Geology and Ore Deposits of the West Slope of the Mosquito Range

By CHARLES H. BEHRE, JR.

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By CHARLES H. BEHRE, JR.

ABSTRACT

This report deals with that part of the western slope of the Mosquito Range surrounding the city of Leadville in Lake County, Colo. The area is bounded by latitude 39°11′ and 39°17′ north, and longitude 106°10′30″ and 106°18′30″ west. The eastern edge, adjoining the Alma mining district, is formed by the crest of the Mosquito Range. Beyond the western boundary is the Arkansas River, with its bordering terraces.

Professional Paper 148 (Emmons, Irving, and Loughlin, 1927) gave a detailed description of the central part of the Leadville district. The present report adds some information concerning the central part of the district, but deals chiefly with the parts surrounding the area to which the earlier professional paper was devoted. The broad general picture of the geologic history and ore deposition presented in Professional Paper 148 is not materially changed. The rocks are better exposed in the marginal region than in the central part, being above timber and near the crest of the range. Moreover, there is far less metamorphism in the marginal part of the district. For these reasons details of stratigraphy and structure that could not be deciphered in the central Leadville district can be clarified in the present report.

In general, the topography is rugged, with a relief of almost 4,000 feet and a maximum altitude of 14,037 feet on the crest of Mount Sherman. Amphitheaterlike valley heads, wide but steep-walled valleys, and relatively level and smooth uplands between the depressions are typical. Timber line is at about 11,850 feet; below it the vegetation is rich in conifers, above it grasses and alpine flowers are the only plants, and bare rock is common.

The region bears the surficial features commonly resulting from stream and ice work at alpine altitudes. Talus piles, landslide forms, and rock streams are common. Erosional and depositional effects of Pleistocene glaciation are striking, and include cirques, hanging valleys, and U-shaped gorges: high lateral moraines are striking, especially in Evans Gulch, and two separate but generally inconspicuous terminal moraines can be recognized in most valleys. Several sets of terraces characterize the lower reaches of the larger valleys; the lowest of these terraces are continuous with the terminal moraines. The higher sets of terraces can be correlated with the higher sets that are so prominent in the valley of the Arkansas River, west of Leadville. They are effects of earlier glaciation and possibly also of a complex alluvial history that antedated the actual coming of the ice. Poorly consolidated, fine-grained, clastic sediments of late Pliocene or early Pleistocene age are largely hidden from view by Pleistocene drift; they are the "lake beds" of undetermined age and origin.

STRATIGRAPHY OF THE BEDROCK

PRE-CAMBRIAN AND PALEOZOIC ROCKS

The most conspicuous pre-Cambrian rocks in the area are several varieties of schist, mainly micaceous; light-gray trachytic Silver Plume(?) granite; and darker, pinkish Pikes Peak(?) granite. The granites are believed to have been intruded during the Algoman revolution; the deposits now represented by schists are believed to have been laid down mainly during Early and Middle Huronian time. The major pre-Cambrian folds trend northwestward and have steep dips, predominantly northeastward.

The Upper Cambrian Sawatch quartzite, which is about 60 feet in thickness, unconformably overlies the pre-Cambrian rocks. It is overlain by 45 feet of shaly beds of the Peerless formation, which also is of Late Cambrian age. Unconformably overlying the Peerless formation is the Ordovician Manitou dolomite; above this is the Devonian Chaffee formation. The Chaffee consists of two members—the Parting quartzite member below and the Dyer dolomite member above. The Parting is a 27-foot unit of shale and quartzite; the Dyer dolomite, about 80 feet of buff to gray dolomitic limestone equivalent to the lower part of the Blue limestone of earlier reports. The Chaffee is unconformably overlain by the Mississippian Leadville dolomite, with the base generally indicated by sandy beds and a limestone conglomerate. The Leadville, equivalent to the upper part of the Blue limestone of earlier reports, averages 140 feet in thickness. The Weber (?) formation of Pottsville (Pennsylvanian) age is the youngest Paleozoic sedimentary formation preserved in the Leadville district. The Weber (?) consists of shales and grits with a few beds of quartzite and limestone. The thickness of the formation averages 1,750 feet but has a considerable range as it rests unconformably on the Leadville dolomite and has undergone various amounts of erosion after deposition.

MESOZOIC(?) AND CENOZOIC IGNEOUS ROCKS

Late Cretaceous(?) Tertary and Pleistocene(?) igneous rocks invaded the pre-Cambrian and Paleozoic rocks, forming sills, dikes, and plugs. One of the most widespread, the Early White porphyry, is a granodiorite of stony to finely granular texture. It forms several thick, conspicuous sills. In the field it is almost indistinguishable from the much younger, later white porphyry. The later white porphyry is a rhyolite porphyry of stony groundmass enclosing scattered phenocrysts of white oligoclase, transparent quartz, and biotite; in general it closely resembles the early White porphyry megascopically but is much younger and, with a single exception, occurs only in dikes.

The Gray porphyry group of Professional Paper 148 has hitherto been separated into three types. Five kinds are distinguished as a result of the present studies. Chief megascopic differences are the granularity of the groundmass, the nature of the phenocrysts, and the general color of the rock. All five kinds are essentially quartz monzonites, but it is possible, with slight reservations, to determine the order of their intrusion. The youngest of the group is the Johnson Gulch porphyry, which, in contrast to the other porphyries of the group, commonly occurs in dikes and probably forms the Breece Hill plug and a smaller plug in Iowa Gulch. The other porphyries of the group have been observed only in sills. The occurrence of the Johnson Gulch porphyry in dikes along faults that offset the sills of the Gray porphyry group, its presence in fissures striking like those that contain ore, and its lateness in the sequence of the Gray porphyry group seem to point to the

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Johnson Gulch porphyry as the igneous rock most closely associated in time with ore deposition.

Still younger than the Gray porphyry group are the later white porphyry previously described, the Little Union quartz latite making up two plugs near the head of Little Union Gulch, and rhyolite and rhyolite agglomerate that form plugs in the central Leadville district and dikes elsewhere. The later white porphyry is probably of early Tertiary, the quartz latite and rhyotic rocks of late Tertiary or even early Pleistocene age.

GEOLOGIC STRUCTURE

As already recognized in Professional Paper 148, the outstanding structural features of the district are faults. They are superimposed on a regional monocline striking generally north or northwest and dipping eastward. In addition to this monocline, there are smaller, local variations in dips, but these are not conspicuous and may well have been caused by drag on fault planes.

With many exceptions, faults trend approximately parallel to the strike of the beds with an upthrow of the east side in a series of steps; as the dips of the fault planes vary in direction, some of the faults are normal, and others are reverse faults. The oldest constitute a set of normal faults largely concealed by later intrusions; they are followed by reverse faults and related normal faults, which are partly mineralized; and these in turn are followed by postmineral normal faults.

Many faults not hitherto recognized are shown on the geologic map and structure sections. The details of the faulting and the ages of individual faults, such as the Mosquito and Weston faults, have received special study because of their possible importance in mining. A large thrust (the South Dyer fault) has been mapped in the marginal part of the district. Several smaller faults on the flanks of Mount Sherman are flat thrusts lying almost parallel with the bedding planes. The Weston fault is interpreted as crossing and offset by the Union fault on Upper Long and Derry Hill. The Mosquito fault is believed to be premineral rather than postmineral in age as hitherto regarded. The Bowden fault, found in the lower levels of the Ibex mine, is a reverse fault that passes upward into a bedding plane. This behavior and the tendency for faulting to be repeated and opposite in direction on the same plane are characteristic of the district, as are the many largely horizontal movements on bedding planes.

Many of the faults trend north-northwest to north, whereas the belt of Tertiary intrusives and the accompanying mineral belt of central Colorado trend north-northeast. This contrast may be attributed to intersection of fissures that trend northeast with others that trend northwest, or to local cross-folding diagonal to the major axis of folding.

GEOLOGIC HISTORY

The earliest geologic events of the region in pre-Cambrian time, though poorly recorded, consisted of varied sedimentation, followed by folding and igneous injection, which formed schists and paragneisses or metagneisses. This series of events was succeeded by intrusions of Pikes Peak(?) granite during the early part of the Algoman revolution and of Silver Plume(?) granite during the latter part of the Algoman. Then came gentle folding, uplift, and erosion, ultimately yielding essential peneplanation, which antedated Cambrian sedimentation.

During Late Cambrian time the sands (now the Sawatch quartzite) and the overlying shale (Peerless formation) were deposited in shallow marine waters, followed by the early Ordovician Manitou dolomite, and later Ordovician rocks no longer preserved at Leadville. Next came gentle uplift and erosion, probably through the Silurian. Resubmergence during the Middle and Late Devonian resulted in the deposition of clay mud, sand, and magnesian and limy muds that form the Parting shale and quartzite, and the Dyer dolomite. Erosion again ensued during late Devonian and early Mississippian time, and was followed by deposition of calcareous shallow-water sediments now constituting the Leadville dolomite. After Leadville deposition there was another uplift and subsequent erosion, resulting in local surficial irregularities, such as sinkholes. When sedimentation was resumed, it consisted mostly of deltaic deposits, yielding the thick, coarse clastic and interbedded fine sediments of the Pennsylvanian and Permian.

Thereafter ensued a more widespread uplift and a withdrawal of the sea, followed in turn by extensive continental and marine sedimentation during the Mesozoic; in the Leadville district, however, all records of Mesozoic events are absent. Near the close of Cretaceous time came the beginning of the Laramide orogeny and its accompanying igneous intrusions. This orogeny comprised a complex series of events, separable into two epochs, each marked by faulting followed by intrusion. The second intrusion period was accompanied by mineralization.

The record after mineralization is not clear. Insofar as the ore deposits are concerned, oxidation and enrichment predominated. Erosion seems to have formed a widespread level surface now preserved at an altitude of approximately 12,000 feet. Regional uplift followed and was characterized by faulting, chiefly as a result of differential vertical movements, which displaced many of the ore deposits. It was also accompanied or followed immediately by the intrusion of dikes and small plugs of later white porphyry, quartz latite and rhyolite. The region was broken into a number of elongate fault blocks, for the most part stepped upward to the east; a few were depressed, forming graben. The resulting changes impeded drainage and caused the formation of lakes, in one or more of which silts and gravels were deposited, as represented in the Leadville district and vicinity by the late Pliocene or early Pleistocene "lake beds" of Emmons and by local high-terrace gravels. Whether glaciation immediately followed uplift is not known.

Still later, two stages of typical alpine Pleistocene glaciation produced moraine topography in the lower valleys and U-shaped sections and cirques higher up.

ORE DEPOSITS

MINERALOGY

The mineralogy of the ores in the central Leadville district has been fully described in Professional Paper 148.

In the marginal parts of the district the mineral composition of the primary ore is simple. The ore minerals are argentite, chalcopyrite, galena, gold, pyrite, silver, and sphalerite—but the precious-metal ores are neither common nor conspicuous. The primary (hypogene) gangue minerals, ankerite, barite, calcite, dolomite, fluorite, jasperoid, quartz, and siderite are generally abundant but fluorite, though widespread, is nowhere plentiful. The mineral distribution shows two distinct facies: a very low temperature zone ("telethermal" zone of Graton), and a low temperature zone ("epithermal" zone of Lindgren). Locally in Iowa Gulch there are masses of ore consisting of enargite, tetrahedrite, hematite, manganosiderite, and other minerals indicating the higher ("mesothermal") temperatures and pressures typical of the central Leadville district. These ore masses may be attributed to small cupolas, which were sources of increased heat and resulted in a more intense mineralization.

The normal order of paragenesis for the sulfides is chalcopyrite, pyrite, sphalerite, and galena. In places the last two are in reverse order. Where barite is abundant in the marginal parts of the district, it is earlier than the sulfides. Quartz was deposited almost continuously throughout the period of mineralization, but markedly crystalline quartz is characteristic of the earlier stages of mineralization, whereas jasperoid is typical of later stages. Calcite is commonly found in two generations—early, essentially rhombohedral crystals and late, scalenohedral (dogtooth) spar. Sphalerite of the central area is generally more coarsely crystalline, more ferruginous, and darker than the olive-green to light-gray mineral of the borders of the district. Other common and significant hypogene minerals present are arsenopyrite, native silver and gold, argentite, and tetrahedrite.

Manganosiderite, sericite, and siderite are conspicuous gangue minerals, the sericite occurring chiefly as an alteration product of the country rock, and the carbonates as replacements in calcareous sedimentary rocks and as fissure fillings. Albite is conspicuous locally as an alteration product in igneous rocks. The oxidized products of these ores consist largely of calamine, cerargyrite, cerussite, malachite, smithsonite, zinciferous clay, and various oxides of iron and manganese. Secondary (supergene) sulfide zone minerals are quantitatively insignificant. Only chalcocite is fairly widespread, but in too small a quantity to be of economic value.

