kevin.
2361	Alhambra placer	1135	25—9—80	68.598	California.
2362	Oscar placer [f]				
2363	Mike placer [f]				
2364	Chapman placer [f]	811			
2372	Richard Steward				
2376	Golden Edge				
2383	Noyes	4051	12, 13—9—80	10.330	Do.
2384	Garfield	1184	7—9—79; 12—9—80	10.330	Do.
2385	Roseville	1185	7—9—79; 12—9—80	8.357	Do.
2389	Mary Ann	1175	32, 33—9—79	8.520	Do.
2390	Mary Jane	1176	32—9—79	7.250	Do.
2400	Little Alice	1357	33—9—79	9.760	Do.
2406	Moonstone	5150	4—10—79	9.000	Empire Gulch.
2407	Uintah placer	1768	27, 33, 34—9—80	149.200	California.
2420	Sweet Home				
2423	Little fraction				
2424	Alta No. 1				
2425	Alta No. 2				
2426	Alta No. 3				
2427	Alta No. 4				
2428	Alta No. 5				
2437	Goldfield	1844	25—8—79	10.320	French Gulch.
2444	Ranson & Irvin Brick Field placer	1223	27—9—80	5.480	California.
2446	Nisi Prius extension	1261	31—9—80	1.821	Sugar Loaf.
2452	Mobile	1193	26, 35—9—79	8.240	California.
2455	Diana	1248	26—9—79	8.370	Do.
2463	Coffee	1804	4—10—79	9.010	Empire Gulch.
2464	California Rose	1805	4—10—79	10.320	Do.
2465	William Pauper	1802	4—10—79	10.320	Do.
2466	Eugenia Texas	1806	4—10—79	10.320	Do.
2467	Louis Stell	1803	4—10—79	2.010	Do.
2470	Newton	1215	19, 30—9—79	4.980	California.
2495	Col. Sellers	1842	30—9—79	5.180	Do.
2496	Accident	1843	30—9—79	1.960	Do.
2510	Baby				
2518	Rasus	1244	20, 29—9—79	8.590	Do.
2531	Tip Top	1286	18—8—78	10.330	Alicante.
2537	Birds Nest	1280	28—9—79	2.550	California.
2542	Peabody				
2552	Little Hope				
2553	Lady Elgin				
2561	Lyons placer	1493	32—9—79	56.062	Do.
2565	Alma Mater	1982	28—9—79	3.500	Do.
2568	St. Julian	2328	29, 30—9—79	2.848	Do.
2570	Galesburg	2323	3, 4—10—79	10.330	Empire Gulch.
2574	Morena				
2593	Dinero	1279	13, 24—9—81	8.460	St. Kevin.
2618	White Star	2555	23—11—81	10.330	Twin Lakes.

[a] Canceled; no patent.

[f] See list of placers in legal subdivisions.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
2619	Slide	1603	33—9—79	8.170	California.
2624	Trans-Atlantic	1385	28—9—79	4.150	Do.
2633	S. T. X	1725	29—9—79	4.970	Do.
2651	Minnesota	2664	19, 20—9—79	2.753	Do.
2658	Ingersoll placer and Lincoln & Hurricane lodes	[a] 1891	----	----	
2659	Aphia	1681	11—81	10.330	Twin Lakes.
2665	Parallelogram	2506	19—9—79	2.611	St. Kevin.
2666	Blue Mountain	1620	13, 24—9—81	10.330	Do.
2678	Ulster	2599	30—9—79	5.836	California.
2682 am	Forest Rose	1445	21—9—79	4.770	Do.
2688	Elva Elma	2324	28—9—79	9.590	Do.
2692	Great Republic	2190	33—9—79	7.935	Do.
2712 am	Australian	2921	21—9—79	5.396	Do.
2715	Kayserine	2358	30—9—79	2.300	Do.
2717	Rebel	2788	29, 30—9—79	3.840	Do.
2719	Olson placer	2390	31—9—79	19.820	Do.
2730	Fluddin	2632	19, 30—9—79	3.020	Do.
2732	Little Mary	----	----	----	
2733	Imogene	----	----	----	
2734	Little Jose	----	----	----	
2744	Finland	1404	21—8—79	9.960	French Gulch.
2745	Best Hope	1402	21, 28—8—79	10.330	Do.
2746	Carondelet	1405	21.28—8—79	8.050	Do.
2747	Patagonian	1403	21—8—79	10.070	Do.
2648	Little Willie	----	----	----	
2751	Valley	1784	21—9—79	8.590	California.
2773	Little Ralph	2980	12—9—80	7.390	Do.
2777	German Bank	3061	7—9—79	7.947	Do.
2778 am	Belle Placer	3919	14, 15—9—79	128.995	Do.
2791	Shelly	----	----	----	
2792	Clara	----	----	----	
2793	Leadville	----	----	----	
2794	Cliff	----	----	----	
2795	Titus	----	----	----	
2796	Little Rex	----	----	----	
2810	Dwight L. Dow	1781	25—8—79	10.330	Alicante.
2817	Mammoth placer	1698	20—9—79	67.406	California.
2840	Minnie	2789	29, 30—9—79	.290	Do.
2848	Napperville	2605	7—9—12; 12—9—80	9.620	Do.
2849	Arrietta	1722	7—9—79	10.330	Do.
2850	Argentine	1722	7—9—79	10.330	Do.
2851	Diamond State	2027, 2726	32—9—79	7.210	Do.
2852	Hawkeye Belle	2071	2, 3—10—79	10.330	Empire Gulch
2860	Hoosier Girl	2359	26—9—79	10.330	California.
2861	Sonora	2359	26—9—79	10.330	Do.
2862	Chihuahua	2359	26—9—79	10.330	Do.
2871	Boulder City	2159	13—11—81	10.330	Twin Lakes.
2872	M. R	2159	23—11—81	10.330	Do.
2876	Tonawanda	1422	32—9—79	10.330	California.
2878	Minneapolis	1984	7—9—79	7.820	Do.
2881	Elk	1605	14—9—79	10.330	Do.
2882	Ethel	1605	14—9—79	10.330	Do.
2883	Daisy	1605	14—9—79	10.330	Do.
2884	Daisy No. 3	1605	14—9—79	6.890	Do.
2885	Rogers	1605	11, 14—9—79	10.330	Do.
2886	Davis	1605	14—9—79	8.610	Do.
2887	A. B	1450	28—9—79	2.960	Do.
2888	Jeannetta	1941	24—9—81	7.000	St. Kevin.
2894	Leonard	1457	32—9—79	7.520	California.
2895	Magenta	1458	32—9—79	6.220	Do.
2896	Black Diamond	2028	28—9—79	6.458	Do.
2897	Mary C	2028	28—9—79	1.509	Do.
2911	Eva	1867	3—10—79	9.550	Empire Gulch.
2916	Ottawa	2030	28, 29—9—79	4.920	California.
2917	Accidental	1938	11—10—79	10.250	Empire Gulch.
2918	Acme	1978	11—10—79	7.180	Do.
2919	Overland	2040	35—10—79	10.330	Union Gulch.
2920	Old Rye	3344	29—9—79	4.131	California.
2925	Centre	2894	32—9—79	6.820	Do.
2932	Little Twins	2300	18—9—79	10.330	Do.
2943	Gunnison	1817	13—9—81	7.830	Sugar Loaf.
2952	Banner	1635	4—10—79	3.380	Empire Gulch.
2953	Detroit	1636	4—10—79	8.070	Do.
2960	Boyd	2382	33—9—79	8.960	California.
2963	Spruce	1838	29—9—79	6.000	Do.
2994	Abe Lincoln	2042	18—9—79	9.760	Do.
3004	R. J	2480	30—9—79	1.070	Do.
3007	Carleton	1974	20, 29—9—79	4.640	Do.
3008	Forest Queen	1974	20, 29—9—79	3.090	Do.
3010	Philadelphia	4468	36—8—81	10.330	Half Moon.
3014	Little Mascot	1676	27—9—79	7.362	California.
3029	Yankee Blade	2037	29, 32—11—79	10.330	Granite.
3038	Bell	1682	18—9—79	5.200	California.
3039	Chicago	1682	18—9—79	5.350	Do.
3040	Omaha	1682	18—9—79	7.880	Do.
3041	Redick	1682	18—9—79	9.460	Do.
3045	Total Eclipse	2201	1—9—80	10.330	Do.
3052	Excelsior	2273	24, 25—9—80	1.460	Do.
3057	Kentuck	1657	32, 33—9—79	4.524	Do.
3067	Consolidated Virginia	2687	24—9—81	7.648	St. Kevin.
3069	Helen	1945	30—9—79	1.300	California.
3070 a.m.	Morning Star	1888	10, 11—11—82	5.150	Red Mountain.
3075	Porphyry	1761	30—9—79	9.757	California.
3076	Golden Treasure	1664	27—8—79	10.330	English Gulch.
3078	Addie Smith	1879	12—9—80	9.706	California.
3079	Leander	1665	21—9—79	.632	Do.
3080	Claum Counell	----	----	----	
3084	Venus	1699	19—9—79	1.770	Do.
3085	Silver Nest	[a] 4119	13—9—80	6.735	Do.
3086	Nightingale	----	----	----	
3091	O'Donnovan Rossa	2781	25—9—80	1.220	Do.
3092	L. M	2349	30—9—79	4.570	Do.