FORMS OF THE ORE BODIES

The shapes of the ore deposits in the central Leadville district have been well described in earlier publications. The shapes characteristic of the marginal parts of the Leadville district are tabular deposits of the "blanket" type, largely formed by replacement, and fissure fillings. The blanket bodies are most conspicuous where the country rock is limestone or dolomite; indeed, they occur most commonly near the top of the Leadville dolomite, where they are capped by porphyry sills or shaly beds. Fissure fillings are found in all kinds of rock. Both blankets and fissure fillings are generally smaller than their counterparts in the central Leadville district. Although transitional forms are not common, they reveal the genetic relationships of the two types; in them fissures were filled with vein matter and the ore also replaced certain beds of the country rock selectively along the feeding fissures. The channels of ingress range from steeply dipping to gently inclined fissures and to complex courses made up in part of openings along bedding planes. Many of the ore bodies are mushroom-shaped, with the lower boundary grading into partly replaced rock, but, despite the extension of the feeding fissure above the zone of replacement, the upper boundary is sharp against a relatively impermeable stratum.

In detail, some of the ore has comb structure, but this structure is not conspicuous. Crustification is well developed locally, but crustified veins make up only a negligible part of the ore. Much of the richer ore, whether primary or oxidized, is massive, the grain ranging from coarse to very fine. Bladed barite is a conspicuous ingredient of the ores of the marginal area; the various minerals in such baritic ore are not intimately intergrown. Breccia ore is conspicuous in some fissures—for example, in the Hellena mine.

ORIGIN OF THE ORE

As in Professional Paper 148 the ore deposits are ascribed to hot solutions rising from small but deep centers from which porphyry typical of the Gray porphyry group was intruded, and recent studies have revealed the genetic importance of the Johnson Gulch porphyry. The source reservoirs of igneous rock are believed to have been cupolas, with plug-like offshoots such as that of Breece Hill. The emanations from these central sources filled some fissures and effected much replacement in the suronding area, which, despite its complexity, shows distinct zoning. The marginal part of the district lay chiefly in the outer (epithermal and telethermal) zones. Not uncommonly minerals representing two zones appear in the same ore shoot because of "telescoping." The temperatures of the solutions cannot be inferred dependably, but for the marginal part of the district they were probably well under 350° C. Initially, the primary solutions are inferred to have been strongly acid, but as a given volume entered a fissure traversing a great thickness of calcareous rock it was doubtless rapidly neutralized, a process to which is ascribed the deposition of the ores. Lest these statements be misunderstood, it may be added that in the preliminary stages, before ore deposition, the solutions were apparently first sodic (yielding albite), then potassic (producing sericite), and it was only in their later, sulfide-rich stage that the solutions became markedly acid. Deposition of sulfates, especially barite, during a late stage of hypogene mineralization appears to have been due to oxidation of the rising sulfide solutions.

FACTORS IN THE LOCALIZATION OF THE ORE

Apparently, folds have played only a negative part in localizing the ore at Leadville. Strong upfolding brought pre-Cambrian rocks to the surface and, as these rocks were resistant to replacement, the central parts of major anticlines have yielded little ore.

In contrast, faulting is of great importance. In general, ores occur in quantity in minor fissures near the major faults rather than in the well-defined faults themselves. There are certain important exceptions, however, such as the Hellena and Mosquito fault fissures. Several faults show both premineral and postmineral movements, as though the ore had entered but had not yet completely healed an earlier fissure when the brittle ore was itself fractured or the edge of the filling pulled away from the wall when stress was resumed. The type of faulting most favorable to mineralization is that which produced much close shattering, as in parts of the Continental Chief mine and on Printer Boy Hill east of the Mike-Pilot fault complex. Deposition is also favored (1) where the ore-bearing fractures pass from one rock type to another; (2) where the rock strata are thick and competent enough to permit the formation and maintenance of continuous fractures; (3) where bedding-plane partings are especially well developed; (4) where the bedding is so poor that fractures can pass through bedding planes without interruption or deflection; (5) where mineralized fissures intersect, whether the intersections lie in horizontal, vertical, or inclined planes. Obviously the third and fourth conditions mentioned are mutually exclusive; other factors will determine which condition is favorable at a given place. Locally gouge "strained out" certain minerals, such as native gold.

Most of the strikes of mineralized fissures range from due north to N. 30° E. No general statement can be made as to prevailing dips.

Mineralization appears to have been favored also by certain relations with igneous rocks. Sills acted as impermeable barriers. In general a thick sill of early White porphyry, well exposed in Iowa Amphitheater, was one of the most widespread ponding barriers to rising solutions. Certain other ore bodies, however, resulted from the damming and ponding of the ore-forming solution by shale or quartzitic beds of post-Mississippian age. As already noted, mineralization was most intense near plugs from whose deeper parts the ore was presumably derived.

Replacement of country rock by ore was especially effective in the upper part of the Leadville dolomite, partly, no doubt, because of the superincumbent porphyry sill and the shale of the Weber(?) formation, but partly also because of the higher calcium content of these beds; the higher lime content caused a greater solubility than characterizes the more dolomitic beds below and thus contributed materially to selective replacement. Probably for these reasons all of the more productive replacement ore bodies in the marginal parts of the district are confined to the upper part of the Leadville dolomite.

SECONDARY CHANGES IN THE ORES

The secondary or supergene changes affecting the central Leadville district were given detailed treatment in Professional Paper 148 and are only briefly reviewed in the present report. In the marginal parts of the Leadville district oxidation and supergene sulfide enrichment are not well marked. This is partly because most workings are not deep enough to pass from the oxide into the sulfide zones. Moreover, most of the mines and prospects are located on range crests above timberline or in the bottoms of amphitheaters or valleys; in such places the preglacial soil and partly weathered rock that might have contained oxidized or secondarily enriched ores has been largely stripped off by glacial or stream erosion. Where glacial stripping has not occurred, glacial deposition has been the dominant recent process; there preglacial bedrock with its possible oxidized and secondarily enriched minerals is generally not exposed because the workings are scarce and generally too shallow to reach bedrock. Even where present, secondary sulfides are inconspicuous, because the main primary ore minerals (sphalerite and galena) do not yield important quantities of recognizable secondary sulfides.

Thoroughly oxidized ores have been mined only in workings at higher altitudes—that is, under parts of the pre-Pleistocene surface, where minerals are still preserved as remnants of the oxidized zone that formed before the Ice Age. The most abundant oxidized ores are those of manganese and of zinc; both are common in the "blanket" or "contact" (bedding-plane) deposits. The list of important oxidized minerals includes smithsonite, wad, psilomelane, pyrolusite, hataerolite, chalcophanite, calamine, zinciferous clay, and hydrozincite. Plumbojarosite and cerussite are not uncommon; malachite and cerargyrite are relatively scarce. Oxidation produces caverns in quartzose ore, gives a buff color to most ore rich in carbonates, and yields "dolomite sand" by removing the cement between grains.

Supergene sulfide ores are negligible, for reasons already given. The absence of significant quantities of supergene copper minerals is noteworthy.

SUGGESTIONS FOR PROSPECTING

As stated, minor centers of late Cretaceous or Tertiary(?) igneous activity associated with the Johnson Gulch porphyry are likely to be places of intense mineralization and to contain mixed ores. For these reasons prospecting is merited in the ground adjacent to the plug of Johnson Gulch porphyry in which the Mansfield shaft is located and the ground containing arsenopyrite, tetrahedrite, and manganosiderite near the Julia-Fisk and First National properties in Iowa Gulch.

Ground near the major faults or related minor, branching faults merits special attention. Examples are both walls of the Mosquito fault, from the head of South Evans Gulch northeastward to the head of Birdseye Gulch, especially north of the Best Friend tunnel in Evans Amphitheater. The same holds true for the territory bordering the Hellena and subparallel faults from Iowa Gulch to the Sunday shaft.

Intersections of lesser faults with the contact between the Leadville dolomite and the overlying sill of early White porphyry are commonly places of ore deposition; hence, search should be made along the several lesser faults on the southwestern wall of the southern head of Evans Amphitheater. The same applies to the northwest slope of Empire Hill near the Eclipse workings, to the north and south slopes of Long and Derry Hill, to the eastern wall of Empire Amphitheater, and especially to the eastern side of the north head of Iowa Amphitheater, south of the Continental Chief mine.

Low-angle thrust faults, even though their displacement is slight, are of much promise where they cut the Leadville dolomite. Several such faults on Mount Sherman may well merit exploration with shallow workings. Similar thrust faults are known between Peerless and Horseshoe Mountains; but mining in this high region would involve serious technical difficulties.

Places of movement on or parallel to the bedding offer promise of containing ore, to judge by observations at Leadville. Prospects near such faults, and meriting further development, are the numerous small openings situated about 1½ miles due west of the crest of Empire Hill. Faults of this type may strike and dip in any direction, being highly irregular as the result of gentle flexures superimposed on a gentle dip

To generalize more broadly, conservative expenditures should be directed to exploring lower dolomites, especially the Manitou. More attention may well be accorded to the recrystallization of limestone into "zebra rock" as a guide to ore: its presence does not prove the existence of ore nearby, but its absence points strongly to the barrenness of the immediate region.

Premineral fractures in large part trend north to N. 30° E.; such a strike coupled especially with a steep dip in a given fissure suggests the probability of mineral deposits along the trace of the fissure where favorable beds are cut; this favorable augury is more auspicious if the fissure in question is a reverse fault.

As regards exploration technology, diamond drilling may furnish many data in preliminary exploration. Exploratory tunneling should be designed to cross as many fissures as possible, while still maintaining position in a favorable stratigraphic horizon, especially that at the top of the Leadville dolomite.

DETAILED DESCRIPTIONS

The last third of the report is devoted to description of the ore deposits and mining operations in the marginal parts of the Leadville district. For this purpose the mines are grouped in regional subdivisions. A map indicates the location of the mine in question by means of a grid system. For each subdivision, the local geology is briefly outlined; then the more favorable prospects and all noteworthy mines are described, including their geology, ores, exploitation, and history. Newly discovered facts regarding the Ibex, Nevada, Resurrection, and South Ibex mines, located in the central part of the Leadville district, are also presented.

INTRODUCTION

In 1886 the first comprehensive study of the Leadville district and of adjacent parts of the Mosquito Range was published by the United States Geological Survey (Emmons, 1886). The report is a model of thoroughness, but the study was undertaken at a time when the district, already well on its way to greatness, had not by two decades reached its period of maximum production, and when, consequently, much of its geology could not be completely understood. Subsequent studies by Emmons and Irving (1907), Loughlin (1918, 1926), and Emmons, Irving, and Loughlin (1927) dealt with minor units of the central Leadville district in much more detail. The value of these revisions has scarcely been adequately understood. The later work, however, though more exact, was more restricted in scope than that of Emmons; further, the geology of outlying sections, such as Prospect Mountain, the crest of the range east of Leadville, and Iowa and Empire Gulches, received no further detailed attention.

It is well known that near fissures along which mineral-bearing solutions might move, the Blue limestone of earlier reports (now divided into the Leadville dolomite and the Dyer dolomite member of the Chaffee formation) is the most promising ground for prospecting. Therefore when contributions of money by the Colorado State Geological Survey Board, the Colorado Metal Mining Fund, and the United States Geological Survey made it possible, a cooperative resurvey of the outlying parts of the Leadville district was undertaken. A prime objective was to disclose mineralized bodies of "Blue" limestone which, because of their small size or supposed distance from faults, had not been adequately explored.

Therefore, a topographic base—part of the new Mosquito Range Mining Region map—was prepared and finished in 1927, on a scale of 1 in. to 2,000 ft. In the summer of 1928 the writer, under the supervision of G. F. Loughlin, was assigned the duty of remapping, in the maximum possible detail commensurate with the scale, the country surrounding the area figured on plates 7 and 13 of Professional Paper 148. Although a few minor changes, suggested by the later field work in the adjacent region, were introduced on plate 13, no attempt was made to revise this mapping systematically. The area here discussed extends about 1½ miles north, 5 miles south, and 5½ miles east of the town of Leadville. The map of that part of the district bounded by 39°13′28″ and 39°16′ N. lat., and 106°13′ and 106°18′17″ W. long., is republished in the center of the new map (fig. 1), only slightly changed from the form in which it appeared as plate 13 in Professional Paper 148.

LOCATION AND GEOGRAPHY

The area discussed in this report comprises the western part of what is sometimes called the Mosquito Range Mining District and the more outlying parts of the restricted Leadville District (see fig. 1). It lies almost wholly in Lake County, in Central Colorado, on the western slope of the Mosquito Range; in the extreme southeastern part near the Hilltop mine, a small strip, the longer dimension of which is parallel to the range crest, lies just across the summit, in Park County. As shown on figure 1, the area mapped comprises about 40 sq mi, between latitude 39°11′ and 39°17′ N. and longitude 106°10′30″ and 106°17′30″ W., surrounding the town of Leadville.