[a] Canceled; no patent.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
	Winan	3178	29, 32—9—79	9.140	California.
3096	Billy Stevens	1769	29—9—79	5.700	Do.
3098	Bessie	1935	20—9—79	10.330	Do.
3099	Bill Sykes	a 2323	27—11—80	10.320	Granite.
3100	Ohio Bonanza	1829	28, 29—9—79	6.733	California.
3109	Two Lauras				
3110	Nettie L.	1685	30—9—79	6.510	Do.
3111	Ollie Reed	2193	21—9—79	9.640	Do
3112	Little Nellie				
3113	Dessery				
3119	Sunset	2816	26—11—81	10.320	Twin Lakes.
3123	Abe Lincoln	2981	7—9—79; 12—9—80	10.310	California.
3124	Jupiter	2425	24—9—81	9.020	Sugar Loaf.
3134	Venus	2854	24—9—81	6.625	Do.
3135	Iowa	1929	32—9—79	2.270	California.
3140	Daniel O'Connell	1953	28—9—79	2.745	Do.
3141	Sally Jane	2467	24—9—81	10.190	Sugar Loaf.
3148	Sedalia	1836	29—9—79	6.585	California.
3154	Bob Ingersol	2137	29—9—79	7.399	Do.
3155	N. Rollins	1898	29—9—79	7.0166	Do.
3156	Hoover	1813	29—9—79	3.079	Do.
3157	American Liberty	2284	33—9—79	8.070	Do.
3160	Milton	2444	25—9—80	3.790	Do.
3161	Ontario	1772	25—9—80	9.790	Do.
3162	Ellen Morgan	4196	21—9—79	1.545	Do.
3163 a.m.	Adams	2644	32—9—79	5.780	Do.
3165	Pauline	1770	29—9—79	4.570	Do.
3166	Satellite	1812	30—9—79	3.090	Do.
3168	Ida and Alice	1811	30—9—79	6.000	Do.
3169	Security	2310	19—9—79	2.850	Do.
3181	Black Iron	2221	18—9—80	10.330	Do.
3182	Nellie S.	4813	32—9—79	2.107	Do.
3184	Lyons	1790	7—9—79	10.136	Do.
3186	Amelia	1913	29—9—79	7.160	Do.
3205	Trans-Atlantic				
3209	U. S. Senator	1873	13—8—80	10.330	Tenmile Creek.
3213	Little fraction	2225	32—9—79	.600	California.
3214	Deer Lodge				
3215	Yale	1807	33—9—79	9.779	Do.
3216	Lillie	1910	29—9—79	4.520	Do.
3217	Starry Flag	2036	33—9—79	10.080	Do.
3218	Bryant and Daley	2047	7—9—79	6.550	Do.
3222	Magnet				
3223	Lady Loftin	2686	24—9—81	9.220	Sugar Loaf.
3224	Lucinda				
3225	Josephine	2835	32—9—79	2.680	California.
3226	Tom Graham placer				
3229	New Delta	3914	32—9—79	2.340	Do.
3231	W. S. Hancock	1854	24—9—81	10.330	Sugar Loaf.
3233	Crown Point	1835	31—9—79	3.000	California.
3241	Conundrum	1827	33—9—79	3.000	Do.
3242	Onondaga	a 1845	29—9—79	7.610	Do.
3244	Fairview	1858	35—10—79	10.330	Union Gulch.
3262	Gates	1859	35—10—79	10.330	Do.
3263	Davis	1860	35—10—79	7.541	Do.
3264	Great Eastern	3904	29—9—79	7.190	California.
3268	Silver Dale	2034	24—9—81	10.124	Sugar Loaf.
3269	Normanna	2035	24—9—81	8.119	Do.
3270	Miners College	2899	19—8—79	10.330	Alicante.
3280	Now or Never	2218	32—9—79	5.290	California.
3322	Golden Rule	2169	27—9—79	7.100	Do.
3324	Blue Bird	2406	6—9—20	10.260	St. Kevin.
3325	Shiloh	2184	24—8—80	10.330	Do.
3330	Shabonah	2185	24—8—80	10.330	Do.
3331	Grindrod	2515	31, 32—8—80	7.900	Do.
3332	Little Mac	1975	30—9—79	2.000	California.
3351	Gwendoline	2668	32—9—79	7.750	Do.
3358	Australasian	1936	36—9—80	10.330	Do.
3361	Belle	2125	1—9—81	10.330	St. Kevin.
3363	St. Kevin	2126	1—9—81	10.330	Do.
3364	Great Western	2108	16—9—79	10.330	California.
3366	Great Eastern	2109	16—9—79	9.769	Do.
3367	Shenango	2236	22—9—79	7.850	Do.
3368	Euphemia Duncin Collins				
3369	Jane Eugene	2635	33—9—79	9.833	Do.
3391	Constance	2148	33—9—79	4.430	Do.
3398	Howell	2131	14—9—79	8.020	Do.
3409	Kemble	2132	14—9—79	10.330	Do.
3410	Plymouth	2074	24—9—81	9.790	Sugar Loaf.
3411	W. F. Ilgenfritz	2075	24—9—81	9.756	Do.
3412	Dante's Inferno	2041	28—9—79	1.640	California.
3413	Edith Tangent	2427	29—9—79	7.680	Do.
3437	Fanny	2430	29—9—79	8.330	Do.
3438	Laura	2429	29—9—79	6.536	Do.
3439	Rothschild	2269	33—9—79	6.770	Do.
3448	Harvard	2146	18, 19—9—79	4.555	Do.
3449	Arcturus	2016	32—9—79	10.160	Do.
3453	Georgia	2660	34—9—79	10.330	Do.
3474	Mountain Queen	2845	7, 8—11—81	10.330	Twin Lakes.
3482	Eastern Rose	2329	20, 21—9—79	3.500	California.
3483	Little Lou	2127	30—9—79	1.210	Do.
3485	Percival	2347	30—9—79	2.050	Do.
3486	Leo	3453	29—9—79	1.270	Do.
3487	Continental Chief	2189	25, 26—9—79	10.330	Do.
3497	Golden Gate	2464	29—9—79	6.790	Do.
3500	International	2414	28, 33—9—79	5.990	Do.
3501	Last Rose of Summer	2330	25—9—80	7.651	Do.
3502	Wilder	2057	11—9—80	10.330	Do.
3529	A. & F.				
3530	Fair Play	3846	10—9—79	6.640	Do.
3544	F. B.				
3549	Champion	3944	29—9—79	1.500	Do.
3556	Seven Thirty	3945	29—9—79	6.180	Do.
3557					

a Canceled; no patent.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
3565	Union	2283	18—9—79	6.480	California.
3574	Boulder Nest No. 2	2348	18—9—79	6.200	Do.
3575	Little Dubuque	2351	2—9—80	10.300	St. Kevin.
3581	St	2352	2—9—80	10.300	Do.
3582	S. S. S	2350	2—9—80	10.330	Do.
3583	Steen	2490	33—9—79	10.307	California.
3604	Almeda	2489	33—9—79	8.249	Do.
3605	Josie	2192	33—9—79	8.879	Do.
3606	Gipsy Carbonate	2659	30—9—79	1.000	Do.
3608	Toyama	2411	20—9—79	9.670	Do.
3613	Comstock	2428	29—9—79	4.629	Do.
3630	Red Porphyry	2263	34—9—79	9.921	Do.
3633	Latch	2514	29—9—79	5.520	Do.
3639 am.	Prince Albert				
3647	Silurian				
3654	Ophir				
3661	Flint				
3665	Jay	2355	18, 19—9—79	3.277	Do.
3667	Robin Hood	2458	36—9—80	6.312	Do.
3671	Silver Queen	3669	12—9—81	10.330	St. Kevin.
3672	Wilson	2539	29—9—79	2.310	California.
3673	No Name	2457	29, 33—9—79	4.600	Do.
3676	Little Addie	2375	31, 32—9—79	5.352	Do.
3687	Philadelphia	2304	13—8—79	10.330	Alicante.
3690	Golconda	2979	21—9—79	5.260	California.
3693	Buckeye State	2658	24—9—81	3.050	Sugar Loaf.
3696	Carleton	2374	24—9—80	.340	California.
3697	Buckeye Belle	2373	24—9—80	.660	Do.
3701	Orinoco	2922	13—9—81	2.220	St. Kevin.
3702	Temptation	a 2465	21—9—79	.600	California.
3723 am.	North Side	3172	24—9—80	5.332	Do.
3724	Gold Chief	2409	28—9—79	5.590	Do.
3732	Carrie F	2371	1—10—79	10.320	Empire Gulch.
3735	Mountain King	2556	7, 8—11—81	6.410	Lackawanna.
3742	Monarch				
3743	Little Angie	2626	2—10—79	10.244	Empire Gulch.
3756	Little Cole	2410	29—9—79	.953	California.
3792	Parr Robinson placer	3193	16—8—79	48.200	Chalk Ranch.
3796	Eagle Horn	2750	31, 32—8—80	10.330	St. Kevin.
3797	Memphis	2594	32—9—79	.655	California.
3798	Kinny Side	2481	32—9—79	5.690	Do.
3820	Susquehanna	2567	6—11—81	10.330	Lackawanna.
3821	Queen of Diamonds	2403	13—11—81	10.330	Red Mountain
3822	Bulldozer	2527	29—9—79	1.810	California.
3829	Northern Spy	2484	32—9—79	4.110	Do.
3840	Pacific	2399	23—8—79	10.330	French Gulch.
3850	Little Doubtful	2762	19—9—80	8.717	California.
3852	Golden Gate				
3859	Golden Fleece	2485	25—8—80	10.330	St. Kevin.
3860 am.	Jimmie Swisher	2416	24—9—81	4.083	Sugar Loaf.
3866	Glacier placer	2487	5, 6—11—80	60.000	Twin Lakes.
3868 am.	Champion	2565	2, 3—11—82	10.330	Lackawanna.
3876	Ten Per Cent	2563	19—9—80	10.320	Sugar Loaf.
3877	Old Maid	2531	29—9—79	6.169	California.
3884	Mountain Lake placer	2494	15—9—79	20.000	Do.
3895	President	2906	5, 6—9—80	10.320	St. Kevin.
3896	Gerald Griffin	2496	6—9—80	10.260	Do.
3897	Carleton	2495	6—9—80	10.040	Do.
3901	Lupe	2508	30—9—79	2.575	California.
3913	Burkey	2505	19—9—79	5.469	Do.
3918	Nezahualcoyotyl	2601	19, 20—9—79	4.096	Do.
3919 am.	Cora Bell	2600	19—9—79	6.701	Do.
3930	Chrysolite No. 2	g 2509			
3934	Little Hugh	2532	33—9—79	6.758	Do.
3948	Minonk	2820	33—9—79	10.120	Do.
3949	Bon Ton	2571	33—9—79	5.920	Do.
3950	Kilkenny Boy	2598	33—9—79	8.940	Do.
3951	Orange Blossom	2583	33—9—79	9.244	Do.
3961	Georgia	2564	31—9—79	7.660	Do.
3962	Edith	2586	33—9—79	9.760	Do.
3963	Pride of the Hills	2797	19—9—79	.880	Do.
3968	Happy New Year	2572	33—9—79	9.760	Do.
3969	Katie	2573	33—9—79	7.160	Do.
3976	Mount Yale placer				
3979	Wilkesbarre No. 1	2814	6—9—80	10.090	St. Kevin.
3980	Wilkesbarre No. 2	2813	6—9—80	10.250	Do.
3981	Wilkesbarre No. 3	2812	6—9—80	9.700	Do.
3984	Big	2576	31—8—80	10.330	Do.
3988	Banner				
3994	Mascotte	2752	28—9—79	5.240	California.
4006	Frisholm	2592	7—9—80	10.330	St. Kevin.
4011	Alice	2987	34—8—81	10.330	Do.
4016	Lucy R.	2828	1—9—81	10.318	Do.
4017	Power	2829	1—9—81	10.330	Do.
4018	Power No. 2	2827	1—9—81	6.450	Do.
4023	R. J. F. Bartlett	2751	19—9—80	10.330	Sugar Loaf.
4033 am.	Helena	2925	33—9—79	9.620	California
4045	Erin	2614	32—9—79	1.730	Do.
4051	Cleveland	4914	13, 24—9—81	10.200	Sugar Loaf.
4052	Copper King	2999	19—9—79; 25—9—80	4.450	California.
4055	Clinetop				
4058	Boss	2748	12—9—81	10.330	St. Kevin.
4059	Kentuckian	2836	13, 14—9—81	10.330	Do.
4062	Cashier	3067	6—9—80	7.972	Do.
4063	Banker	3068	6—9—80	7.875	Do.
4078	Crystal Lake Placer	2671	20, 28, 29, 30—11—81	100.000	Twin Lakes.
4080	Gaw placer	2696	25—9—80	1.060	California.
4081	A. W. D	a 2744			
4083	Boulder	2692	20—9—79	3.250	Do.
4084	Holy Cross	2691	20—9—79	4.350	Do.
4091	Kosciusko	2846	14—8—81	10.330	St. Kevin.
4095	Silver King	2650	14—8—81	8.420	Do.
4098 am.	Olive Branch	2976	19—9—79	1.090	California

a Canceled; no patent.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
4099	Vermont	2681	5—10—79	10.320	California.
4100	New Hampshire	2680	5—10—79	10.280	Do.
4101	Pine Tree	2679	5—10—79	10.330	Empire Gulch.
4108	Rough and Ready	2862	27—8—79	10.330	Alicante.
4110	Eldorado	2666	1—9—81	10.330	St. Kevin.
4111	Wasicakin	2667	6—9—80; 1—9—81	10.330	Do.
4119	Victor Hugo	2678	1—9—81	8.965	Do.
4131	Poor Boy	2699	4—9—81	10.330	Do.
4133	Harry Earl	2861	26, 27—11—82	10.330	Red Mountain.
4153	South Eagle	3031	2—10—79	8.114	Empire Gulch.
4159	Liberty	2727	33—9—79	10.330	California.
4161	Snow	2688	20—9—79	3.714	Do.
4162	X. Y. T	2689	20—9—79	7.056	Do.
4163	Elbert	2690	20—9—79	3.630	Do.
4167 am	Clarence	2953	29—9—79	.773	Do.
4176	Butcher Boy	2866	1—9—81	10.330	St. Kevin.
4184	Comet	2863	32—9—87	3.646	California.
4193	Badger	2684	26, 27—10—79	10.330	Union Gulch.
4194	Farragut				
4195	Lottie	2837	19—9—79; 24—9—80	.202	California.
4208	Vulcan	2711	25—9—79	10.330	Do.
4209	John Schaffer	2710	26—9—79	9.840	Do.
4227	J. M. C	2764	36—9—80	9.800	Do.
4229	Bessie Stewart	3038	31—9—79	.686	Do.
4230	V. R	2723	1—9—81	9.680	St. Kevin.
4241 am	Clyde	2753	19—9—79	2.150	California.
4244 am	General Grant	2844	19—9—79	2.854	Do.
4245	Yellow Chief	[h] 2725		2.690	Do.
4246	Whittelsey	2772	13, 24—9—81	5.192	Sugar Loaf.
4249 am	H. F	2718	18—9—79	4.178	California.
4253	Frank	2722	29—9—79	7.047	Do.
4254	Laurel W.	2722	29—9—79	1.845	Do.
4261	Island	3009	18—9—97	1.970	Do.
4263	Hiawatha				
4264	Sterling	2796	18—9—79	4.760	Do.
4269	Paragon	2777	18—9—79	9.970	Do.
4271	Kildare	2776	18—9—79	6.880	Do.
4272	Isabel	2778	18—9—79	6.450	Do.
4276	New Discovery	3732	24—9—81	5.160	Sugar Loaf.
4297	Preston	2732	4—10—79	10.313	Empire Gulch.
4299	K. R. L.	2830	20—9—79	5.160	California.
4305	Little Floy				
4310	Ontario	2939	13, 14—9—80	1.970	Do.
4311	Penrose	2758	24—9—80	6.860	Do.
4314	St. Paul et al. (3)	3851	28, 29—9—79	16.538	Do.
4315	Stark County	2822	28—9—79	5.867	Do.
4329	Columbia placer	2874	23—8—80	64.335	St. Kevin.
4330	Alps	2784	28—8—79	10.330	English Gulch
4334	No Name placer et al. (4)	2849	25—11—82	289.17	Twin Lakes.
4337	Baby	2781	30—9—79; 25—9—80	4.849	California.
4352 am	West Point	3168	24—9—79	7.500	Sugar Loaf.
4356 am	White Prince	2926	20—9—81	2.635	California.
4357	The Boy	2900	20—9—77	1.157	Do.
4362	Sangre	2804	1, 2—8—81	10.330	Homestake.
4379	Emma Sophia et al. (2)	2832	9—10—79	20.653	Thompson Gulch.
4380 am	Finland et al. (2)	3024	13—9—81	15.227	Sugar Loaf.
4384	General Lee	2847	24, 25—9—81	8.950	Do.
4386	Autocrat				
4390	Lord Clyde	2911	18—9—79	9.937	California.
4391	Albion	2912	18—9—79	9.431	Do.
4397	Laplander et al	2905	13—9—81	16.858	Sugar Loaf.
4403	Alice Mason	2943	22—9—79	10.330	California.
4413	Springfield	2970	28—9—79	4.120	Do.
4414	First Chance	2923	1, 2—9—81	10.323	St. Kevin.
4425	Orphant Boy	3220	8—11—82	10.330	Red Mountain.
4426	Brown	2933	13—9—81	8.349	Sugar Loaf.
4436	Zuni placer	2889	27—9—80	147.400	Union Gulch.
4442	Garnett				
4450 am	New Years	3027	25—9—80	.390	Do.
4454	Yankee Boy	[a] 3495	6—9—80	10.080	St. Kevin.
4455	Father Ryan	3459	6—9—80	6.930	Do.
4456	Goldsmith	3461	1—9—81	10.200	Do.
4457	Rockland	3460	1—9—81	10.331	Do.
4458	Catheleen	3458	1—9—81	9.020	Do.
4459	Banim	3462	6—9—80	10.200	California.
4460	Bess	2908	25—9—80	.650	Do.
4461 am	Kismet	3475	18—9—79	1.360	Do.
4462 am	Hunkidori	2955	19—9—79	.441	Do.
4463	Wax	2917	5—10—79	7.910	Empire Gulch.
4475	Ground Hog	3417	19—8—78; 13—8—79	8.030	Alicante.
4477	Louise	3002	21—9—79	5.661	California.
4481	Snow	3085	14—9—79	10.272	Do.
4482	Oro Nogo	3086	14—9—79	10.281	Do.
4485	Nellie C. et al. (2)	3849	24—9—81	13.407	Sugar Loaf.
4486 am	Sonoro	2916	24—9—81	4.500	Do.
4495	Yellow Jacket	2919	24—9—81	4.073	Do.
4496	Prince Albert				
4497	Lecompton	4043	31—9—79	3.932	California.
4499	Blanche	2920	24—9—81	10.202	Sugar Loaf.
4500	Arty	3550	6—9—80	5.013	St. Kevin.
4501	Humboldt	2909	24—9—81	8.396	Sugar Loaf.
4528	Kyle et al. (2)	3001	19, 30—9—80	13.718	California.
4532	Midnight	3146	21—9—79	4.310	Do.
4536	Emma				
4537	Aid de Camp				
4542	Mosquito	3145	21—9—79	7.900	Do.
4546	D. H. Moffat	2938	21—9—79	8.264	Do.
4549 am	Prospect placer	2950	6—9—79	20.000	Do.
4554	Famous et al. (4)	3201	21—9—79	32.909	Do.
4562	Consolidated Capt. Kirby placer		6—9—80	47.390	St. Kevin.
4563	Abandoned	3182	1—9—81	10.330	Do.
4567	Birdie R.	3283	24—9—81	5.050	Sugar Loaf.
4573	Eugene	2915	19—9—80	7.590	Half Moon.

[a] Canceled; no patent.

[h] Canceled June 6, 1895.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
4586	Maxy	2985	21—9—79	10.330	California.
4590	Kentuckian No. 2	3223	13, 14—9—81	8.163	Sugar Loaf.
4591	Sifter et al. (3)	3121	7—9—79	23.160	California.
4598	Theodolite No. 8 et al. (9)	3194	2—11—82	92.970	Lackawanna.
4605	Pawnolus et al. (3)	3029	17, 18—9—79	30.222	California.
4608	Knickerbocker				
4623 am	Eighteen Ninety Two	2960	21—9—79	3.050	Do.
4624	My Day	3014	29—9—79	9.520	Do.
4626 am	Hermes	2963	19—9—79	2.040	Do.
4640	St. Ann	4145	21—9—79	6.667	Do.
4650	White House	[a] 3673	5, 6—9—80	6.870	St. Kevin.
4653	Golden Ledge et al. (5)	3075	18—9—79	48.892	California.
4554	Silver Dollar	3303	18—9—79	8.280	Do.
4659	Reed	3173	32—9—80	10.330	Sugar Loaf.
4660 ab	National lode and Farrish mill site	3367	32—8—80; 5—9—80	7.917	St. Kevin.
4667	General Sherman	3004	31—8—80	10.111	California.
4668	Cache et al. (3)	3042	30—9—79; 25—9—80	8.550	Do.
4686	Park	3017	32—8—80; 5—9—80	10.040	St. Kevin.
4687	C. I. Thomson	2974	14—9—81	10.330	Sugar Loaf.
4691	Lewis	3019	31, 32—8—80	10.330	St. Kevin.
4692	Silver Moon	3477	19—9—80	10.260	Sugar Loaf.
4701	Silver King	2998	19, 24—9—81	8.821	Do.
4703	Kansas and Inez (2)	3005	5, 6—10—79	20.662	Empire Gulch.
4711 am	Little Allie et al. (2)	3313	24—9—81	11.110	Sugar Loaf.
4715	Ulrica and Superior (2)	2996	14—9—79	19.530	California.
4724	Bank	3050	33—9—79	6.116	Do.
4725	North Star No. 2	3076	33—9—79	7.940	Do.
4727	Little Fred	3125	33—9—79	2.460	Do.
4728	Eagle et al. (3)	3252	33—9—79	6.479	Do.
4739	Juno	3109	18—9—79	9.456	Do.
4743	Oxford et al. (6)	3000	33, 34—9—79	49.055	Do.
4752	Law Placer	3463	36—9—81	97.030	Sugar Loaf.
4769 am	Amazon and Honduras (2)	3102	18—9—79	14.296	California.
4775	Silver Champion et al. (2)	3077	18—9—79	16.301	Do.
4781	Scotia	3080	7, 18—9—79	10.330	Do.
4782	Mercantile	3079	18—9—79	5.732	Do.
4818	Little Anna	3151	33—9—79	3.113	Do.
4822	Benjamin	3235	18, 19—9—80	10.070	Half Moon.
4833	Long Tom	3059	19—9—81	7.690	Sugar Loaf.
4866	Silver Crown	3237	13—9—81	7.436	Do.
4893	Triangle	3181	29—9—79	1.100	California.
4934	Oro	3117	7, 18—9—79	9.800	Do.
4959	Rough and Ready No. 2				
4970	What is Left	3120	21—9—79	7.102	Do.
4971	Weil		21—9—79	5.000	Do.
4973	J. G. M	3101	17—9—79	10.090	Do.
4980	Dolomite	3093	19—9—79	1.261	Do.
4985	Tillie H.	3161	18—9—79	10.330	Do.
4992	Eureka	3089	19—9—79	.699	Do.
5005	Minneapolis	3291	29—8—79	10.330	Buckeye.
5006	Logan	3150	18—8—78	10.330	Alicante.
5018	Little Aurora				
5035	Water Jacket	3156	18—9—79	8.440	California.
5036	Lucky Star	3155	18—9—79	6.610	Do.
5037	Eliza	4063	17—9—79	9.090	Do.
5038	Rocky and Snow Flake (2)	3184	21—9—79	9.395	Do.
5044	Puritan	3570	6—9—80	6.430	St. Kevin.
5052	Stormy				
5067	Schulherr				
5089	Dunboy	3186	5—10—79	10.330	Empire Gulch.
5116	Lord Byron	3136	32—9—79	4.270	California.
5134	Bessie	3222	5, 8—10—79	10.330	Empire Gulch.
5135	Pritchard	3221	8—10—79	10.330	Do.
5136	O'Neil and Lady of the Lake (2)	3219	5, 8—10—79	20.660	Do.
5143	Sulphide No. 1 et al. (4)	3113	7—9—79	40.940	California.
5152	Malvina	3106	16—9—79	10.330	Do.
5170	Bradford Belle	3119	5—10—79	10.110	Empire Gulch.
5178	Wellington				
5199	Little Troy	3120	30—11—79	10.328	Granite.
5201	Baby	3316	18—9—79	1.954	California.
5209	Arlington No. 1 et al. (3)	3185	17, 18—9—79	25.070	Do.
5214	Proserpine et al. (2)	3157	19, 30—9—79	10.413	Do.
5228	Wisconsin	3174	6—9—80	10.330	St. Kevin.
5229	Iron Hat	3198	6—9—80	10.330	Do.
5242	Finis et al. (4)	3596	17, 18—9—79	33.808	California.
5252	Treasurer	3286	19, 30—9—79	2.047	Do.
5255	Pawnolos No. 4 et al. (3)	3364	17—9—79	30.990	Do.
5263	F. M. C	3309	6—9—80	10.330	St. Kevin.
5271	Little Link	3317	24—9—81	6.402	Sugar Loaf.
5282 am	Roy No. 1 et al. (6)	3162	17, 20—9—79	58.730	California.
5289	Mammoth				
5296	Arabi Bey	3171	19—9—79	.560	Do.
5299	Hattie Clark No. 2 et al. (3)	3242	28—9—79	26.810	Do.
5307	Iron Duke	3211	12—9—81	10.330	St. Kevin.
5325	Patience et al. (4)	3183	15—9—79	41.320	California.
5347	Monitor No. 1 et al. (20)	3342	16, 17—9—79	202.112	Do.
5356	Hill	3369	36—9—79	10.330	Do.
5357	Silver Chief	3370	36—9—79	8.071	Do.
5405 am	Equitable et al. (6)				
5405	Blue Ribbon et al. (8)	3331	16, 21—9—79	65.242	Do.
5406	Cloud City				
5422	Evans No. 1 et al. (2)	3263	17—9—79	14.500	Do.
5423	Silver Dollar No. 1 et al. (2)	3264	18—9—79	11.796	Do.
5436	Alice R	3482	1—9—81	9.253	St. Kevin.
5494	T. P. M	3354	25, 6—9—79	10.330	California.
5525 am	Pawnolos No. 4 et al. (3)				
5531	Mammoth	3224	26—9—79	10.330	Do.
5541	Carr	3348	25—9—80	6.286	Do.
5548	Climax et al. (3)	3347	1, 2—10—79	28.617	Empire Gulch.
5558	Independence et al. (3)	3278	35—8—80	30.993	Birds Eye.
5561	Little Nellie placer				
5563	Colorado Belle placer	3424	27, 26, 28—8—79	156.270	English.
5594	Iron Mask	3239	7—9—80	10.330	St. Kevin.