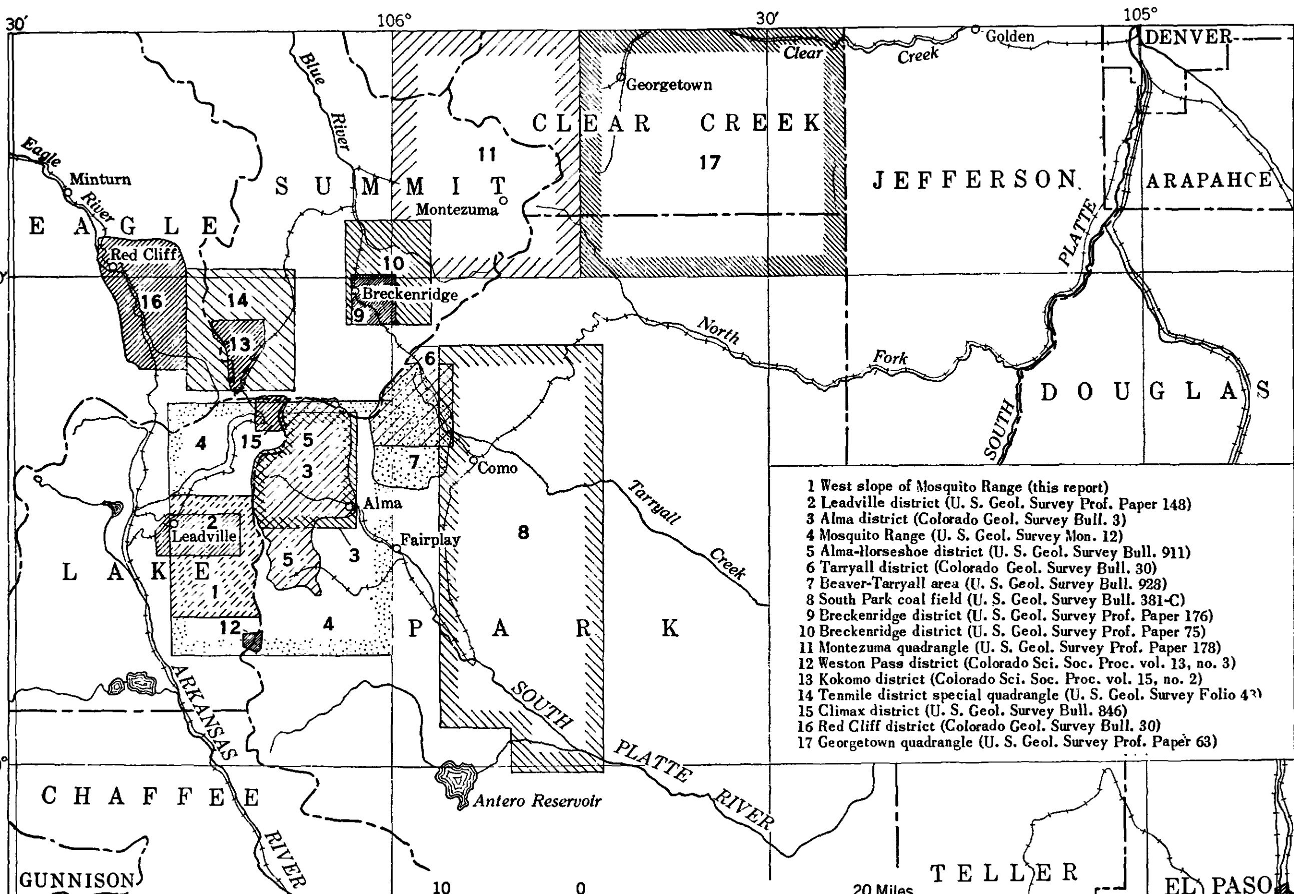

FIGURE 1.—Map of central Colorado, showing location of this and other mining districts.

The general physiographic features of the surrounding region are shown in figure 2. About two miles beyond the western edge of the area the main Arkansas River flows southward. One of its largest tributaries, the East Fork, forms an approximate northern boundary for the district; farther south, lesser tributaries flow westward, finally joining the Arkansas River south of Leadville.

Of great economic importance to mining in this region are possible railroad connections, chiefly afforded through the town of Leadville. The Arkansas Valley smelter of the American Smelting & Refining Co. is located at Leadville, on the Denver & Rio Grande Western Railroad. Connections are accessible also with a short branch of the Colorado & Southern Railroad to Climax, Colo. The former railroad follows the Arkansas Valley, whereas the latter follows the East Fork from Leadville and thence northward toward the mining camp of Climax. Roads in fair condition lead from Leadville up Evans, California, Iowa, and Empire Gulches, and up Weston Gulch, immediately south of the area. Branch wagon roads, not sufficiently well maintained to permit automobile travel, lead up Little Evans, Thompson, and Little Union Gulches. The

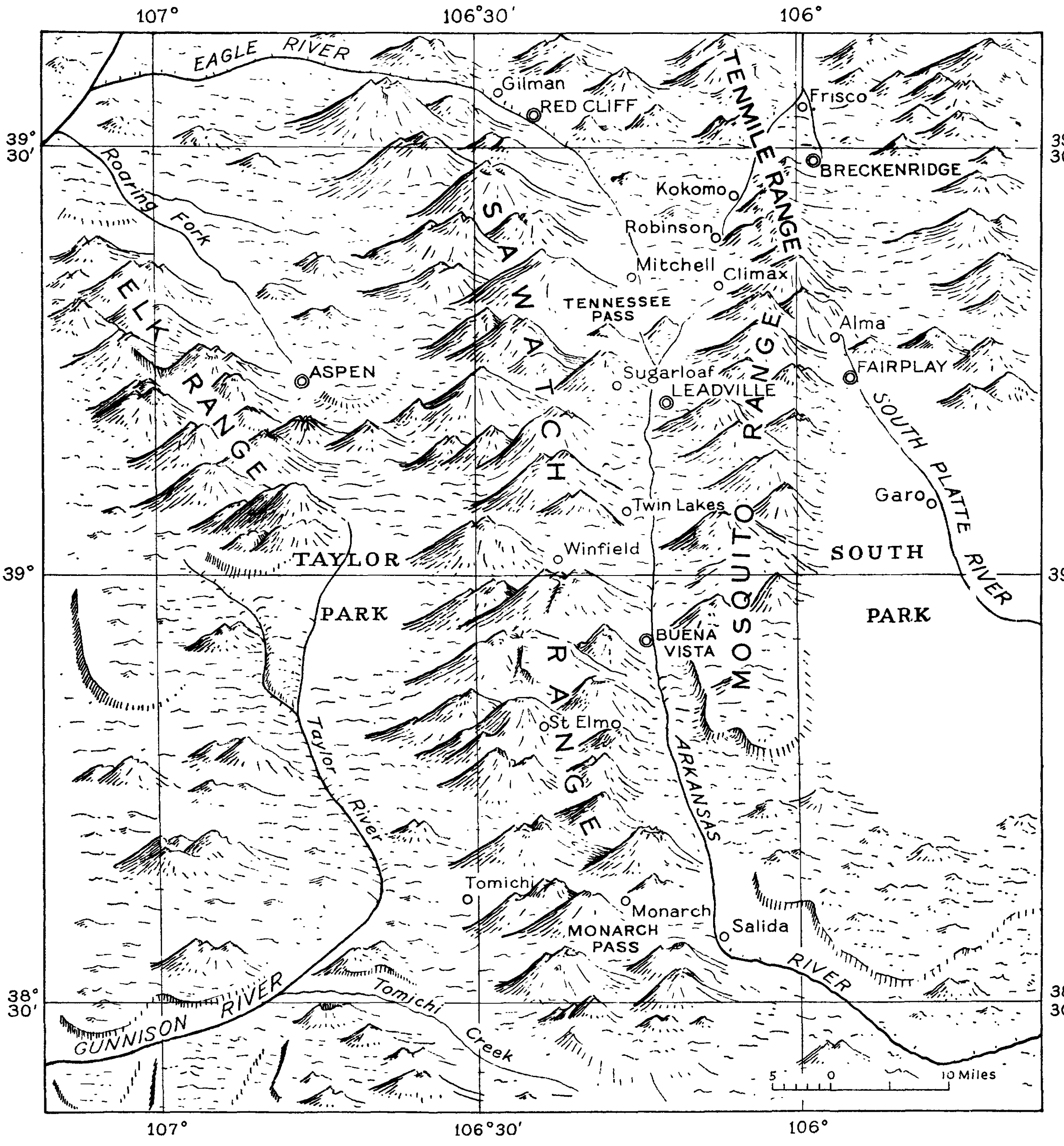

FIGURE 2.—Sketch map of central Colorado near Leadville, showing chief physiographic features, towns, and mining districts.

maximum haul to Leadville through such gulch roads is about 12 miles.

Leadville, which had a population of 4,774 in 1940, is the only town of importance in the immediate region. Small ranches lie at the lower ends of Empire, Thompson, and Iowa Gulches. The mapped area north, south, and east of Leadville is virtually uninhabited except for a few ranchers, individual prospectors, and the crews of a few small mines in operation during the period between 1928 and 1938, when the writer worked intermittently in the district.

Of special interest to the mining industry of Leadville is the new Government-financed drainage tunnel. The portal is located on the East Fork of the Arkansas River about 1½ miles north of Leadville, at an altitude of 9,960 ft. The course was designed to lead about S. 30° E., to pass under Fryer and Iron Hills, draining many of the deeper operations and ore bodies there and on Carbonate Hill, as well as the Downtown area in part (Elgin, Volin, and Townsend, 1949). After a recess of five years in the work, driving was resumed in September, 1950 and completed February 26, 1952 (Matsen and Salsbury, 1952). Exploration from the Hayden and other shafts is already going forward. The finished drainage project includes four laterals—to the Downtown area, and to shafts on the Hayden, Robert Emmett, and the New Mikado ground.

FIELD WORK AND ACKNOWLEDGMENTS

The topographic work done in preparing the base used in plates 7 and 13 of Professional Paper 148 and in the central part of the area here mapped was done before 1911. The larger part of the district, however, was topographically surveyed in 1927. The writer of the present paper spent the summers of the years 1928, 1929, and 1930 in the field, in the study of the areal geology and of the mines. The summer of 1931 was spent at Leadville, but devoted chiefly to preparing this report. Shorter visits in later summers yielded details about the geology and mining operations, but very few field data were obtained since 1935.

The advice and criticism of the late G. F. Loughlin of the U. S. Geological Survey were invaluable and to him this report should be gratefully dedicated. The late C. W. Henderson of the U. S. Bureau of Mines furnished most of the production data and helped the work in many ways. E. N. Goddard and A. E. Sandberg served most helpfully and efficiently as field assistants. Special thanks are due Jeanette Allen Behre, the wife of the author, for assistance in field work, drafting, and the preparation of the manuscript. W. S. Burbank has made suggestions of great value in the preparation of this report. Nevin Johnson especially aided in guiding the preparation of the illustrations. Thanks are also due to J. Harlan Johnson, Q. D. Singewald, and T. S. Lovering for helpful comments based upon their work in nearby regions.

To the mining men of Colorado, particularly of Leadville, who have given so much of their time and energy toward the completion of this work, the author is greatly indebted. Messrs. John Cortellini and W. E. Bowden (both now deceased), and G. O. Argall, of Denver, merit special thanks. Messrs. J. M. Kleff and Fred J. McNair, mining engineers, of Leadville, generously contributed information and mine maps. Particular thanks are due also to Mr. E. P. Chapman, geologist, formerly of Leadville, and to the E. J. Longyear Co., for permitting the use of data resulting from their studies; the Longyear Co. generously shared information obtained under its auspices by Messrs. R. D. Longyear and G. M. Schwartz.

SURFACE FEATURES

TOPOGRAPHY

The Leadville district is on a northward-trending, high, rugged mountain mass, both flanks of which are characterized by gentle lower slopes and much steeper ones near the crest. This is the Mosquito Range, whose higher summits, such as Mosquito Peak (13,780 ft), Mount Sherman 14,037 ft), and Horseshoe Mountain (13,903 ft), near Leadville, approximate an altitude of 14,000 ft above sea level. These mountain crests lie well above timberline. Their summits show bedrock, and piles of talus that largely mask the slopes down to the level of vegetation. East of the Mosquito Range is the wide valley of the South Platte River, opening southeastward into the still broader flats of South Park. West of the range is the valley of Arkansas River, about 17 miles in width from crest to crest in the latitude of Leadville. The mountains decline in a series of gently sloping terraces toward the floor of this valley. West of Arkansas Valley, in turn, are the still higher and more rugged Sawatch Mountains, which include some of the highest peaks of the United States—many well above 14,000 ft in altitude.

The northern end of South Park and the northern part of the Arkansas Valley are topographically similar. Both are broadly terraced, and both contain relatively sluggish master streams which wander through level areas of sage and grass in most of the upper part of their courses. Both streams flow southward and both are fed by tributaries that rise in the higher bordering country to east and west. The mountains that flank both of these two valleys on the west, however, differ somewhat in topographic form. The Mosquito Range, west of South Park, culminates in a narrow, virtually level crest with individual summits greatly elongated in one general direction. In contrast, the Sawatch Range, west of the Arkansas Valley, lacks this striking ridgelike character and instead is crowned by rounded peaks, many lying several miles east of the Continental Divide.

Closer examination of the west slope of the Mosquito Range, on which the Leadville district is situated, reveals that many of the valleys have wide, horseshoe-shaped heads. So conspicuous are these features that the upper ends of Evans, Iowa, and Empire Gulches are generally referred to as amphitheaters. The walls of such valley heads are cliffs, in places so steep as to defy climbing, and where the amphitheater heads on opposite sides of the range meet, the mountain crest has been worn to a serrate ridge and attains its greatest sharpness.

Downstream the broad valleys have the same **U**-shaped cross section, their walls losing some of their precipitousness, yet rising to average altitudes of 500 ft above the valley floors. In general these steep-walled valleys possess wide bottoms, half a mile across, and uniform and relatively gentle gradients. These gradients, however, are interrupted by a few abrupt declivities and narrow gorges with turbulent rapids, especially where the streams cross rocky ledges, as in Empire Amphitheater half a mile below the Finnback mine; or where, as at the mouth of the Dyer Amphitheater, tributary valleys join the master drainage lines; or again where irregular, moundlike masses of boulders and gravel, 50 to 100 ft high, form barriers across the streams.

Projecting from the crest of the range and extending between the valleys of **U**-shaped section just described are ridgelike spurs. Farther from the range crest, these spurs assume the form of flat, benchlike divides, declining, also by gentle gradients, toward the Arkansas Valley. Bedrock is exposed generally at the surface for about four miles west of the range crest, but farther down the spurs are covered with boulders, gravel, and silt, become more flat and tablelike, and finally slope down to the Arkansas River as striking mesalike terraces. Many of these terraces front the river valley flats with relatively steep slopes a hundred feet or more in height.

In addition to the broad **U**-shaped valleys a smaller type, narrower at the bottom and shorter, is seen in the region. Such valleys generally lie higher than the others, at the level of the flat divides described above, and are roughly parallel in trend to the **U**-shaped, larger stream valleys; they finally unite with the latter. Little Union Gulch, at the southern edge of the area mapped, is an example of this kind of valley. From its head on the western slope of Empire Hill down to the southern edge of the mapped area the stream flows in a narrow **V**-shaped gorge, and falls 400 ft or more to the mile in comparison with only 250 or 300 ft of the broader master valleys. Another such example is California Gulch, 1½ miles southeast of Leadville.

VEGETATION

From the summits down to an altitude of about 11,850 ft there is little or no timber on the west slopes of the Mosquito Range. The only exceptions are scattered small groups of stunted juniper (*Juniperus scopulorum*), spruce, and pine, which have been bent, twisted and gnarled by the force of the wind. On such higher slopes, there are two kinds of plant communities—those where the surface exposed is either bare rock, with relatively rare patches that contain soil enough for plants to grow, and those of the somewhat lower, moister, high-level valley bottoms. The former comprises a small group of beautiful alpine flowers. In the lower, moister, open meadows the assemblage differs most conspicuously in the presence, especially along the water courses, of scattered thickets of mountain alder (*Alnus tenuifolia*).

Below timberline, in addition to flowering shrubs, there are several kinds of conifers, among which the lodgepole pine (*Pinus succinifer*), the Colorado blue spruce (*Picea pungens*), and the Engelmann spruce (*P. engelmanni*) are most conspicuous; on the lower slopes and where talus blocks cover the surface the aspen (*Populus tremuloides*) adds a lighter shade of green.

Still lower, at an altitude of about 10,250 ft, where heat and relatively xerophytic conditions combine to thin out the trees, the shrubs again predominate. Sagebrush (*Artemisia*), the purple lupine (*Lupinus argenteus*) and several other legumes predominate, and the vegetation does not differ greatly from that of the plains east of the Rocky Mountains at comparable latitudes.

Though not of great geologic importance the shrubs and trees do play a significant part in the development of the topography. By gradually advancing over the talus and cliffs, they hinder undercutting of the hillsides and make the slopes more gentle, and hence reduce the tendency toward landslides that is always strong in areas with such steep declivities. The trees are of some economic importance, though not adequate for a large lumbering industry. The local timber, eked out in larger mines with the stronger and heavier fir and spruce brought in from the northwestern part of the United States, has served for stulls and lagging. The stump-covered hillsides, notably south of Evans Gulch, amply testify to the importance of this natural resource in the earlier mining operations at Leadville.

RECENT DEPOSITS

The most recent deposits in the region comprise talus, deposits made by flowing water and by landslides, and snow-bank deposits resulting from movements induced by gravity.

TALUS

The most conspicuous and freshest deposits of recent origin in this area are those composed of talus or rock waste (Behre, 1933b). They are found chiefly at the higher altitudes. When rock is exposed to the action of the weather in regions of high altitudes such as this, temperature changes, especially rapid ones, are likely to produce sudden expansion or contraction of the rock and a consequent spalling of fragments of various sizes and angular forms. The blocks fall from the rock mass and move downhill at a rate depending on the declivity of the surface upon which they have been dislodged. In fissured rock, exfoliation is accelerated by the repeated freezing and consequent expansion of water. The fragmentation of rock faces is most rapid above the timber line (here at an altitude of about 11,850 ft) owing to the rapid and frequent temperature changes, freezing temperatures, and general absence of soil.

Talus piles, most of them deltaic in ground plan, extend below many of the steep rock surfaces, especially in and near the heads of valleys. The shapes of some deposits have been modified by fingerlike extensions of finer material deposited by streams that form during rainstorms and flow rapidly down the talus slopes and out upon the flatter valley floor.

In vertical section fresh talus piles have angles of rest ranging from 28° to 36°, and averaging about 32°, though the angles of old piles reworked by water or those overgrown by vegetation fall below the lowest of these figures. Detailed observations by the writer clearly show the correlation between particle size and angle of rest (Behre, 1933b); thus, material composed of fragments that range in diameter from 0.5 to 2 in. rests on slopes of 26° to 32°, whereas those of diameters that average about 12 in. rest on slopes of 35° to 36°.

The average size of particles is indicated above, but blocks as much as 50 ft in diameter have been noted. The pieces are angular and show all variations from flat chips to equidimensional fragments, depending chiefly upon the rock of which they are composed. In general the material has undergone only slight chemical weathering, if any at all. On old slopes, however, especially those having low angles, vegetation has begun to appear, and concurrently rock decay has set in; this is especially true where the slopes are on pre-Cambrian granite, which decays very rapidly under the existing climatic conditions.

In many places the talus surface slope is separated from the floor of the valley by a low ridge. (See fig. 3.) This ridge results from the rolling of individual blocks over the snow bank that covers the talus during the colder part of the year and accumulates some distance away from the main talus slope. A useful term for such a feature is "snow-front ridge."

STREAM DEPOSITS

Deposits of Recent alluvium in stream valleys are few in this region. They are noted only where glacial moraines had temporarily ponded the valleys upstream. Such deposits generally cannot be distinguished from outwash from valley glaciers of Pleistocene age, formed while active ice-scour was still taking place in the higher regions.

The valley flat at the Mitchell Ranch was produced by ponding of the stream and silting up of its valley on the upstream side of a recessional moraine of the Empire glacier. The downstream projection of the rock floor of upper Empire Gulch indicates that stream deposits here do not exceed 250 ft in thickness and are probably somewhat less.

Some stream deposits occur in the lower part of Little Union Gulch (a postglacial valley) but the deposits east of longitude 106°15′ are negligible, and even west of this line they are probably merely a thin veneer over the terrace gravels.

LANDSLIDES

The effects of landslides, where large rock masses have moved as a unit, are clearly evident in a few places.

One such place is on the north side of Long and Derry Hill about 500 ft east of the Doris mine (pl. 4). Here is a steep slope of black shale and grits comprising the

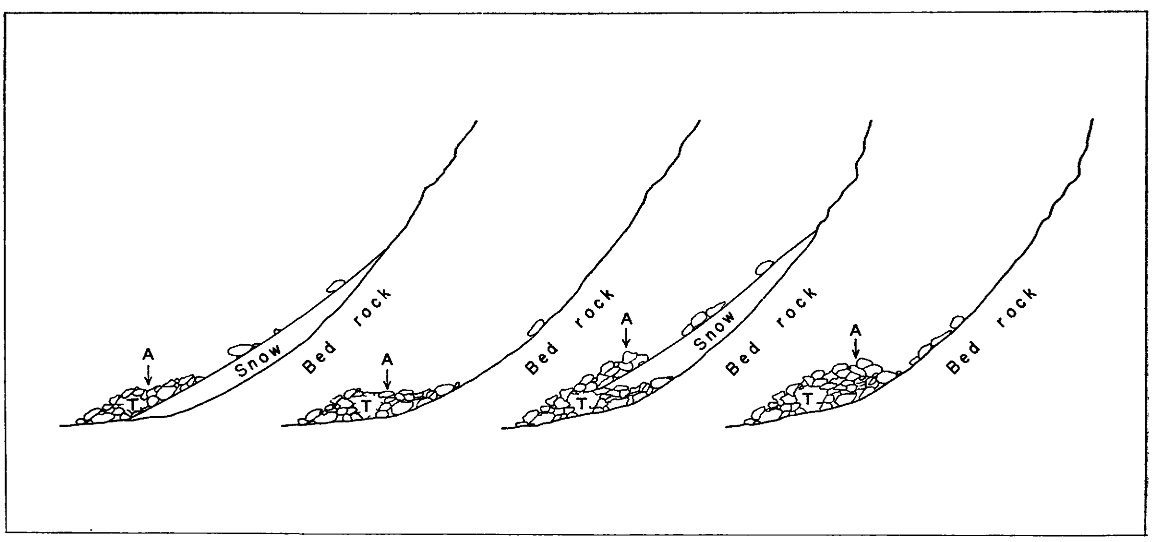

FIGURE 3.—Diagram to show progressive sapping of a steep cliff by frost action, with the development of a "snowfront ridge." A, crest of Talus (T).

lower part of the Weber(?) formation and intercalated porphyry sills. The dip is southeastward, into the hillside, and consequently erosion of the slope has produced sapping of the Weber(?) rocks. Under these conditions, the shales have absorbed some water and tended to slough off, slumping down the hillside. No bedrock is exposed in place, but much clayey matter, soil that had accumulated on the surface of the slope before movement began, and large blocks of sandstone and porphyry, all intermingled with tree roots, cover the surface. Into this heterogeneous material water penetrates and reappears in small seeps downhill, making a plastic mass that even now moves intermittently. This landslide is probably of recent origin or at least it records recent movement, for landslide cracks are common on the present surface, and there are numerous uprooted trees and many trees standing with trunks tilted at various angles.

There are other localities where the slightly hummocky topography suggests landslides, but the only other place where the features are unmistakable is farther down Iowa Gulch, on the south wall at an altitude of 10,800 ft and less, approximately half a mile south of the point where the road into upper Empire Gulch rises to the crest of Long and Derry Hill. Here the Leadville water ditch once burst and washed the surface northward down into Iowa Gulch, and the scar produced on the hillside is still visible. Downslope to the north, the hummocky topography is very striking and clearly distinguishable from that due to moraine deposits near the bottom of the gulch. It forms a conspicuous shoulder, above which is a landslip scar, now partly concealed by later small-scale slumping and erosion, and by the recent growth of vegetation.

ROCK STREAMS

Masses of rock waste, tonguelike in ground plan and consisting of angular boulders as much as 50 ft in diameter, are common above timberline in glaciated regions where slopes are steep. There are two such rock streams of noteworthy size in the region.

One is the upper part of Evans Gulch, near the lower end of Evans Amphitheater. Around its head are steep cliffs, behind which in turn are great cracks parallel to the cliff face. The rock stream trends northwest from the east wall of the amphitheater, a short distance south of the Miller mine. It is about 1,500 ft square—an area of about 50 acres. The surface of this rock flow stands well above the adjacent bedrock surface, and its average thickness is estimated to be at least 125 ft. The slope at its outermost edge is very steep, about 38°, but farther back toward the cliffs it is very gentle—about 8° or less. Near its lower margin ridges parallel to the edge and averaging 5 or 10 ft in height are distinguishable; between these ridges snow remains well into the earlier summer months. Almost all of the fragments observed are of the same kind of porphyry as that which makes up the cirque wall at the upper end of the slide. They are fresh, showing no case hardening and very little surface staining with iron oxide.

A smaller rock stream in Iowa Gulch almost adjoins the landslide mentioned above. It lies between the Doris mine and the floor of the gulch, and has apparently forced Iowa Creek against its north bank where it is actively undercutting. This rock stream extends about 500 ft in a north-south direction and 650 ft east and west. Its thickness is nowhere more than 100 ft and in most places it is probably less, as dumps of the shallow shafts sunk through it contain bedrock fragments. The rock-stream surface is slightly hummocky, with inconspicuous ridges parallel to the lower margin. In general it is similar to the Evans Amphitheater rock stream and similarly lies just below a greatly oversteepened slope at the head of which are great crevices parallel to the brink. Most of the rock fragments are pieces of early White porphyry.