[a] Canceled; no patent.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
5596	Hidden Treasure	3625	25—9—80	1.174	California.
5631	Triangle	3260	30—9—79	.344	Do.
5640	Crown Point	3340	18—9—80	8.238	Do.
5644	Tripoli et al	3238	22, 23, 26, 27—10—79	41.320	Union Gulch.
5645	Pauline et al. (4)	3287	11—10—79	40.634	Empire Gulch.
5649	Wintry	3329	6—9—80	9.666	St. Kevin.
5650	Julia et al. (4)	3343	31—8—80; 6—9—80	30.993	Do.
5662	Diamond and Harrison (2)	3299	21, 22—9—79	12.398	California.
5664	October	3262	30—9—79	.118	Do.
5665	Eighty Eight	3261	30—9—79	1.305	Do.
5682	S. D. and Q. D. (2)	3327	22—9—79	20.660	Do.
5691	Two Brothers et al. (5)	[a] 3400			
5692	Clyde	3746	2—10—79	4.921	Empire Gulch.
5694	Paterson	3392	8—10—79	10.307	Do.
5697	Massive placer	3362	26, 27—9—80	160.000	California.
5701	Elbert placer	3361	33—9—80	132.256	Do.
5711 am	Cornelius	3470	29, 30—9—79	.680	Do.
5729	Zeolite	3272	24—9—81	8.303	Sugar Loaf.
5740	Nanny Catch et al. (5)	3268	33—9—79	33.000	California.
5764	Oil'd Irishman et al. (3)	3578	18, 19—9—80	22.643	Sugar Loaf.
5786 am	Crouse et al. (13)	3993	12, 13—9—79	104.290	California.
5802	Sidney and Melburn (2)	3273	31—8—80	9.531	St. Kevin.
5843	Houlton placer	3276	7—9—79	29.730	California.
5848	Abel	3274	31, 32—8—80	9.624	St. Kevin.
5876	Retort				
5919	Hector placer	3451	32—8—79	47.894	California.
5953	Mayflower and Sunflower (2)	3546	30—9—79	6.073	Do.
5995	M. A. P	3674	6—9—80	2.397	St. Kevin.
5996	Tontine	3498	26—9—79	10.330	California.
5997 ab	Peak Lode and Palisade mill site (2)	3352	25—9—79	15.125	Do.
6020	Woodland et al. (5)	3301	8—10—79	46.792	Empire Gulch.
6022	Horse Shoe Prince	3409	36—9—79	10.3245	California.
6042	Huckleberry	3351	6—9—80	7.288	St. Kevin.
6057	Gemini No. 1 et al. (2)	3353	25—9—79	20.660	California.
6069	Red Cap	3517	10—9—80	10.330	Tennessee Park.
6076	Eureka et al. (3)	3318	33—8—79	25.045	Birds Eye.
6087	Keystone	3335	6—9—80	9.179	St. Kevin.
6091	Caribou	3443	19—9—80	5.098	Sugar Loaf.
6140	Yellow Jacket	3325	31—8—80; 6—9—80	7.453	St. Kevin.
6164	Unknown et al. (5)	4485 3479	26—9—79	46.368	California.
6173	Molly et al. (4)	3402	4—10—79	21.801	Empire Gulch.
6180	Collier and Lewis	3328	12, 13—8—79	9.397	Alicante.
6188	Reynolds and Taylor (2)	3410	36—9—79	17.127	California.
6190	Satellite	3422	2—10—79	10.330	Empire Gulch.
6210	Redwood et al. (5)	3408	8, 9—10—79	43.949	Do.
6211	Ruby	3836	18—11—81	10.330	Lake Creek.
6232	Silver Wheel et al. (3)	3414	8—10—79	21.778	Empire Gulch.
6260	Midland	3583	13—9—81	10.100	Sugar Loaf.
6279	Xmas	3520	28, 29—9—79	6.448	California.
6291	O. Z.	3391	24—9—80	2.450	Do.
6333	Augusta No. 2				
6334	Grand View	4616	1—9—81	9.550	St. Kevin.
6357	Iron	3438	10, 15—8—80	10.330	Homestake.
6379	Alice and Marjory (2)	3601	31—9—79	7.980	California.
6380	S. C. B.	3600	31—9—79	2.538	Do.
6391	A. V. B. and Valentine	3589	24—9—80	2.465	Do.
6397	Peggy McCallum	3598	20—9—79	2.910	Do.
6404	Tingle Tangle	3439	26, 35—9—79	10.326	Do.
6454	Equator	0459	9—79	9.5	Do.
6455	Slide	4885	36—9—79	2.810	Do.
6459	Galbolinsky	3606	35—9—79	10.052	Do.
6462	Black Cloud	3733	16, 17—11—81	10.330	Twin Lakes.
6464	Free Coinage et al. (2)	3590	33—9—79	7.549	California.
6466	Frank	4473	32, 33—9—79	4.973	Do.
6478	Supervisor et al. (8)	3532	25—9—79	79.761	Do.
6490	Fourth of July	3531	36—9—79	3.582	Do.
6503	Jim Blaine	3624	4—10—79	9.662	Empire Gulch.
6508	Silver Cliff	3699	35, 36—9—79	10.133	California.
6518	Extension Copper King	3835	13, 24—9—81	10.331	Sugar Loaf.
6528	Rachel	3472	36—8—81; 1—9—81	10.331	St. Kevin.
6579	Lone Star et al. (2)	3544	27—11—81	19.795	Twin Lakes.
6590	Summit and Summit No. 2 (2)	3575	36—9—79	20.156	California.
6649	Panama and Mason (2)	3549	8—10—79	19.663	Empire.
6650	Snow	3488	6—9—80	6.503	St. Kevin.
6663	Smuggler	3523	31—8—80	9.980	Do.
6664	Hattie K	3524	31—9—80	10.320	Do.
6670	Ocean Wave	4547	18—9—80	10.218	Do.
6727	Little Joe	3554	13, 14—11—81	10.134	Twin Lakes.
6728	Avalon	3589	19—11—81	7.456	Do.
6729	John Wannamaker et al. (2)	3555	18—11—81; 13—11—82	20.662	Do.
6757	Thistle et al. (2)				
6758 a. b.	A. M. Thomas et al. (5)	3710	18, 19, 20—11—81	46.066	Do.
6759	Sumac	3866	18—11—81	10.331	Do.
6760	Centennial				
6765	Hildegarde et al. (2)				
6774	Nora and Ground Hog (2)	3574	26—9—79	20.662	California.
6804	Little Comstock	4913	19—9—80	10.331	Do.
6826	Inspector				
6834	Edna Dolloff	3559	18—9—79	4.5795	Do.
6843	Carbonate King				
6855	Lincoln	3745	23, 26—11—81	10.330	Twin Lakes.
6880	Crytogram	3581	32—8—80	10.330	St. Kevin.
6884	Black Hawk	3647	11—9—81	10.330	Do.
6885 a. m.	St. Jo	3744	11—9—81	9.234	Do.
6900	May Queen	3692	19—9—80	6.954	Sugar Loaf.
6918	Midland	3618	25—9—80	1.663	California.
6919	Merrimac No. 1 et al. (3)	3999	17—9—79	26.870	Do.
6920	Diamond Field	3871	36—9—79	4.408	Do.
6931	White Quail et al. (3)	3961	15, 16, 21—11—82	28.547	Red Mountain.
6932	Gold Bug et al. (3)	3962	15—11—82	30.779	Do.