The origin of such rock streams has been discussed for more than forty years (Sharpe, 1938, pp. 42–46; Kesseli, 1941, pp. 202–227). They seem to be distinct from the "stone rivers" described from arctic regions, for the "stone rivers" do not start at cliffs, their gradient is much gentler, and they occur in regions of essentially glacial climate. Rock streams or "talus glaciers" like those in the Leadville region have been explained (1) as talus piles, moving forward slowly under their own gravitative "head", largely as the result of adjustments incidental to the melting and refreezing of interstitial ice (Chamberlin and Salisbury, 1909, p. 232); (2) as loose slide-rock that fell as landslide material or talus and later advanced partly by melting and refreezing of the interstitial ice (Capps, 1910, pp. 371–375); (3) as loose slide-rock that fell on the ice and advanced as push moraines of recent alpine glaciers (Kesselli, 1941, pp. 226, 227); (4) as avalanchelike landslides like that at Frank, Manitoba, the fragments being the result of breaking of larger blocks, either while in transit or at the beginning of actual movement, the mass probably having in some cases fallen after the melting of the ice (Howe, 1909, pp. 52–54) because it had been undermined by glacial scour. Excellent descriptions of similar slides in the San Juan Mountains of Colorado are given by Howe, and his explanation of these features as analogs of those resulting from the Frank, Manitoba, and Elm, Switzerland landslides appears to be well established. If further evidence were needed, the character of the individual blocks (which could scarcely have retained their present freshness and angularity if the accumulations were of glacial origin), the correlation of rock composition between the fragments and the adjacent cliffs rather than with the cliffs at the head of the cirque, the fact that the rock stream near the Doris mine is not regularly cemented with ice, the absence of such streams in some glacial valleys such as Empire Gulch, and the association with the Doris rock stream and in similar physical conditions elsewhere of undoubted landslide topography all indicate the same origin. Such rock streams seem to have originated by the sudden breaking away and falling of rock masses from oversteepened cliffs on valley walls, the large blocks having been broken into smaller fragments as they struck other blocks while in transit. In this explanation continued later motion is not excluded, but it is regarded as relatively unimportant in bringing the material to its present position.

FEATURES OF PLEISTOCENE AND PLIOCENE(?) AGE

OUTLINE

The glaciation of this region has been described in a general way in several publications, the more detailed accounts being given by Capps (1909), Emmons, Irving, and Loughlin (1927), Westgate (1905), Behre (1933a), and Powers (1935). A digest of these works is given below, with the addition of some details and the slight modification of some conclusions. Certain glacial features of the region are depicted on plate 4.

WISCONSIN STAGE

EROSIONAL FEATURES

The characteristic **U**-shaped transverse section of most of the valleys has already been noted. Weston Gulch, immediately south of the area mapped, Empire, Iowa, and Evans Gulches, and the valley of the East Fork of the Arkansas—these and their tributaries are all distinctly **U**-shaped in cross section. In every one, however, the **U** is very broad and low. In the lower parts of the valleys, where valley floors are at altitudes of 11,000 ft or less, the ratio of the width of the **U** to its depth is about 5:1. Here the valley walls slope down gently from the divides and then abruptly steepen to form an inner **U** notched in an outer, more gently walled **V**. In the upper parts of the valleys, however, the valley cross-section is generally an unbroken slope from divide to valley bottom; the valley is much wider but the ratio of width to depth is reduced to about 4:1. In general, the walls in the upper valleys are steeper than in those farther downstream and are essentially vertical. Such **U**-shaped valleys were obviously made by the erosive action of valley glaciers during Pleistocene time.

The heads of most of the larger valleys are amphitheaters whose walls slope steeply on three sides to the divides; on the downstream side, the valleys open into the **U**-shaped cross section described above. The heads of Dyer, Iowa, and Empire Gulches, and the small amphitheaters lying on both sides of the ridge that connects Mount Sheridan with West Sheridan Mountain are excellent illustrations. These features were produced by the headward cutting of glacial ice in Pleistocene time. They are properly termed cirques, but their form has led to the popular name of "amphitheater." Some are occupied by small lakes, such as those in the Dyer Amphitheater and Lake Isabelle on Prospect Mountain.

In the higher parts of the region many tributary valley streams discharge by abrupt falls into the main stream valleys. To a tributary valley with an abrupt change in gradient at its discharge point, the term "hanging valley" is applied. This gradient change probably resulted from more rapid downcutting by the glacier that occupied the main valley, leaving the rock floor under the tributary glacier so high above the rock floor of the main glacier that the tributary ice stream cascaded down to join the ice in the main valley. Excellent examples are the amphitheaters north and south of the ridge between West Sheridan and Sheridan Mountains. They have valley floors that slope very abruptly—some 400 ft vertically in 1,500 ft of horizontal distance—giving sharp drops to the main streams into which they discharge.

Between the glaciated valleys the higher uplands are nearly level, descending in gentle slopes toward the Arkansas Valley from the range crest (see p. 8). These are areas where glacial erosion was not effective. They represent remnants of an old pre-glacial surface, now largely destroyed by glaciation and stream work.

These features characterizing a region of glacial erosion are obviously no longer as clear as when first exposed by the melting of the ice. The steep valley walls must have been somewhat modified—chiefly by a reduction of their slopes—through landslides, the accumulation of talus, "sapping" back by frost action and other effects of temperature changes, and through erosion by running water. Erosion has also to a small extent reduced the declivities at the mouths of hanging valleys. The growth of vegetation has at least somewhat modified the steepness of the slopes. On the whole, however, the present valley and cirque topography above timberline is essentially as it was immediately after the disappearance of the last valley glaciers, partly because none of the processes that produce change is very rapid and partly because the time available for such changes has not been very long as measured in geologic terms.

GLACIAL DEPOSITS

CHARACTERISTICS OF GLACIAL DEPOSITS

Of the unconsolidated deposits in the region mapped those resulting from glaciation are the most clearly defined. They are of two types—glacial till or moraine material (deposited under or at the edge of the ice), and glacial outwash or glacio-fluvial material (deposited beyond the ice by streams flowing from the ice front). All the unconsolidated surface materials, especially these two types of deposits, are commonly known by the miners as "wash."

In detail, till and outwash differ. Till consists of clay and sand irregularly mixed with boulders, the finer material forming a sort of matrix studded with boulders. Outwash consists of stratified silt, sand, gravel and boulders—well sorted and laid down in beds characterized by variations in coarseness of the sediment.

The boulders in the till are as much as 20 feet across and although such large ones are rare, they are typical of the moraine material. Glacial till is borne along in the solid ice which can carry much larger pieces than the largest boulders in the outwash. The boulders and pebbles of the outwash, having been rolled to their present position by water, are limited to rock fragments sufficiently small to be transported in that manner.

Moreover, because individual boulders of the glacial till are held firmly in the ice and are ground against the floor or sides of the glacial valley or against their fellows, they are likely to show faceted forms, beveled edges, and scratched or striated surfaces, in contrast to the rounded boulders that were rolled along by the streams discharging from the ice and were deposited in the outwash.

There are in this area no marked differences in the kinds of rock making up the glacial till as compared with the outwash or glacio-fluvial material. Any of the kinds of country rock may be represented in the boulders, but the most common are the quartzites of Cambrian and Devonian age. Almost all of the material is fresh, resisting strong blows with the pick; exceptions are mentioned later.

The deposits representing the two glacial stages, are distinguishable on the basis of their degrees of erosion and weathering. Those of the latest or Wisconsin stage, being the more striking, are described first.

The most conspicuous glacial deposits are attributed to the five valley glaciers, which occupied the five main valleys. These glaciers are called the East Fork, Evans, South Evans, Iowa, and Empire glaciers after the gulches they occupied. On the whole, their terminal moraines and outwash deposits are not conspicuous, nor is the extent to which they hide the bedrock and affect mining development of great economic importance. The areas and thicknesses of their deposits in the region here mapped are given briefly below; for a description of these features in the immediate vicinity of Leadville the reader is referred to the works of Capps (1909, pp. 90–96) and the later and more detailed treatment by Emmons, Irving, and Loughlin (1927, pp. 10–17). The distribution is shown in plate 4.

DEPOSITS OF EAST FORK GLACIER

Though the valley of the East Fork of the Arkansas lies almost wholly north of the area here described, a small part of the moraine deposits made by the glacier that occupied it in Wisconsin time occurs north of Poverty Flat and on the northwest slope of Canterbury Hill. In the region around the mouth of the Canterbury tunnel it is a veneer about 75 ft thick. It forms a southward-trending band which may be part of the south lateral moraine of the East Fork glacier. No line can be drawn with certainty between it and the terminal moraine of the Evans glacier just south of Little Evans Gulch.

The terminal moraine of this large ice tongue is not readily distinguished from the gravel terrace north of Leadville. It lies west of the Tennessee Pass highway which locally follows lower Evans Gulch, and hence is mainly west of the area here mapped.

DEPOSITS OF EVANS GLACIER

The Evans glacier of the Wisconsin stage deposited very little material on the valley floor from the head of the Evans Amphitheater northward to the place where the valley axis falls to an altitude of 11,500 ft. North of this place, however, the till of the north lateral moraine appears, and at the lower end of the Board of Trade Amphitheater it attains a thickness of about 30 ft. From there westward the morainal material thickens abruptly and forms a conspicuous ridge separating Evans and Little Evans Gulches (fig. 4). Here the moraine has a thickness of 150 to 250 ft. Within the area described in this report the base of the thicker part of the moraine has not been reached by mine workings.

The south lateral moraine of the Evans glacier first becomes conspicuous about 1,500 ft east of the lower of the two large Leadville reservoirs, at the foot of the north slope of Little Ellen Hill. Its maximum thickness here is 100 ft. Westward, it forms the north slope of Breece Hill, across the mouth of South Evans Gulch. Small ice tongues occupied the two cirques in which the Board of Trade mine and Lake Isabelle lie, but their deposits were negligible and their role seems to have been chiefly erosional.

The terminal moraine of the Evans glacier is about due north of Leadville and only a small part of it occurs in the area here mapped. Small patches fringe the southwest slope of Canterbury Hill, northwest of the Chicago Boy shaft. A marked thickening of drift in the center of upper Evans Gulch, however, due south of the Board of Trade Amphitheater, is probably attributable to recessional moraine deposition. The maximum thickness of this moraine, as judged by connecting (in projection) the surface of the rock outcrops in the stream bottom south of the Vega shaft with rock outcrops farther eastward, is probably not more than 50 ft.

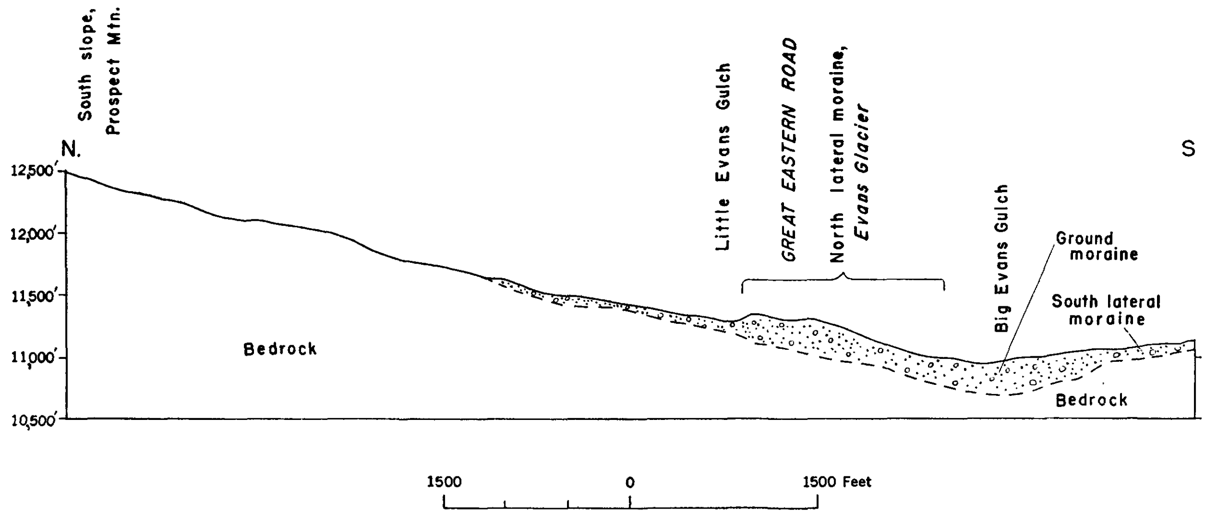

FIGURE 4.—Vertical section S. 5° E. from Prospect Mountain across northern slope of Evans Gulch, to show prominent north lateral moraine of Evans glacier.

DEPOSITS OF SOUTH EVANS GLACIER

A glacier occupied the head of South Evans Gulch, as shown by the cirquelike valley head and by the glacial fill in the valley floor below the 11,550-ft contour. The South Evans ice tongue was a part of the Evans Gulch glacier until an appreciable retreat had taken place. The deposit, comprising both lateral and ground moraine, probably is nowhere more than 75 ft in thickness.

DEPOSITS OF IOWA GLACIER

The Iowa glacier of the Wisconsin stage was fed by three branches which headed in Iowa and Dyer Amphitheaters and in the cirque between Mount Sheridan and West Sheridan Mountain. Of them, the Iowa Amphitheater branch was by far the largest, the ice from the other two glaciers pouring down out of hanging valleys into the main valley of Iowa Gulch. Neither of the two tributary glaciers deposited noteworthy moraines, but the north lateral moraine of the main Iowa glacier formed a sharp ridge 50 ft high extending across the lower end of Dyer Amphitheater. This ridge forces the stream that drains that amphitheater to flow three-quarters of a mile westward before it breaks through the moraine ridge and enters Iowa Gulch. The morainal material here probably has a maximum thickness of about 100 ft.