[a] Canceled; no patent.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
6933	Elmira placer	[a] 3963	15—11—82	160.000	Red Mountain.
6949	Silver Issue et al. (2)	3588	31—8—80	19.939	St. Kevin.
6965	Capitol et al. (4)	0186	24—9—80	35.590	California.
6971	Minnie placer	3585	10—8—79	70.617	Alicante.
7003	Storm King	3582	1, 2—9—81	10.320	St. Kevin.
7005	Riffle	3685	24—9—81	1.890	Sugar Loaf.
7014	Texas Star	3730	16—11—82	10.253	Red Mountain
7018	Idaho	3576	30—9—79	1.100	California.
7071	Last Batch	0491	9—79	6.337	Do.
7124	Silver Anchor	3702	18—9—79	7.104	Do.
7125	Helen and Native Silver (2)	3608	4, 9—10—79	14.600	Empire Gulch
7141	Jew	3036	21—9—79	1.482	California.
7142 a. m	Silver King et al. (4)	3623	4—10—79	30.280	Empire Gulch
7180	Harry D. et al. (15)	4016	15, 16—9—79	154.793	California.
7197	H. M. L. et al. (4)	3704	8, 17—10—79	40.807	Empire Gulch
7210	Bullion	3636	27—9—79	10.331	California.
7226	Little Monia				
7230	Fickle	3731	25—9—80	8.118	Do.
7233	Jack	3644	8—10—79	10.300	Empire Gulch.
7242	Reliable	4090	25—8—79	4.213	Alicante.
7256	Connection	3970	18—9—79	5.602	California.
7259	La Plata et al. (3)	3680	23—8—79	30.993	English Gulch.
7269	Hope	3709	23—9—81	7.753	Sugar Loaf.
7294	Spar	3671	31—8—79	10.331	Buckeye.
7306	Buffalo et al. (5)	3831	31—9—79	19.519	California.
7314	Florida et al. (9)	4003	7, 18—9—79	64.400	Do.
7316	Minnie et al. (8)	4020	25—9—79	82.640	Do.
7344	Little Nellie and Little Maud (2)	4011	19—9—80	20.660	Sugar Loaf.
7355	Little Eva and Willie S. (2)	3987	35—10—79	20.660	Union Gulch.
7382	Oskaloosa	3953	7—9—80	9.956	Do.
7557	Gordon and Bengal Tiger (2)	3792	13, 23, 24—11—81	18.453	Twin Lakes.
7572	Buckskin et al. (3)	3753	13, 23, 24—11—81	28.718	Do.
7579	Gulch and Geneva (2)	3881	33—9—79	9.646	California.
7581	Fairplay	3727	2—10—79	5,593	Empire Gulch.
7620	Basin	3700	27—9—79	10.331	California.
7725	Keystone et al. (4)	3739	32—9—79	33.661	Do.
7759	Leadville et al. (5)	3743	31—9—79	56.474	Do.
7868	Phenix				
7875	Kearsage et al. (3)	4144	13, 24—11—81	23.555	Twin Lakes.
7899	Pickaway et al. (4)	3814	8—80; 6—9—80	27.501	St. Kevin.
7926	Lone Hand	3844	24, 25—11—81	10.330	Twin Lakes.
7928	Ypsilanti No. 2	4489	24—9—80	1.652	California.
7933	Mauch Chunk et al. (3)	3780	36—9—79	27.408	Do.
7997	Alice S.	3819	8—10—79	10.282	Empire Gulch.
7998	Silver Chief et al. (4)	3842	2—10—79	40.620	Do.
8015	Mikado	4007	22, 23—9—79	9.250	California.
8036	Margaret	3791	21, 28—9—79	2.055	Do.
8040	Little Joe	3813	18, 19—11—81	10.067	Twin Lakes.
8052	Mary Murphy	4201	30—9—79	3.788	California.
8060	Michigamme	4122	18—9—80	9.633	St. Kevin.
8201	Horace et al. (5)	3852	21—9—79	30.752	California.
8215	San Francisco	3796	18—9—79	5.880	Do.
8232	Evening Star	3860	1—9—81	9.539	St. Kevin.
8248	Pilgrim	3867	32—9—79	4.141	California.
8249	Little Alice	3801	27—9—79	8.114	Do.
8300	J. H. & P. C. (2)	3911	18, 17—9—79	6.435	Do.
8328	Pioneer	4271	29—11—79	10.330	Granite.
8361	Bank Placer	4558	33—9—80	118.967	California.
8457	Club	3873	19—9—79	0.719	Do.
8466	Onota No. 2	3874	20—9—79	1.932	Do.
8469	Hamburg	3880	21—9—79	1.763	Do.
8509	Theodolite No. 1 placer				
8512	Theodolite No. 3 placer				
8514	Putman	3840	28, 29—9—79	2.700	Do.
8515	Minnetonomah	3845	6—9—80	4.214	St. Kevin.
8521	Scraps	3841, 5133	28—9—79	3.015	California.
8536	Belle of Granite	4028	30—11—79	8.910	Granite.
8554	Goldsmith and Thistle (2)	3854	18—11—81	7.766	Twin Lakes.
8576 a. b	Theodolite No. 9 et al. (4)	3912	35—10—82; 2—11—82	30.180	Lackawanna.
8594	Ovens	3840	19—9—79	.790	California.
8595	Newhall	3865	27—8—79	10.168	English Gulch.
8613	Garnet et al. (3)	3850	7—9—79	27.960	California.
8621	Saginaw City	3864	19—8—78	10.262	Alicante.
8650	Overlooked	3857	21—9—79	2.928	California.
8658	Walter Scott et al. (7)	3879	18, 19—8—78; 13—8—79	99.279	Alicante.
8727	Sheridan	3875	29—9—79	5.915	California.
8728	Norway	3863	31—10—81	10.331	Half Moon.
8779	New Year	3878	28—11—79	10.232	Granite.
8817	Little Tom	3892	14—11—81	4.586	Twin Lakes.
8835	Mountain Line No. 2 et al. (4)	3885	28—9—79	26.672	California.
8881	Omega	3896	19—9—79	.968	Do.
8891	Ingomar et al. (4)	3902	20, 29—9—79	14.877	Do.
8942	President	4026	20—9—79	10.330	Do.
8979	Argentum No. 1 et al. (2)	3891	28—9—79	5.265	Do.
8980	Ophir No. 1 et al. (2)	4018	27, 28—9—79	13.871	Do.
8982	Grover Cleveland	5267	9—79	3.729	Do.
8990	Terrible No. 1 et al. (4)	4002	21, 28—9—79	14.910	Do.
8991	Gold Ledge	5311	9—79	3.281	Do.
8996	Pembinah	3951	27—9—79	5.000	Do.
8999	Rex et al. (4)	3890	32—9—79	20.299	Do.
9010	Evansville et al. (4)	3968	27—9—79	39.815	Do.
9039	Chloride	3907	33—9—79	3, 274	Do.
9073	Monarch	4131	25—8—79	10.331	English Gulch.
9074	Queen City	4132	25—8—79	10.331	Do.
9078	Powderly	3901	18—9—79	5.551	California.
9099	Lincoln and Joiner (2)	3900	29—9—79	2.765	Do.
9105	Plaza				
9111	Rose Placer	4019	61, 17—9—79	117.206	Do.
9112	Vega No. 1 et al. (9)	3927	15—9—79	84.067	Do.

[a] Canceled; no patent.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
9119	Annie C. et al. (4)	5358	9—79	32. 209	California.
9177	Crown Point et al. (8)	3908	15, 16—9—79	72. 317	Do.
9208	Hokitaka	3909	31—9—79	2. 240	Do.
9234	Eulalia et al. (2)				
9248	Acme and Villa	019	24—9—80	16. 943	Do.
9254	Liddia	4985	26—9—79	8. 582	Do.
9261	Spot Cash	3921	21—9—79	1. 454	Do.
9269	Resurrection No. 1 et al. (15)	3972	22—9—79	148. 169	Do.
9274	Markt Jr. et al. (3)	3922	8—10—79	22. 837	Empire Gulch.
9275	Elk No. 1 et al. (10)	3935	31—9—79; 6—10—79	100. 780	Do.
9277 am	Dives et al. (3)	4155	32—9—79	20. 715	California.
9281	Manhattan et al. (5)	4107	(See 9292)		
9286	Empire et al. (6)	3990	8—10—79	50. 291	Empire Gulch.
9292	Manhattan et al. (10)	4107	31, 32—9—79; 5—10—79	85. 466	Do.
9293	Larkin	3923	8—10—79	6. 764	Do.
9294	Rhode Island et al. (6)	3979	5—10—79	59. 832	Do.
9300	Davis No. 1 et al. (5)	4085	16—9—79	10. 247	California.
9301	New Buffalo and Carleton (2)	4038	5—10—79	15. 690	Empire Gulch.
9303	Mickey Joys				
9304	Tyrant	3931	33—9—79	7. 046	California.
9309	Yellow Jacket	3918	13—11—81	9. 123	Twin Lakes.
9316	Defiance No. 1 et al. (4)				
9318	Governor Waite et al				
9319	Marshall	3947	4—10—79	9. 327	Empire Gulch.
9324	Antonetta	4160	20—9—79	6. 330	California.
9347	James	3937	8—10—79	7. 701	Empire Gulch.
9351	Sedan and Metz (2)				
9352	Gold and Silver	4083	27—9—79	5. 205	California.
9353	Mary and Beryl (2)	3930	4, 5, 8, 9—10—79	19. 061	Empire Gulch.
9361	Unicorn No. 1 et al. (12)	3942	22, 23—10—80	112. 410	Do.
9362	Dick Bland et al. (3)	4123	5—10—79	24. 192	Do.
9371	Eveline Walsh et al. (2)	3992	4, 5—10—79	18. 528	Do.
9372	Little Ed. et al. (6)	3929	8, 17—10—79	58. 385	Union.
9373 am	Content et al. (3)	3973	15, 22—9—79	21. 133	California.
9377	Angora placer	4034	16—9—79	58. 930	Do.
9379	American	4193	32—9—79	1. 091	Do.
9387	Baltimore	3943	17—10—79	10. 331	Union Gulch.
9390	Chicora et al. (2)	4879, 4944	20—9—79	3. 514	California.
9393	Deer Foot				
9405	Nellie Fay	4041	27—9—79	10. 317	Do.
9413	Golden Eagle	3950	8, 17—10—79	8. 041	Union Gulch.
9414	Mud Sill et al. (4)				
9415	Kauffman	3969	33—9—79	2. 071	California.
9422	Ready Cash et al. (6)	3949	9, 16—10—79	61. 986	Union Gulch.
9424	Pussy et al. (16)	4094	14, 15, 23, 22—10—79	152. 527	Do.
9432	Mayflower et al. (3)	4060	8, 17—10—79	21. 509	Do.
9440	Rustler	3940	4—10—79	7. 985	Empire Gulch.
9441	Golden Rod	055	20—9—79	4. 089	California.
9443	Colorado No. 1 et al. (21)	4102	26, 27, 34, 35—10—79	213. 168	Union Gulch.
9444	Little Dot	4000	32—9—79	1. 974	California.
9448	Belle of the West et al. (4)	4488	27—9—79	29. 272	Do.
9468	Defiance No. 5				
9470	Mineral and Puzzler (2)	3957	21, 22—9—79	7. 883	Do.
9482	Great Wyoming et al. (6)	4166	8, 17—9—79	55. 358	Do.
9489	Yalu	3952	21—9—79	3. 959	Do.
9492	Little Iowa	4105	32—9—79	2. 496	Do.
9497	Hard Times and Good Times (2)	3965	22—9—79	15. 186	Do.
9509	Argonaut	4010	32—9—79	8. 086	Do.
9510	Birdie C				
9512	Ajax et al. (11)	3978	6—10—80	112. 808	Sugar Loaf.
9522	Whip	3981	29—9—79	1. 896	California.
9530	Eclipse	4221	29, 32—9—79	6. 279	Do.
9533	St. Julien	3975	28, 33—9—79	9. 315	Do.
9537	Part of Chieftain				
9539	Ruth and Rose	3960	33—9—79	5. 329	Do.
9551	Rose et al. (3)	4065	9—10—79	21. 008	Union Gulch.
9552	Zebra	3955	20—9—79	9. 241	California.
9566	Monte Christo	4048	29—11—79	10. 331	Granite.
9581	Brown	4108	13—9—80	10. 139	California.
9583	Part of May Queen	3981	19—9—79	. 386	Do.
9585	Equator et al. (3)	4422	15—9—79	21. 120	Do.
9649	Cleveland	3996	14, 23—11—81	9. 089	Twin Lakes.
9664	Four Per Cent	4392	13, 24—9—80	4. 219	California.
9676	Jason	4998	24—9—80	7. 202	Do.
9702	Hard Chance and W. G. (2)	4009	8—10—79	20. 561	Empire Gulch.
9716	Fairy Eitel No. 1 et al. (3)	4118	4, 9—10—79	30. 370	Do.
9725	Nestegg	3982	9—10—79	6. 059	Do.
9739	Hard Luck et al. (3)	4071	35—9—79	28. 907	California.
9743	Fairview	3980	22—9—79	10. 330	Do.
9747	Coleman	4021	20—9—79	1. 446	Do.
9796	M. E. C	0715	24—9—80	1. 922	Do.
9846	Yuma	4020	18—9—79	4. 796	Do.
9864	Whale	4997	13, 24—9—80	8. 417	Do.
9865	Neptune	4996	24—9—80	8. 003	Do.
9894	Emma et al. (4)	4055	4, 5, 8, 9—10—79	29. 326	Empire Gulch.
9916	Omega No. 1 et al. (18)	4109	16—9—79	163. 502	California.
9918	Luzerne	4731	24—9—80	1. 498	Do.
9923	Tokio	4147	21—9—79	1. 007	Do.
9935	Berlin No. 4 et al. (4)	4082	34, 35—10—79	41. 015	Union Gulch.
9936	Palmer	4066	33—10—79	10. 330	Do.
9939	Bi-Metallic No. 1 et al (10)	4067	23—10—79	93. 991	Do.
9958	Smuggler and Star of Hope	4076	30—9—79	8. 000	California.
9995	Friday et al. (5)	4031	5—10—79	19. 272	Empire Gulch.
10009	Columbine	4059	18—9—79	10. 115	California.
10084	Joe No. 3	4040	22—9—79	6. 170	Do.
10087	Little May	4073	29—9—79	. 989	Do.
10090	Saginaw Valley No. 1 et al. (3)	4039	22—9—79	25. 345	Do.
10098	Essie et al. (3)	4042	17—9—79	19. 272	Do.
10127	Alexander placer				
10171	Gold Buckle et al. (5)	4044	2, 11—10—79	51. 650	Empire Gulch.
10183	Little Mollie et al. (10)	4064	5—9—79	103. 310	California.
10210	La Juanita	4054	13—9—80	2. 044	Do.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
10230	Golden Eagle et al. (3)	4078	4, 5—10—79	16.988	Empire Gulch.
10345	Florence No. 1 et al. (3)	4120	15, 22—9—79	22.853	California.
10354	Little Maggie No. 1 et al. (2)	4173	16—9—79	20.662	Do.
10382	Yalu No. 2	4223	21—9—79	4.912	Do.
10389	Mary et al. (9)	4087	7, 8—9—79	92.978	Do.
10412	Zoo	4057	13—9—80	8.230	Do.
10448	Vestibule et al. (4)	4058	8, 9—10—79	40.952	Empire Gulch.
10511	Wandering Refugee	4127	5—10—79	9.302	Do.
10512	Kansas Boy	4128	5—10—79	8.753	Do.
10771	Favorite and Blanche (2)	4117	21—9—79	4.531	California.
10807	Minnesota et al. (5)	4088	14—10—79	42.416	Union Gulch.
10840	Lafayette No. 1 et al. (4)	4595	14—9—79	41.014	California.
10844	Seigniorage et al. 12	4409	23, 27—9—79	88.680	Do.
10872	Mary				
10987	Monarch				
11051	John J. No. 1 et al. (7)	4072	15—9—79	61.539	Do.
11052	"A." et al. (6)	4408	22—9—79	56.228	Do.
11121	Blue Belle No. 1 et al. (8)	4130	22—9—79	62.165	Do.
11126	Union	4101	24—9—80	.474	Do.
11187	Onondaga	4195	29—9—79	7.522	Do.
11206	Honest Dollar	4103	19—9—79	4.466	Do.
11237	Fourth of July No. 1 et al. (4)	4183	16—9—79	40.060	Do.
11238	Commet et al. (9)	4170	13—9—80	75.416	Do.
11264	Gold Belt No. 1 et al. (3)	4217	11, 14—9—79	30.990	Do.
11265	Augusta No. 1 et al.	4216	11, 14—9—79	29.750	Do.
11286	Hubert	4146	21—9—79	1.139	Do.
11296	Bertha	4342	12—9—81	10.331	St. Kevin.
11297	General Grant et al. (2)	4191	8, 17—9—79	20.054	California.
11323	Steam Boat and Pilot (2)	4137	17—9—79	20.558	Do.
11329	Clipper	4143	7—9—79	9.470	Do.
11341	G. L. N	4486	18—9—79	3.918	Do.
11353	E. C	4141	13—9—80	4.647	Do.
11357 am	Virginia Dare and Mina (2)	[a] 4398	12—9—81	18.592	St. Kevin.
11359	County Line	4132	11—10—79	7.748	Union Gulch.
11375	Stanton No. 1 et al. (2)	4133	22—9—79	15.956	California.
11382	McGoff's Last Chance	4142	33—9—79	.458	Do.
11390	Julia V	4203	24—9—81	9.866	Sugar Loaf.
11396	Cleaves placer	4152	33—8—79	38.126	Birds Eye.
11421	Dexter et al. (7)	4213	17, 19, 20—11—82	70.198	Red Mountain.
11436	Little Bob	4192	21—9—79	.470	California.
11443	Cliff	4212	26—11—81	10.331	Twin Lakes.
11446	Diamond et al. (2)				
11468	Misanabie et al. (2)	4112	15, 16—9—79	16.280	California.
11478	Mule Skinner	4211	24—11—81	10.331	Twin Lakes.
11479	Lonney C. and Edward E. (2)	4209	24—11—81	20.662	Do.
11480	Jack Whacker	4210	24—11—81	10.331	Do.
11485	Whale et al. (3)	4175	11—10—79	30.879	Empire Gulch.
11492	Cornucopia				
11501	C. M. Fraction	4213	33—9—79	2.954	California.
11555	Gold Spoon No. 1 et al. (2)	4159	34—9—79	15.858	Do.
11567	Eclipse No. 1 et al. (5)	4150	14—9—80	40.248	Do.
11614	John Lawrence	4178	34—8—79	10.330	Birds Eye.
11617	Pharmacist No. 1 et al. (2)	4265	19, 30—9—79	1.198	California.
11622	Sequah et al. (9)	4167	13, 14—9—80	68.833	Do.
11657	Alpine	4162	27—9—79	9.290	Do.
11668 a. b	W. J. Bryan				
11682	John Reed et al. (10)	4172	12, 13—8—79	89.034	Alicante.
11698	Grover Cleveland	4168	31—9—79	6.993	California.
11701	Honest John No. 1 et al. (4)	4185	8—9—79	33.764	Do.
11715	C. K. and Quincy (2)	4245	35—10—79	15.561	Union Gulch.
11721	Hennesy	4165	24—9—81	2.242	Sugar Loaf.
11741	Easton and Weston (2)	4270	13—9—80	12.356	California.
11770	Cayuga placer	4524	23—9—80	12.835	Do.
11771 am	Brown placer	4182	23—9—80	78.323	Do.
11777	Bow	4180	21—9—79	3.139	Do.
11809	Extended Hope	4188	35—10—79	8.437	Union Gulch.
11873	Ticket Broker No. 1 et al. (3)	4219	14—9—79	24.362	California.
11878	Laundry	4190	17—10—79	10.331	Union Gulch.
11894	Katie H	4289	22—9—79	2.691	California.
11934	Clark No. 1 et al. (3)	4341	11—9—81	30.921	St. Kevin.
11942	John A. Logan				
11947 am	Ruby	4220	35, 36—10—79	2.500	Union Gulch.
11998	Claremount	4261	16—9—79	7.705	California.
12046	Chieftain	4312	29, 31—11—79	7.970	Granite.
12054	Collin Campbell	4313	35, 36—10—79	10.323	Union Gulch.
12064	Strike	4256	19, 20—9—79	.452	California.
12065	Berlin No. 1 et al. (3)	4264	35—10—79	29.146	Union Gulch.
12067	James	4353	32—9—79	.866	California.
12071	Eddie et al. (3)	4279	32—9—79 5—10—79	12.356	Do.
12076	Frank et al. (3)	4267	35—10—79	25.480	Union Gulch.
12077	Can				
12079	Diamond S. et al. (6)	4276	10, 15—9—79	58.083	California.
12090	Collin Campbell No. 2	4417	35, 36—10—79	10.307	Union Gulch.
12091	J. C				
12101	Louise D'Or et al. (9)	4393	13—9—80	64.283	California.
12126	Mosul	4260	35—10—79	9.494	Union Gulch.
12127	Portland and O. K. (2)	4288	13—11—82	20.662	Lake Creek.
12167	Board of Trade No. 1 et al. (11)	5052	9, 10, 15, 16—9—79	106.194	California.
12176	Anita et al. (10)	4222	1, 2—10—79	72.018	Empire Gulch.
12198	Alaska	4275	24, 25—9—81	8.250	St. Kevin.
12237	Helen Frances and Nina (2)	4287	15, 22—9—79	18.697	California.
12249	Rattler	4288	29, 30—8—79	10.331	Buckeye.
12264	Klondyke	4293	36—9—79	6.526	California.
12305	O. K. and Five Per Cent (2)	4391	13, 24—9—80	10.142	Do.
12310	Dispute	4319	21—9—79	2.646	Do.
12343	Intermural	4596	28—9—79	1.120	Do.
12370	Harris No. 1 et al. (5)	5027	14, 15—9—79	51.578	Do.
12389	Zanzibar No. 1 et al. (4)	0988	9—79	18.712	Do.
12443	Mary C. et al. (4)	[a] 4350			
12486	Polaris No. 1 et al. (3)	0257	9—79	5.702	Do.
12498	O'Malley No. 1 et al. (4)	4339	22, 25, 26, 27—9—79	40.400	Do.