On the steep south slope of Printer Boy Hill the north lateral moraine of the Iowa Glacier forms only a thin cover, so that bedrock is generally struck in mining at depths of less than 50 ft. The bedrock surface on Printer Boy Hill, however, is buried under a cover of glacial till which thickens steadily westward and wholly covers the top of the ridge that extends westward under the name of Rock Hill. Here the glacial ice reached the crest of the divide between Iowa Gulch and California Gulch, and some of the water from the melting ice flowed over the divide and down into California Gulch; indeed, a similar but higher spillway lies at an altitude of 11,325 ft, about 1,500 ft east of the crest of Printer Boy Hill (Emmons, Irving, and Loughlin, 1927, p. 15). Despite the fact that the bedrock topography was covered by the lateral moraine, that on the southern slope of Rock Hill, like that similarly situated on Printer Boy Hill, was very thin.

The south lateral moraine of the Iowa glacier is not conspicuous higher up the valley than the Doris mine. From that point westward, however, it is recognizable as a distinct bench on the valley wall. As the crest of the divide slopes up westward, this morainal bench rides up over the bedrock surface on Long and Derry Hill at the point where the road from Iowa Gulch to Empire Gulch crosses the crest of the ridge. From here westward the moraine extends as a conspicuous ridge 50 ft or more above the terrace on which it lies. The Continental shaft, 0.3 mile west of the road just mentioned, is 175 ft deep in "wash," which is probably almost wholly composed of morainal material. On the slope toward Iowa Gulch there has been some slumping of the till. The lateral moraine is continuous with glacial deposit in the valley bottom.

In the valley of Iowa Gulch the bedrock is largely concealed beneath glacial drift downstream from a point approximately a third of a mile upstream from the Hellena mine. This drift must have been deposited on a very irregular surface, as glacial material ("wash") is about 50 ft deep near the Helena mine, whereas bedrock crops out at road level three-quarters of a mile west of the Hellena shaft and is concealed by till a little farther downstream. On the south side of Iowa Gulch west of the westernmost point reached by the road from Iowa Gulch to Empire Gulch, the prospects have a cover of glacial deposits, but it is only a very shallow one.

The terminal moraine of Iowa Gulch is an elevated arcuate lobe that extends southwestward from the ridge north of Iowa Gulch almost across the valley, causing an abrupt southward deflection of the stream. As these glacial deposits were laid down upon earlier alluvial deposits (described below), they are not readily distinguishable from the latter, and the exact thickness of the terminal moraine is therefore not known.

An usually thick deposit of glacial and glacio-fluvial material extends up the valley bottom from where the stream crosses the 10,350-ft contour to a point opposite the Mansfield shaft. This belt of thicker drift is highly generalized on the map, plate 4, for want of detailed data as to thickness. It probably represents a recessional moraine. It was deposited mostly on a rock floor that lies buried at a depth of about 50 ft, to judge by projecting downward the bedrock surface exposed on the valley slopes.

DEPOSITS OF EMPIRE GLACIER

The valley glacier that occupied Empire Gulch during the Wisconsin glacial stage had no tributaries of appreciable length. In the sag south of the spur connecting West Sheridan Mountain with Upper Long and Derry Hill a small ice sheet of the nature of a cliff glacier probably existed, as shown by scattered faceted boulders. The flatness of the floor of this little basin indicates that sedimentation occurred here for a time while the main Empire glacier, its surface standing at an altitude of about 11,650 ft, ponded the discharge waters of the cliff glacier. This interpretation is supported by the form of the surface of the flat which is slightly convex upward in east-west vertical section, and by the occurrence of some thin beds of poorly stratified, gravelly alluvium along the northwest fork of the creek that now drains the flat. This alluvium is evidently outwash from the cliff glacier mentioned above. The limits of outwash in this locality clearly outline the lower edge of a small glacier that was not continuous, at least during its later history, with the Empire glacier; thus there was a small ice-free area upon which the glacial outwash was deposited.

A similar small glacier, continuous however with the main Empire ice, occupied the amphitheater south of the ridge connecting West Sheridan and Sheridan Mountains, but left no distinct deposits, its effect being chiefly erosional.

The main Empire glacier deposited conspicuous lateral moraines on both sides of the valley. The north lateral moraine is noticeable not far from the head of Empire Gulch, appearing as a low shoulder on the valley slope at an altitude of 11,600 ft, due south of West Sheridan Mountain. Westward it loses altitude gradually, and on the south slope of Long and Derry Hill it appears as a distinct bench whose top is at an altitude of about 11,250 ft,. Despite its topographic prominence, this feature is not made by a thick deposit but rather by a veneer which built out the hillside horizontally, for shallow mine workings have reached the underlying bedrock in several places. In this respect it resembles the moraine on the south side of Printer Boy Hill, where the steep rock slope did not furnish a favorable foothold for much drift. Still farther west the moraine forks. Its northwesterly older branch is continuous with the most advanced terminal moraine of the Empire glacier, extending southward as an ill-defined crescentic ridge of irregular topography, recognizable just west of the Hatch Ranch. The southeastern branch of the lateral moraine occupies a position roughly parallel to the other, but a mile and a half farther east it merges with the recessional moraine that lies about a quarter of a mile southwest of the Mitchell Ranch.

The south lateral moraine of the Empire glacier is recognizable in the upper part of Empire Gulch. Due south of West Sheridan Mountain it forms a noteworthy ridge, rising fully 30 ft above the floor of Empire Gulch to the north and shutting off a meadow fringed with timber along whose northern edge the moraine can be traced for a distance of half a mile. The altitude of the morainal ridge is here about 11,650 ft. Like its northern counterpart, it declines in altitude westward and is not very thick on the steep north slopes of Empire Hill. However, it forms a 30-ft ridge at the lower end of the meadows on the flat northern shoulder of Empire Hill, a ridge which serves as a dam for the Empire Reservoir. On the western slope of Empire Hill, south of the Mitchell Ranch, this moraine forks into two lobes; the more southerly is continuous with the terminal moraine and the more northerly is continuous with the recessional moraine already mentioned in the description of the north lateral moraine of the Empire glacier.

It is difficult to estimate the thicknesses of the north and south lateral moraines of Empire Gulch from the Mitchell Ranch westward. They probably differ greatly from place to place because of the irregular bedrock surface, but average about 50 ft, as indicated by their heights where they were deposited on alluvial terraces.

The outer edge of the terminal moraine of the Empire glacier, 0.6 mi west of the Hatch Ranch, is marked by characteristic topography. East of the Hatch Ranch the bottom of Empire Creek has a steep slope, falling 250 ft in ½ mi. The irregular surface of the valley bottom near the Hatch Ranch is in sharp contrast with the wider and smoother valley bottom east of the Mitchell Ranch. The rolling topography a mile southwest of the Hatch Ranch is obviously of glacial origin, and appears to be a direct continuation of the outermost prongs of the north and south lateral moraines. Farther west, below the Hatch Ranch, the valley is studded by lakes and has the pitted surface of a valley train.

Upstream from the irregular topography of the terminal moraine just described, about a quarter of a mile southwest of the Mitchell Ranch, the stream plunges over irregular hillocks of gravel. Though not sharply set off from the terminal moraine, this part of the valley bottom is slightly rougher than the area between it and the western part of the moraine and may be regarded as a recessional moraine that ponded the main stream at the Mitchell Ranch, forming the present lake flat.

Ground moraine forms the floor of the valley between the recessional moraine just described and the lowest bedrock outcrops in the valley floor—those at an altitude of 11,000 ft. In the neighborhood of the Mitchell Ranch the ground moraine is about 175 ft thick, as determined by projecting downstream the bedrock surface visible above the ranch.

Attention is directed to the fact that Capps (1909, plate 1) draws the crest of the terminal moraine half a mile east of the locality at which it is recognized by the writer, evidently regarding what is here described as a recessional moraine as part of the terminal moraine of the Empire glacier.

DEPOSITS OF HORSESHOE GLACIER

A glacial lobe was mapped by Capps (1909, p. 89 and plate 1) as occupying the cirquelike valley head between Empire Hill and Horseshoe Mountain. The drift cover here is thin, probably nowhere exceeding 30 ft. It represents essentially ground moraine. The ice in this region must have been generally stagnant, to judge by the fact that there was so little heaping up of morainal material.

TERRACES RELATED TO GLACIATION OF THE WISCONSIN STAGE

Capps (1909, pp. 21–22, pl. 1), Westgate (1905, pp. 288–289, 299), Emmons, Irving, and Loughlin (1927, p. 16, pl. 7), Behre (1933a, pp. 785–814), and Powers (1935, pp. 184–199) have described the gravel terraces of nearby regions. The areal distribution of these terraces indicates clearly that they are of the Wisconsin glacial stage. They consist of moderately well sorted gravel that is very little weathered and only very slightly indurated. These terraces are trenched to a depth of as much as 200 ft by the action of recent streams, and have their upstream beginnings at the lower ends of the terminal moraines of the latest (Wisconsin stage) glaciation, such as the terminal moraines described above.

In the southern part of the region here discussed no such terraces are seen, though farther away, just west of the Iowa terminal moraine, two patches were mapped by Capps (1909, pl. 1). On the south bank of the East Fork of the Arkansas River, however, east of where the stream is crossed by the highway from Leadville to Tennessee Pass, there are two well-formed terraces of glacial outwash of the Wisconsin stage, rising to altitudes of 25 and 60 ft above the present river level. The material consists of gravel and sand, fairly well sorted. The boulders are well rounded and fresh, with no striations. Locally there are pockets of laminated clay. These gravels are worked intermittently for road ballast.

East of the highway and south of the East Fork of the Arkansas River, the higher of the two terraces has a gentle slope, heading where Evans Gulch crosses the 10,100-ft contour line. Despite this form, which gives the appearance of purely local outwash or of an alluvial fan, the lower edge of this terrace is level with the terrace on the north side of the East Fork. The writer has discussed elsewhere (Behre, 1933, pp. 801–802) the correlation of terraces such as these, which lie upstream from terminal moraines of Wisconsin glaciation. In accordance with his view, the terrace 60 ft above river level is regarded as outwash from a late glacial stage and correlated with certain deposits that represent a recessional moraine farther upstream in the valley of the East Fork.

SUMMARY OF WISCONSIN GLACIAL HISTORY

All of the glacial and glacio-fluvial deposits described in detail above are the result of glaciation generally assigned to the Wisconsin stage. This Wisconsin glaciation resulted in the building of morainal deposits and outwash terraces, followed apparently by ice recession and then by a distinct pause in retreat, during which recessional moraines and corresponding outwash terraces were formed. Examples of the deposits that resulted from these two recognizable substages of the Wisconsin stage of glaciation are seen in Empire Gulch and the valley of the East Fork of the Arkansas River.

The existence of two distinct glacial substages is also suggested by the double rock benches and double cirques in longitudinal profile at the head of Dyer Amphitheater (fig. 5), in upper Evans Gulch at an altitude of 12,000 ft, in Iowa Gulch at 11,850 ft, and in Empire Gulch at 12,000 ft.

INTERGLACIAL HISTORY

There is no very striking physiographic evidence of a period of deglaciation preceding the glaciation described above. After studying the physiography of the general region, however, and noting the extent to which earlier glacial deposits have been eroded, Capps (1909, pp. 20–21) concluded that there was active pre-Wisconsin erosion. He also noted the weathered condition of pre-Wisconsin glacial deposits in comparison with the freshness of the Wisconsin morainal material—a difference that can be explained only by a long period of weathering of the older deposits before they were covered by ice sheet and till during the Wisconsin stage. From these facts he inferred that the inter-

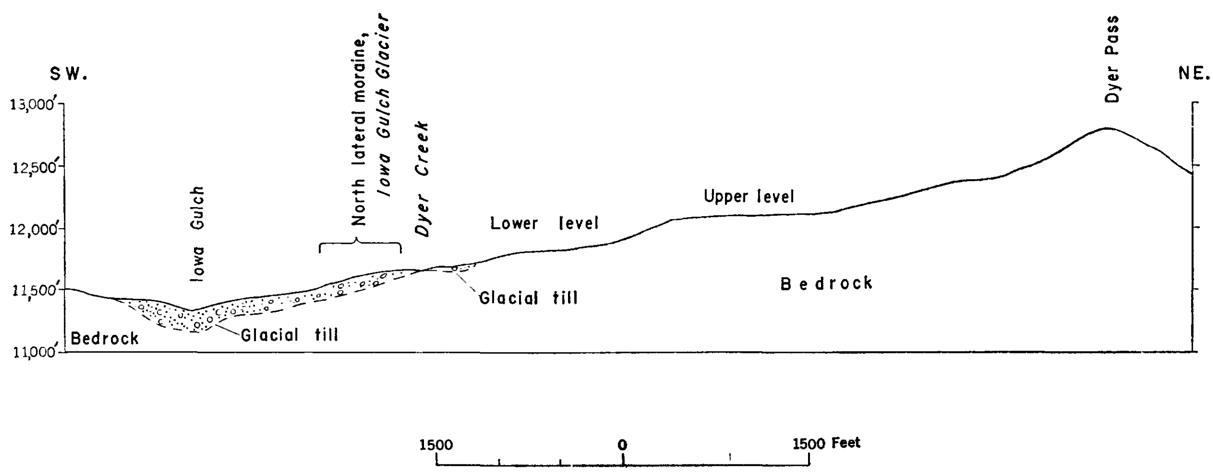

FIGURE 5.—Vertical section up Dyer Amphitheater, to show the two distinct levels believed to represent the valley floors developed in two glacial stages.

glacial interval was at least as long as that which has elapsed since the last or Wisconsin glaciation.