[a] Canceled; no patent.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
12514	1898 No. 1 and 1898 No. 2 (2)	4487	14—9—79	16.235	California.
12587	Murray No. 1	4406	31, 32—9—79	4.754	Do.
12600	Webster	4389	19—9—79	.549	Do.
12626	Gold Chain No. 1 et al. (3)	4384	21—8—79	30.993	French Gulch.
12656	Hap Hazard No. 1 et al. (3)	4369	11—9—81	30.993	St. Kevin.
12657	Little Ed	4397	13—8—79	10.035	Alicante.
12658	Hazel et al. (6)	5020	8, 17—9—79	41.299	California.
12663	Nanticoke et al. (2)	4480	11—9—81	20.662	St. Kevin.
12675	Crown Point	4300	18—8—78	10.331	Alicante.
12713	C. T. L.	4416	24—9—80	.866	California.
12718	Pueblo et al. (6)	4394	22—9—79	36.534	Do.
12739	Lenora	4374	5—10—79	10.331	Empire Gulch.
12740	Jay Bird				
12747 am.	Clover	4451	21—9—79	.726	California.
12765	Lackawana Belle et al. (2)	4827	2, 11—11—82	20.662	Lackawanna.
12793	Morgan No. 1	5011	15—9—79	9.792	California.
12859	Aurora No. 1 et al. (2)	4415	33—9—79 4—10—79	15.308	Empire Gulch.
12867	Bartlett No. 1 et al. (5)	4791	11, 12, 14—11—81	51.655	Twin Lakes.
12882	Chautauquan	4430	21—9—79	1.474	California.
12885	High Line placer	4790	14—11—81	56.148	Twin Lakes.
12896 am.	Evansville No. 5 et al. (5)	4593	9, 16—9—79	51.588	California.
12905	McNulty No. 1 et al. (3)	4455	17—9—79	20.796	Do.
12993	Part of Searl placer				Empire Gulch.
13002	Board of Trade No. 1 et al. (4)	[a] 4418	5, 6—10—79	31.167	California.
13021	Yankee	[a] 4229	26—9—79	7.318	Do.
13046	V's	5217	25—9—80	3.827	
13047	Cowcumber				Do.
13097	Constance	4470	30—9—79	.549	Do.
13098	Chemita	4450	21—9—79	2.894	Do.
13167	Free Coinage	4780	30—9—79	1.829	St. Kevin.
13173	Anchor	4506	11—9—81	10,307	California.
13195	May placer	4572	17, 20—9—79	19.652	
13218	Katie				Do.
13228	Buglet	4550	32—9—79	1.697	Do.
13229	Onyx No. 1 and Onyx No. 2 (2)	4532	29—9—79	4.216	
13238	Volunteer	4466	21—9—79	2.359	Do.
13246	St. Mary et al. (2)	4461	16—11—82	15.155	Red Mountain.
13251	J. G. Fraction	4552	20—9—79	1.744	California.
13304	Aetna et al. (3)	4570	14, 23—9—79	30.474	Do.
13314	May D. No. 1 et al. (6)	4497	23—9—79	61.986	Do.
13340	Emma et al. (2)	4540	10—10—79	19.081	Empire Gulch.
13344	Medium	4641	20—9—79	4.752	California.
13400	Embolite	4517	20—9—79	2.264	Do.
13427	Birds Eye No. 1 et al. (6)	4515	10—9—79	61.986	Do.
13448	G. T. M.	4523	29—9—79	2.527	Do.
13520	Acacia	4534	4—10—70	10.180	Do.
13540	Secundus	4613	28—9—79	1.410	Do.
13591	Red Rock				
13599	Hoosier Boy et al. (2)	4556	12, 13—8—79	17.828	Alicante.
13691	Altamont No. 1 et al. (7)	4915	10—9—79	72.000	California.
13698	Golden and Cord (2)	4606	22, 27—8—79	20.149	English Gulch.
13702	Leadville et al. (6)	4787	8, 9—10—79	55.120	Empire Gulch.
13716	Bug No. 1 et al. (5)	4601	22, 27—8—79	43.944	English Gulch.
13717	Gloucester et al. (6)	4568	36—9—79	51.428	California.
13741	General Sheridan et al. (3)	4640	8, 17—9—79	30.893	Do.
13754	The Little Joe mill site	4672	24—11—81	5.000	Do.
13761	Ralph	4629	29—9—79	.706	Do.
13776	Zion No. 3	4578	11—9—80	10.331	Do.
13778	Governor	4786	2—9—79	10.331	Birds Eye.
13840	Bohen and Lane No. 1 et al. (3)	4621	35—10—80 2—11—80	30.606	Union Gulch.
13850	Cecil et al. (5)	4592	7, 8—10—79	47.213	Empire Gulch.
13887	Don No. 1 et al. (3)	4581	14, 23—9—79	30.865	California.
13905	L. W. and F. B. fraction	4628	27—9—79	1.716	Do.
13940	Woodbine	4646	18—9—79	2.544	Do.
13942	Greater New York No. 1 et al.	4600	26, 27—9—79	45.550	Do.
13951	Miller	0411	2—11—82	9.349	Lackawanna.
13969	K. C. et al. (6)	4793	14—9—81	32.294	Sugar Loaf.
14079	Bo	4714	18—9—79	2.101	California.
14099	Little Nancy	4591	19—9—80	10.331	Sugar Loaf.
14189	Mark	4649	13—9—80	2.608	California.
14192	American Eagle et al. (2)	4623	16, 17—11—81	9.470	Twin Lakes.
14248	Little Annie	4620	25—11—80	7.619	Granite.
14268	Boa	4715	18—9—79	3.969	California.
14277	Maude F.	4633	29—11—79	10.290	Granite.
14278	Venture	4632	28—11—79	10.331	Do.
14291	Vesuvia et al. (2)	4647	4—10—79	17.811	Empire Gulch.
14294	Tom et al. (3)	5186	13—9—80	16.479	California.
14295	Benson No. 1 et al. (4)	4635	8—9—79	39.849	Do.
14310	A. L. S.	4648	18—9—79	1.022	Do.
14321	Walker et al. (4)	4709 4968	22—9—79	34.041	Do.
14333	Great Hope No. 1 et al. (8)	4654	35, 36—10—79	79.125	Union Gulch.
14336	Climax	5063	18—8—78	10.330	Alicante.
14338	Hugh	4636	19—9—79	.314	California.
14341	Olive Branch No. 2 et al	[i] 4779	13—8—79	11.771	Alicante.
14406	Prince of Wales	4783	18, 19—9—79	6.320	Sugar Loaf.
14413	Little Louise et al. (21)	4656	22, 26, 27—8—79	160.912	English Gulch.
14436	Clover Leaf	4653	21—9—79	1.548	California.
14465	Lucy No. 1 et al. (2)	4693	2—10—79	16.516	Empire Gulch.
14482	Rankin	4676	10—9—79	9.873	California.
14508	M. S.	4774	24—9—80	.950	Do.
14514	Bismark et al. (3)	4657	22—8—79	30.993	English Gulch.
14534	W. J. Bryan	4673	5, 8—10—79	10.331	Empire Gulch.
14604	Lulu B. et al. (3)	4683	35—8—80	30.993	Tennessee Park.
14614	Esther	4675	21—9—79	.262	California.
14616	May Day No. 1 et al. (2)	4688	35—10—79	20.550	Union Gulch.
14636	Nettie S. placer	5178	15—9—79	13.821	California.
14677	C. and S. No. 1 et al. (9)		7, 8—9—79	92.690	Do.
14685	Nellie et al. (3)	4687	25, 26—8—80	30.978	French Gulch.

[a] Canceled; no patent.

[i] Mill site canceled.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
14727	Winner	4691	19—9—79	0.945	California.
14741	South Down et al. (4)	4708	27, 34—8—79	39.911	French Gulch.
14769	T. O. M.	4760	20—9—79	1.659	California.
14769	J. I. M	4761	20—9—79	1.270	Do.
14769	J. A. C. K.	4883	20—9—79	4.113	Do.
14792	Maine No. 1 et al. (10)	4794	12, 13—9—79	60.024	Do.
14841	Banner				
14891	Mammoth	4729	21—8—79	10.331	Chalk Ranch.
14923	Mary et al. (4)	4936	7—9—79	26.749	California.
14925	Maid No. 1 et al. (4)	4773	7—9—79	31.809	Do.
14986	Isabelle No. 1 et al. (5)	4770	22, 23—8—79	51.638	English Gulch.
15010	St. Mary No. 1 et al. (2)		26—10—79	20.527	Union Gulch
15040	Burnice	4745	14—9—81	10.331	St. Kevin.
15054	Prince Rudolph No. 1 et al. (2)	5075	2—9—79	30.993	Birds Eye.
15076	Sterling et al. (6)	4919	3—9—79	61.986	Do.
15094	Union	4800	16—9—79	6.089	California.
15102	Faun	4781	18—9—79	.802	Do
15103	P. K. No. 1 et al. (3)	4769	5—9—79	28.610	Do
15105	Great Southern et al. (2)	5033	16—9—79	20.662	Do.
15110	St. Mary No. 1 et al. (2)	4788	26—10—79	20.527	Union Gulch.
15121	H. Alexander				
15169	C. W. No. 1 et al. (6)				
15173	Cornfield	4789	20—9—79	.862	California.
15176	J. F. W	4797	21—9—79	.023	Do.
15210	Queen of May et al. (2)	4798	11—9—79	20.494	Do.
15218	Grace	4947	26—9—79	5.525	Do.
15224	New Orleans	[a]4825	19—9—79	.369	Do.
15286	Point Breece	4822	15—8—80	10.330	Homestake.
15297	Bertha et al. (2)	5212	9—79	17.210	California.
15313	Hortense No. 2 et al. (2)	4821	23—9—79	20.662	Do.
15320	Mabel	4867	29—9—79	4.817	Do.
15336	Prince Frederick No. 1 et al. (2)				
15373	Michigan	4904	2—9—79	.940	Birds Eye.
15399	Stillings	4916	23, 24—9—81	7.866	Sugar Loaf.
15401	New Klondyke	4949	23, 24—9—81	8.746	Do.
15436	Little Alex	5115	15, 16—11—82	7.648	Red Mountain.
15437	Golden Fleece	4852	17—11—81	9.336	Twin Lakes.
15438	Last Rose	4851	17—11—81	10.331	Do.
15439	Camp Bird No. 1 et al. (2)	4853	17—11—81	19.618	Do.
15440	Camp Bird No. 3 et al. (2)	4854	17, 20—11—81	20.655	Do.
15453	Pan Handle et al. (2)	4943	20, 21, 28—8—79	17.583	Chalk Ranch.
15491	London Extension No. 1 et al. (6)	4984	35—8—79	61.410	Birds eye.
15507	Evin	4856	14—8—81	8.420	St. Kevin.
15509	Killarney et. al. (3)	5670	2—9—79	28.049	Birds Eye.
15548	Copper Prince	4872	23, 26—8—79	10.331	English Gulch.
15560	Imperial et al. (4)	4848	18—9—80	24.044	Do.
15599	Annie Merrill No. 1 et al. (9)				
15721	Extra	0713	9—79	4.292	Do.
15736	Philip No. 1 et al. (6)	5057	10, 11, 14, 15—9—79	60.092	Do.
15743	Big Johnnie No. 1 et al. (5)	4911	22—10—79	51.383	Union Gulch.
15803	Two Bit	4875	1, 2, 11, 12—11—80	9.167	Two Bit Gulch.
15817	Bunker Hill et al. (2)	4960	28—11—79	20.662	Granite.
15863	Lorraine Gibson et al. (4)	4933	29, 32—11—79	30.350	Do.
15864	Inez	01306	9—81	.924	Independence.
15865	Inez No. 1				
15871	Gertrude	4918	24—9—81	8.731	Sugar Loaf.
15880	Belle of Granite mill site	0526	29—11—79	5.0	Granite.
15908	Lady Alice	4950	33—9—79	1.164	California.
15926	Tartar				
15965	California	4920	29—11—79	10.331	Granite.
15991	News Boy	4962	21—9—79	.274	California.
16064	Greater New York B	4970	28—9—79	2.620	Do.
16106	Mary	5200	1, 2—10—79	7.730	Empire Gulch
16127	Orphan	4974	18, 19—9—81	10.259	Sugar L
16128	B. M. No. 1 et al. (2)	5076	11—9—79	20.662	California.
16167	Denver	4994	21—9—79	.057	Do.
16178	Northern	5112	14—8—81	10.203	St. Kevin.
16193	Bonnie Bell	4991	28, 29—11—79	8.902	Granite.
16210	Quaker				
16245	Cable	5034	31—9—79	10.015	California.
16266	General Lawton				
16267	Mamie Ross et al. (9)	5044	28, 32, 33—11—79	66.000	Granite.
16278	Dundee	4992	28, 29—11—79	9.243	Do.
16302	Murtha et al. (2)				
16313	Minnie S.				
16318	Spokane et al. (9)	5030	11, 14—11—81	89.690	Twin Lakes.
16320	Smuggler	5029	28, 29, 32—11—79	5.000	Granite.
16340	The Nellie placer	5041	24, 25—11—81	32.890	Twin Lakes.
16352	Miner et al. (9)	5042	23, 24—11—81	79.118	Do.
16358	Long et al. (23)	5033	11, 12—9—79	216.944	California.
16375	Eagle No. 1 et al. (2)	5138	4—10—79	16.159	Empire Gulch.
16386	The Seabright placer	[a]5031	12—11—81	25.760	Twin Lakes.
16417	Eleventh Hour et al. (5)	5167	28, 29—11—79	48.907	Granite.
16452	Nevada	5012	29—11—79	10.325	Do.
16454	Bland et al. (2)	5046	13, 24—11—81	16.109	Twin Lakes.
16593	Virginia	5086	30—11—79	10.331	Granite.
16604	Cosmopolitan et al. (14)	5095	3—9—79	127.385	Birds Eye.
16634	Providence No. 1 et al. (5)	5088	25—8—79	51.065	English Gulch.
16708	Blue Bird et al. (5)	5078	7—9—79	26.221	California.
16734	Gold Coin No. 1 et al. (4)	5074	10—9—79	40.060	Do.
16740	Mud	5125	13, 14—11—81	9.245	Twin Lakes.
16743	Dundaff	5082	7—9—79	9.539	California.
16788	Daisy	5140	19, 20, 29, 30—11—79	10.331	Granite.
16789	Little Albion	5113	18—9—79	2.008	California.
16790	Hot Spur	5144	1, 2—9—80	10.331	St. Kevin.
16802	Hummer No. 1	5103	24—8—79	10.331	Alicante.
16897	Bryan et al. (2)	5127	24—11—81	13.126	Twin Lakes.
16910	Zion No. 1 et al. (4)	5122	29, 32—8—79	40.019	Buckeye.