PRE-WISCONSIN GLACIATION

Mainly from studies of nearby areas, Capps (1909, pp. 14–15), Westgate (1905, pp. 291–292), and others have concluded that at least one important glacial stage preceded the Wisconsin stage. The strongest evidence for this is: (1) the occurrence of so-called "high-level terraces", believed to be made up of outwash from the earlier glaciers, and (2) the presence of isolated deposits of earlier glacial till. The "high-level terraces," the heads of which are well above the uppermost terrace level referred to glacial outwash, will be considered under a separate heading. Of the older till only one patch is recognized in the area here described. It consists of a number of erratic boulders, greatly weathered and lying 100 yards beyond the edge of the south lateral moraine of Wisconsin age on the west slope of Empire Hill, south of the Mitchell ranch. The boulders were described by Capps and attributed by him to a pre-Wisconsin glacial stage (1909, p. 91).

Erosional features, taken by themselves, give no clear evidence that glaciation of an earlier stage affected this region. There are no clear examples of typically U-shaped glaciated valleys of pre-Wisconsin age. Emmons, Irving, and Loughlin have interpreted sections across Evans Gulch as indicating the existence of a higher glacial valley of pre-Wisconsin age, trenched by the steeper-walled valley that resulted from Wisconsin glaciation (Emmons, Irving, Loughlin, 1927, p. 11, fig. 1, sec. J–J′), but this evidence is not conclusive.

Immediately south of the area, however, the west slope of Horseshoe Mountain is drained by two small tributaries of Weston Gulch, the faintly amphitheater-like heads of which suggest a possible early glacial origin; under this interpretation they have been greatly modified by erosion preceding and following the Wisconsin glacial stage.

There is no known evidence in the Leadville district of any still older glaciation, although Powers (1935, pp. 196–199) has clearly recognized older outwash farther south along the Arkansas River, and remnants of such deposits may lie buried and unrecognized in the high-level terraces described below.

HIGH-LEVEL TERRACES

In this discussion "high-level terraces" are distinguished from terraces definitely proved to be of glacial origin because the writer doubts that these higher terraces can be positively correlated with any known glacial or interglacial stage. A brief discussion of the terraces follows.

A terrace level about 350 ft above the Arkansas River near the valley axis, is typically formed on the east side of the river from Twin Lakes some 10 miles north to Malta. This terrace consists of well-sorted, well-rounded gravel and minor quantities of interstratified sand. At the surface the boulders are fairly well decayed, but at depth decay is not extreme, as revealed in recent cuts like that at Malta. The material is moderately well indurated, the cement consisting mostly of calcium carbonate. Near the middle of the Arkansas Valley the terrace surface slopes about 2° toward the river axis, but farther away the slope increases to 5° or even more. For further description of these terraces, the reader is referred to the work of Capps (1909, pp. 15–20), and of Emmons, Irving, and Loughlin (1927, pp. 15–17).

It has been shown elsewhere (Behre, 1933a, pp. 798–801) that these high-level terraces are higher than those definitely known to be continuous with the moraines of the pre-Wisconsin glaciers recognized on the west side of the Arkansas River—for example, on lower Lake Creek, near Twin Lakes, and on Half Moon Gulch, as described by Westgate (1905, pp. 288–289, fig. 3) and by Capps (1909, pp. 52–53, 62). Considering this greater altitude, it seems less likely that the high-level terraces east of the Arkansas River in the neighborhood of Leadville are outwash from the older of the two moraines of Capps than that one of the two following explanations is correct. They may be (1) terraces of an even earlier ice-sheet or (2) alluvial material dating back to a preglacial or interglacial period of alluviation. A more detailed discussion of these alternatives is presented in the writer's paper just cited. Briefly, the terraces are here regarded not as glacial outwash but as remnants of a huge piedmont alluvial fan formed after a period of rapid uplift and erosion. Recently obtained evidence seems to show that the gravels of the highest terraces overlie an ancient, heavily weathered morainal deposit at Cache Creek, south of Twin Lakes, and thus that they are outwash from the earlier of two pre-Wisconsin glacial stages or represent alluviation following this earlier pre-Wisconsin stage.

In the area here described, the high-level terraces are conspicuous both north and south of Leadville. From the western slope of Canterbury Hill westward, they dominate the landscape. Here they have been so eroded that their top surface is not as regular as elsewhere, but the absence of terminal moraines of Wisconsin age causes the typical terrace material to be well exposed, especially at the 10,200-ft ridge about ½ mile north of the Leadville racetrack. Still farther north the terrace material is concealed by the southwestern part of the terminal moraine of the East Fork glacier of Wisconsin age.

But it is in the southwestern part of the area that the high-level terraces become most conspicuous. On the divides north and south of Iowa and Empire Gulches at altitudes below 10,600 ft they are the most striking feature of the topography. (See fig. 6.) Below that altitude and locally at even higher levels, these divides, instead of extending westward as narrow, somewhat steep-sided ridges, widen and are flat-topped in north-

FIGURE 6.—Typical moraine and high terraces, Empire Gulch; view westward from vicinity of Hatch Ranch; note flat-topped terraces in middle distance.

south sections. Their mesalike surfaces slope westward toward the Arkansas River at angles ranging from 2½° to 7°, depending on the distance from the mountain crests. The gravel veneer thins upslope until near the head of Little Union Gulch and along the road from Iowa to Empire Gulch on lower Long and Derry Hill it is represented only by scattered boulders whose rounded shapes preclude a morainal origin.

West of the points just mentioned the thickness of these gravel deposits is unknown. In comparison, the gravel at the Spurr drill-hole on Capitol Hill, immediately north of Leadville, is 500 ft thick. In the neighborhood of Rock Hill, on the northern slope of Iowa Gulch, thicknesses average 200 ft (Emmons, Irving, and Loughlin, 1927, p. 17), but may include the "lake beds" described below. The thickness still farther south is indicated by the fact that on the divide between Iowa and Empire Gulches no workings whatever west of the latitude of the Musk Ox shaft penetrate to bedrock. In the absence of deep drillings or shafts west of the Musk Ox shaft, perhaps the best thickness estimate can be obtained by projecting westward the slope of the bedrock surface exposed on rock divides. This method is subject to possible serious errors, especially those introduced by the flattening of the curve by which the bedrock surface declines toward the middle of the valley and by rather recent faults that have dislocated the overlying "lake beds." The probable maximum thickness is about 800 ft on the western border of the area, as determined near the divide between Iowa and Empire Gulches.

A second method of estimating the thickness of the high-terrace gravels is by noting the height of the divide crests above the present valley bottoms, the points of comparison on the different divides being along a line drawn at right angles to the valley axis. This method yields an average thickness of 250 ft for the western edge of the area mapped. In this immediate area the valleys have nowhere been cut to bedrock; moreover, in the divides the bedrock surface may be high above its altitude beneath the valleys. This method likewise is subject to error, but the figure given is probably close to the minimum.

In 1942 J. H. Swartz (Oral communication) made geophysical surveys near the proposed site for the deep drainage tunnel, driven in 1943 from the East Fork of the Arkansas southeastward. He found that the bedrock surface between the lower parts of Thompson and Iowa Gulches might be about 500 ft beneath the present surface, but he could not distinguish with certainty between bedrock and thoroughly compacted "lake beds". He also found in Iowa Gulch indications of a preglacial gorge, the bedrock floor of which might be at least 1,000 ft below the present gulch bottom. This old gorge was apparently filled with "lake beds" overlain by gravels. According to Swartz, north of Iowa Gulch the altitude of bedrock may reach 9,400 ft or more, 700 ft below the present surface of the gravels, and here, too, bedrock is immediately overlain by "lake beds." These facts tend to confirm the order of thickness of the high-terrace gravels presented in the foregoing paragraphs.

In summary, it is wholly likely that the maximum thickness attained by the high-level gravels lies between 250 and 800 ft and probably approaches the thickness of 500 ft recorded in the Spurr drill-hole previously mentioned. These figures may include some of the "lake beds" described below.

"LAKE BEDS"

Still older than any of the deposits described above and almost everywhere covered by such deposits, are poorly consolidated, clayey sandstone and marls, generally called "lake beds." In a drill hole in Pawnee Gulch they have a thickness of about 640 ft, but the average is probably much less. Within the area under consideration the deposits are well exposed only in mine workings, and as none of the mines in which they have been reported is now accessible the only descriptions available are those in earlier publications. The deposits are generally similar to those described by Emmons (1886, pp. 71–72). Attention is directed to the scattered angular blocks found as a sort of "basal conglomerate" in the finer matrix described above. The history thus depicted is that of ponding on an old, partly weathered surface and the formation of local lakes in which the fine-grained sediments accumulated, but little is known about the extent of these lakes.

In age the "lake beds" are known to be late Pliocene or early Pleistocene, as indicated by mammalian remains found in the Bessie Wilgus mine on Rock Hill, just north of the area studied (Emmons, Irving, and Loughlin, 1927, p. 19).

From their character and distribution, the "lake beds" are thought by Emmons, Irving and Loughlin to have been the result of ponding by the glaciers of a stage preceding the earlier of the two glacial stages discussed above. Under this hypothesis there would be three glacial stages, and the authors mentioned assign the "lake beds" to the first, the "high-level terraces" and local patches of older drift to the second, and the lower terraces and prominent moraine deposits of the region to the third or Wisconsin stage. By the interpretation of the writer, the "lake beds" would have been deposited prior to the first glacial invasion in depressions in the bedrock surface, after which they were covered by the high-terrace gravels of a Piedmont alluvial plain.

STRATIGRAPHY OF BEDROCK

PRE-CAMBRIAN ROCKS

GENERAL RELATIONS

The pre-Cambrian rocks are divided into two large groups: (1) Highly metamorphosed rocks of sedimentary and igneous origin, here generally referred to as metamorphic rocks, and (2) slightly metamorphosed or unmetamorphosed granites and related igneous rocks, intruded into the metamorphic rocks and thus clearly of later age.

The metamorphic rocks comprise several kinds of schist and gneiss. The granitic and related rocks comprise two different granites, a quartz diorite, and the pegmatitic and aplitic differentiates of these intrusives. In some localities fine-grained dikes cut the pre-Cambrian rocks and, being confined to the latter, are of indeterminate age; however, a petrographic comparison with dike rocks occurring elsewhere and known to be of late Cretaceous and Tertiary age clearly shows their close resemblance, and suggests a similar age.

METAMORPHIC ROCKS

GENERAL FEATURES

Under the heading of metamorphic rocks are grouped schists and gneisses of pre-Cambrian age which represent highly recrystallized igneous and sedimentary rocks. Similar rocks of the Sawatch Range clearly include quartzite and marble that were originally sediments as well as schists and gneisses of uncertain origin (Stark and Barnes, 1935, pp. 472–473). The metamorphic rocks of the Mosquito Range in the neighborhood of Leadville have not been as thoroughly examined, partly because such studies appeared to promise little of significance to the purpose of this report and partly because the exposures are few and discontinuous, and therefore less amenable to successful detailed work.

All of the metamorphic rocks are cut by large granitic intrusives of the types described below. The metamorphic rocks occur as large bodies that may be parts of a continuous basement of country rock only superficially separated by the granites. Most such bodies, however, appear as isolated blocks or xenoliths surrounded by granite; they range in size from a few feet to a quarter of a mile across.

No general subdivisions of the metamorphic rocks are recognized, but the more important kinds are described below.

DISTRIBUTION

Dark-colored biotite schists and other highly recrystallized metamorphic rocks have a distribution far more restricted than that of the pre-Cambrian granites. They form the greater part of the pre-Cambrian terrain in the northern head of Evans Gulch, south of the Kemble and Daisy mines (pl. 1, mines C–60 to C–62). Large inclusions are also well exposed on the east wall of

South Evans Amphitheater; in the floor of the Dyer Amphitheater; on the northwest slope of Mount Sheridan, southwest of the trail to the Hilltop mine; and in Iowa Gulch just east of the Liddia fault, where the stream crosses from the pre-Cambrian rocks into the Paleozoic sedimentary strata. For detailed study, however, the best exposures are small inclusions on the northeast and northwest slopes of Finnback Knob.