[a] Canceled; no patent.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
16912	Twin Brothers et al. (3)	5110	2—9—79	15.855	Birds Eye.
17042	Electric et al. (6)	5211	25—11—81	50.234	Twin Lakes.
17057	Manzanola No. 1 et al. (6)	----	----	----	
17089	Bonton et al. (4)	5204	13, 14—11—81	41.289	Do.
17154	Grace	5195	13, 24—9—80	8.470	California.
17155	Ella	5196	13, 24—9—80	7.576	Do.
17156	Vesuvius	0148	13, 24—9—80	7.699	Do.
17160	Iron Rose et al. (2)	5172	28—8—79	30.990	Buckeye.
17212	Raven	5256	30, 31—9—79	3.690	California.
17243	W. J. Bryan No. 2	5151	5, 8—10—79	10.220	Empire Gulch.
17248	Big Jim et al. (2)	5163	16—11—82	20.662	Red Mountain.
17250	Venus No. 1 et al. (4)	5224	33—9—79	41.324	California.
17256	Dominion No. et al. (21)	5244	31—9—79; 36—9—80	214.176	Do.
17268	Butterfly and Homestake (2)	5210	2—11—81	20.423	Twin Lakes.
17312	Ohio	5176	31—9—79	5.244	California.
17342	Stormy Petrel	5208	21—9—79	.478	Do.
17385	Pontiac	5193	15—9—79	3.597	Do.
17412	Blanche	5203	21—9—79	1.876	Do.
17437	Alice	5251	18—9—80	9.906	St. Kevin.
17449	Seabright Placer	5218	12—11—81	20.000	Twin Lakes.
17501	Willard et al. (3)	5239	28, 29—8—79	30.993	English Gulch.
17521	Iowa No. 1 et al. (5)	5205	36—9—79	40.82	California.
17542	Martha	5199	28, 29, 31, 32—11—79	9.656	Granite.
17619	Gertrude	9285	24—9—81	9.999	Independence.
17743	Great Eastern et al. (3)	5238	22, 27—9—79	21.249	California.
17839	Rocky Point	5313	30—9—79	.318	Do.
17841	Ausable	5266	30—9—79	.185	Do.
17884	Saturday	5274	28—9—79	.527	Do.
17906	A. B. C	5304	32—9—79	1.997	Do.
17915	Long No. 11	5273	11—9—79	10.331	Do.
17923	Yamagata	5344	21—9—79	.159	Do.
17925	Emerald	5298	21—8—79	10.331	Do.
17927	Croppy Boy et al. (7)	5281	20—8—79	71.833	Do.
17948	Great O'Sullivan	5297	30, 31—9—79	1.523	Do.
17968	Jenny June	----	23—8—80	10.24	Do.
17972	Santiago	5303	24—9—80	3.406	Do.
17998	Janet	----	----	----	
18013	Golden Gate No. 2 et al. (3)	5290	23, 24, 25, 26—8—80	30.271	Do.
18023	Friday	5310	28, 33—9—79	3.157	Do.
18045	Comstock et al. (8)	5314	29, 30—8—79	81.6	Do.
18048	Gold Hill	5364	9, 16—11—81	10.331	Lake Creek.
18067	Last Chance No. 1 et al. (7)	5325	17, 20—11—81	72.317	Do.
18112	F. X. O	5338	29—9—79	1.402	California.
18121	Lucky Baldwin	5332	20, 21—9—79	2.007	Do.
18132	Exchange No. 1 et al. (4)	5352	23, 24—8—80	41.324	Do.
18136	Adirondack	5329	30—9—79	.075	Do.
18137	Mulberry et al. (8)	5356	9, 16—9—79	64.928	Do.
18153	Idlewild et al. (3)	0534	14, 23—9—81	30.65	Independence.
18184	Lost Team	5342	30—9—79	2.58	California.
18189	Geo. F. Monahan et al. (2)	5343	2—9—79	16.528	Do.
18227 a. b	Confidence et al. (3 and mill site)	5362	7, 16, 17—11—81	21.602	Twin Lakes and Lake Creek.
18277	Sunnyside No. 1 et al. (4)	5341	31, 32—8—79	38.584	California.
18336	Little Maude	----	----	----	Half Moon.
18337	16 to 1	----	----	----	Do.
18338	Young American et al. (2)	----	----	----	Do.
18414	Parrott mill site	018	20—11—81	5	Lake Creek.
18415	Coyote	037	35, 36—10—79	9.863	Union.
18417	M. N	0128	20—9—79	.418	California.
18428	One Hundred & Halcyon (2)	085	18, 19—9—80	5.824	Independence.
18429	Delphian & Isthmian	----	19—9—80	5.824	Do.
18436	Gold Sulphide No. 1 et al. (10)	5360	31, 32—8—79	97.642	California.
18444	Emmet et al. (3)	5368	18, 19—11—81	22.244	Lake Creek.
18497	Golden Key et al. (5)	0545	16, 17—11—81	29.270	Do.
18590	Hand Saw	08	25—9—80	2.406	California.
18688	Last Chance	([a])	----	----	
18689	E. A. C	0185	19, 20—9—79	2.328	Do.
18710	Aurum	0458	21—9—79	.126	Do.
18814	Old Dan, Old Dan Nos. 2 and 3, and Sunnyside (4)	0556	13—11—81	34.94	Twin Lakes.
18829	Hudson	0653	30—11—79	10.331	Dewey.
18877	Genevieve	0753	35—9—79	10.311	California.
18878	Royal	0582	17—9—79	.449	Do.
18932	Almena	0594	19, 30—9—79	.057	Do.
18944	Dennis	0587	21—9—79	1.986	Do.
18960	September	0634	28—9—79	3.458	Do.
18969	Surprise	----	28—9—79	----	Do.
18975	D. & A. No. 5 et al. (5)	0626	9, 10—9—79	47.604	Do.
19017	Teddy Roosevelt	j 0680	8—81	10.331	Independence.
19115	Little Keystone	(a j)	24—9—81	----	Independence.
19134	Little Major	j 0718	24—9—81	10.331	Do.
19139	C. H. S. et al. (4)	j 0707	24—9—81	41.324	Do.
19149	Apex	j 0937	11—9—81	8.499	Do.
19184	Gold Plate No. 1 et al	(j)	9—81	----	Do.
19193	Golden Gate	0754	23—8—80	4.559	California.
19199	Roosevelt, Helen Gould, Rita M. Willow (4)	j 0756	24—9—81	34.194	Independence.
19231	Last Chance et al. (2)	j 0763	11—9—81	12.982	Do.
19248	Comstock No. 1 et al. (8)	0796	11—9—79	30.993	California.
19267	Little Pony	0818	27—9—79	2.312	Do.
19268	Ground Dog No. 1 et al. (2)	0819	27—9—79	18.794	Do.
19273	Canestota	0847	18—9—79	7.409	Do.
19287	Lanphier No. 1 et al. (17)	0851	5, 6, 7, 8—9—79	170.907	Do.
19287 am	Lanphier Nos. 8, 19, 20 (3)	----	----	----	
19289	Olga No. 2, Silver King and H. A. (3)	(j)	19—9—80 9—81	---- ----	Independence. Do.
19295	Lone Star et al. (3)	j 01078	7—9—79	22.718	California.
19297	Great Republic and Pitcher (2)	0832	19—9—80	15.781	Independence.
19209	Lady Margaret	0836	19—9—80	7.988	Do.
19314	Edna M	j 0848	24—9—81	6.814	Do.
19317	J. K	0856	28—9—79	5.855	California.
19318	Greater New York D	0845	27—9—79	10.013	Do.

[a] Canceled; no patent.

j Suspended.

Mining claims in Lake County, Colo., officially surveyed for patent from Sept. 10, 1870, to July 15, 1925—Continued

Survey No.	Name	Mineral entry No.	Location	Area (acres)	District or place
19333	Sangamon fraction and Quarto (2)	0872	32—9—79	8.008	California.
19357 a. b.	Acme et al. (9 and 3 mill sites)	01048	2, 3—11—82; j 10—82	a 66.984; b 15.	Lackawanna.
19365	Bessie H. and Brother (2)	j 0938	34—10—82	20.662	Do.
19423	Oriole	01043	30—9—79	.476	California.
19518	Dauntless et al. (2)	01185	16—11—81	41.182	Lake Creek.
19526	Humbug et al. (5)	01143	17—11—81	51.634	Do.
19529	Lone Star et al. (6)	j 01159	10—82; 1, 2—11—82	97.951	Half Moon and Lackawanna.
19544	Lillian et al. (2)				
19581	Logan	01238	16—9—79	.201	California.
19616	Mauser No. 1 et al. (2)	01253	3—11—82	38.701	Lackawanna.
19621	West fraction	01276	30—9—79	.142	California.
19634	Franklin	01505	31—9—79	.876	Do.
19660	Expansion	01354	5, 6—9—80	6.885	Independence.
19669 a. b.	Mount Champion No. 1 et al.	j 01365	36—10—82	10	Half Moon.
19730	Hawk No. 1 et al. (24)	01587	10—9—79	475.622	California.
19797	Vanderbilt	01855	19—9—79; 24—9—79	.981	Do.
19804	Texas	01940	10—9—79	.783	Do.
19810	Maggie fraction	01912	18, 19—9—79; 24—9—80	2.055	Do.
19835	Ozark No. 3 et al. (2)	01995	1, 2—11—82; j 10—82	41.322	Half Moon and Lackawanna.
19838	Inez	j 01942	24—9—81	1.345	Independence.
19847	Colonel Duggan	01998	6—9—80; j 9—81	18.698	Do.
19848	Annie G., Griffin No. 2, and Hilder	01997	6—9—80	35.09	Do.
19868	Shamrock	01987	2—9—79	20.116	California.
19909	Cliff	02162	18—8—78	10.331	Alicante.
19910	Miner's Dream and Gold King (2)	02163	18—8—78	29.697	Do.
19941	Mary Jane	02484	14, 23—11—81	20.661	Lake Creek.
19976 k	Climax No. 2	2405	12, 13—8—79	18.179	Alicante.
19978	Fox mill site	02411	27—11—81	5.000	Lake Creek.
19979	Liberty B	03120	12, 13, 14—8—79	18.436	Alicante.
19980 k	Rare Metal Nos. 12-17	02439	11, 12—8—79	49.487	Alicante, Cons. Tenmile.
20005	Mauser Nos. 3-10	02993	2, 3—11—82	155.046	Lackawanna.
20058	Walsh No. 1 et al. (3)	j 03231	9—81	57.416	Independence.
20065	T. M. Molybdenite Nos. 1, 2, and 5	03117	11, 12—8—79	55.907	Alicante.
20066	Bull Dog	03116	19—9—80; j 9—81	9.095	Independence.
20086	Atlas	j 03352	9—81	8.088	Do.
20156	Colima	j 03565	9—81	16.895	Do.
20197	Wheeler	j 03672	9—79	.011	California.
20157	Senah	j 03564	9—81	12.217	Independence.
20261	Kittie D.	03725	24—8—80	11.331	California.
20296	St. John				

j Suspended. k Partly in Summit Country.

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