KINDS OF ROCK

Biotite-hornblende gneiss.—East of Empire Hill on the north slope of the knob that attains an altitude of 12,686 ft, and also on the north slope of Finnback Knob (the 13,405-ft knob half a mile northwest of Horseshoe Mountain), the granite includes xenoliths of a dark, gneissoid rock with a hackly fracture. This rock is classified as biotite-hornblende gneiss. It is dark gray, almost black, finely spotted with pink microcline crystals. Under the microscope the rock is seen to consist chiefly of green hornblende, quartz, microcline, partly bleached brown biotite, and small quantities of oligoclase-albite. Accessory minerals include rutile, sphene, and apatite, partly well crystallized. Alteration products are sericite—largely in spherulitic or sheaf-like masses—and limonite. The hornblende, biotite, and quartz are intimately intergrown, but the microcline occurs in scattered grains among the other minerals and in tiny aplitic veinlets that cut across the rock; it is clearly later than the other chief constituents.

The origin of this rock is in doubt, because of the extreme metamorphism. There is nothing to suggest a sedimentary origin, and Lovering considers a similar rock in the Front Range to be intrusive (Lovering, 1929, p. 66).

Quartz-biotite gneiss.—The quartz-biotite gneiss is a fine-grained, medium-gray rock, having pronounced lamination that is probably due to bedding. It commonly assumes the appearance of an injection gneiss, occurring as inclusions in the pre-Cambrian granites and cut by closely spaced veinlets and stringers of granitic material. Some of it consists almost wholly of quartz and biotite; other facies contain much feldspar. Individual laminae or beds as much as half an inch thick consist wholly of quartz, much of which is in rounded grains suggestive of quartz sand.

Structure, texture, and the constituent minerals all indicate that this rock is of sedimentary origin. It probably represents an impure sandstone, originally rich in clayey matter and now highly metamorphosed.

Rock of this kind appears as roof pendants or xenoliths on the north slope of Finnback Knob and in the area of pre-Cambrian rocks in upper Iowa Gulch near the Liddia mine. A more massive variety, which contains much hornblende, is found under structurally similar conditions, grading into the quartz-biotite gneiss described.

Locally, as in some inclusions in the granite on the north slope of Finnback Knob, the quartz-biotite gneiss becomes an injection gneiss, characterized by numerous stringers of microcline and quartz, 0.5 cm (0.2 in.) or less thick, that follow the schistosity. The veinlets and the gneissic banding are minutely crinkled, and in addition the biotite has largely been bleached and recrystallized to tablets measuring as much as 1.0 by 0.3 cm, and about 0.25 cm thick in the basal sections. These numerous large mica tablets, having similar orientation, impart to the rock an excellent cleavage not observed elsewhere, and also a bright luster on the cleavage surface.

Biotite-sillimanite schist.—Rock that strongly resembles the biotite-sillimanite schist described from the Front Range by Ball (Spurr, Garrey, and Ball, 1908, pp. 38–40) and that occurs also in the Climax district north of Leadville (Butler and Vanderwilt, 1931, p. 325), is found in small yet widely distributed masses in the Leadville area. A small body is exposed in the north head of Empire Gulch, and a larger one in the amphitheater at the head of South Evans Gulch. It is a gray to black, banded, medium-grained rock that glistens on surfaces parallel to lamination.

The bands mentioned consist of alternate layers of the typical sillimanite-biotite schist and of a rock richer in quartz but containing moderate amounts of sillimanite and biotite. The sillimanite, which forms slender, silvery laths as much as 2 centimeters (0.8 in.) in length, is especially conspicuous on the fresh fracture. An accessory mineral in noteworthy quantities is a plagioclase feldspar, probably oligoclase. The biotite-sillimanite schist is believed to have been originally an alumina-rich sediment that became completely recrystallized as a result of dynamic metamorphism.

METAMORPHISM

The extent to which the present composition, structure, and texture of these rocks are due to simple recrystallization under high compression, or to the effects of granitic intrusion is impossible to determine. The bands of biotite-sillimanite schist, for example, are believed to reflect original differences of the layers, but the growth of sillimanite and micas may well have been due largely to the influence of emanations from the intruding granite. Clearly, much of the quartz, biotite, and hornblende have been introduced during metamorphism. The most reasonable interpretation of the present character of these rocks is that they were severely folded and, concomitantly or slightly later, permeated, recrystallized, and partly replaced by igneous material.

GRANITES AND RELATED ROCKS

KINDS OF ROCK

Two kinds of granite are recognized, but they may be merely different facies of a single magma. The reasons for distinguishing them in this description are given on a later page. The first kind is coarsely porphyritic and has a gray groundmass studded with large pink microcline phenocrysts. From its resemblence to granite at Pikes Peak, Colorado, as described by Cross (1894, p. 1), this kind is here referred tentatively to the Pikes Peak granite. The distance from Leadville to the type locality of the Pikes Peak granite, however, is too great to permit definitely assigning it to the Pikes Peak. It also resembles the Rosalie granite as described by Ball (Spurr, Garrey, and Ball, 1908, pp. 58–60), but Lovering (1929, p. 70) has shown that these two similar granites—the Rosalie and the Pikes Peak—are facies of the same intrusive mass; hence the older name, Pikes Peak, has been retained.

The second kind of granite is distinguished from the Pikes Peak(?) granite by its more uniform texture. The groundmass is gray, but pink lath-shaped microcline crystals, generally with subparallel or trachitoid orientation, give the rock as a whole a light-pinkish tint. Lithologically similar granite in the Front Range has been described by Ball (Spurr, Garrey, and Ball, 1908, pp. 58–60) and others under the name of Silver Plume granite. The type locality of the Silver Plume granite also is so far from Leadville as to preclude positive correlation, but the resemblance is so striking that the local rock is here referred tentatively to the Silver Plume granite. Near it in one locality is an apparently related dioritic rock.

Within or near masses of these two granites are pegmatitic and aplitic dikes so similar lithologically to the granites as to suggest a genetic relationship; hence the pegmatites are grouped with the granites in the descriptions which follow.

PIKES PEAK(?) GRANITE

Petrology.—The rock here referred to the Pikes Peak granite is a coarsely porphyritic granite (fig. 7), which is generally darker gray than the Silver Plume(?) granite, though it has a pinkish cast as seen at a distance. This pink color is not evenly distributed because it is due to large phenocrysts of microcline, commonly well separated, and scattered somewhat irregularly through the rock. The phenocrysts measure 3 by 2 cm (approximately 1.2 by 0.8 in.) in maximum observed dimensions. They are set in a moderately dark-gray groundmass of medium-coarse, granitoid texture, and composed of plagioclase, quartz, biotite, and muscovite. All minerals except the last are visible to the unaided eye (fig. 8). There is no distinctly trachitoid arrangement of any of the constituents, nor in general any definite elongation, though in a few places the mica forms ill-defined gneissic bands.

FIGURE 7.—Coarsely porphyritic Pikes Peak(?) granite cut by aplite facies of Silver Plume granite and enclosing schist fragments.

Under the microscope the plagioclase is seen to occur in both anhedral and euhedral grains. Its composition approximates that of andesine. The quartz appears in anhedral grains which exhibit strain shadows. Locally some of the quartz is in micropegmatitic intergrowths with the feldspar. Microcline individuals are not nu-

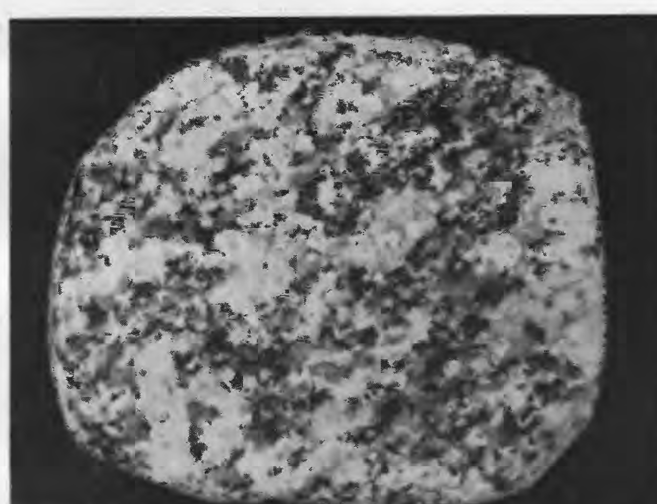

FIGURE 8.—Pikes Peak(?) granite; note coarsely crystalline texture and conspicuous dark minerals; length of specimen, 3 inches.

merous, but are so large that under medium power they nearly cover the field of the microscope. In places of extreme alteration both kinds of feldspar, but especially the plagioclase, have been converted to sericite, and also to kaolinlike materials. Most of the biotite is golden brown but some has a greenish hue; it is commonly bleached and chloritized. Generally, muscovite is present in only small amounts.

Accessory minerals include magnetite, which in places is segregated in relatively large masses, many of which have been altered to limonite. Apatite grains of unusually large size are common. Pyrite is locally an important constituent; it generally occurs in quartz veinlets and thus has clearly been introduced after the solidification of the rock. Its oxidation, far more than that of the magnetite, is responsible for the limonite stains so commonly seen. A few isolated patches of a dark amphibole, probably hornblende, have been seen in some places. Still more uncommon are zircon inclusions in the biotite, mostly surrounded by pleochroic halos.

In summary and to compare it with the Silver Plume(?) granite of the region, the distinctive features of the Pikes Peak(?) are (1) the large microcline phenocrysts that are equidimensional and lack a trachitoid arrangement, (2) the small quantities of potash feldspar in the groundmass, as compared to the amount in phenocrysts, (3) the small amount of primary muscovite, and (4) the brownish color of the biotite, as opposed to the green mica common in the Silver Plume(?) granite.

Distribution.—In some parts of the region the distribution of the porphyritic Pikes Peak(?) granite is very irregular. For example, in the cliffs that form the south wall of Empire Gulch east of the Empire Reservoir there are numerous small areas of this coarsely porphyritic granite, but much of the Silver Plume(?) granite occurs here also. Elsewhere, however, the Pikes Peak(?) granite is by far the dominant pre-Cambrian rock, notably at the head of South Evans Gulch, in upper Iowa Gulch, east of the Liddia cabins, and in general on the west slopes of West Sheridan Mountain wherever pre-Cambrian rocks crop out.

SILVER PLUME(?) GRANITE

Petrology.—The Silver Plume(?) granite (figs. 9 and 10) is generally light colored and equigranular. The color may be light bluish-gray or faintly greenish, especially where bleached in connection with mineralization, but pinkish tones predominate. The pink color is less intense than in the Pikes Peak(?) granite; the color is also more uniform, as the pink feldspar in the Silver Plume(?) granite occurs as smaller crystals that are more uniformly distributed.

In the hand specimens (fig. 10) microcline, quartz, plagioclase, biotite, and muscovite are recognizable, their relative abundance being in the order named. Of

FIGURE 9.—Finely granular Silver Plume (?) granite with inclusions; note fracturing of inclusions but lack of corrosion.

them the microcline is most conspicuous, forming lath-shaped crystals as much as 1.5 cm (0.6 in.) in length. These laths are commonly arranged with their longest dimensions parallel, giving a trachitoid texture that is very characteristic of the rock. In large part, because of the small size of constituents other than microcline, the rock is porphyritic, and its trachitoid texture is

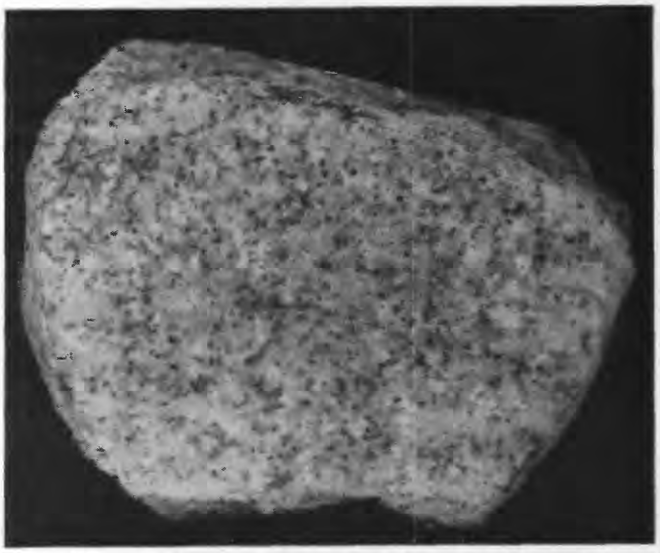

FIGURE 10.—Silver Plume(?) granite; note finely crystalline texture and faintly trachitoid arrangement of crystals with banding parallel to long dimension of specimen; length of specimen, 3 inches.

even more striking. Quartz, the only other commonly distinguishable mineral, occurs as grains measuring 0.5 cm (about 0.2 in.) in diameter.

The essential primary constituents identified under the microscope are microcline, plagioclase, quartz, biotite, and muscovite. Accessory minerals are magnetite, garnet, zircon, and apatite. Sericite, epidote, chlorite, secondary hematite, and limonite are alteration products.

Microcline forms the largest individuals and also smaller grains crystallized interstitially among the other mineral constituents. Well-formed grating structure is characteristic. Scattered areas of micropegmatite are seen, and perthitic intergrowths are common, in which the plagioclase forms thin bands transverse to the 010 face. Some of the microcline is replaced by sericite, which forms felty aggregates of tiny flakes. The potash feldspar consists of microcline with submicroscopic twinning, but some orthoclase may be present.

The plagioclase lies between oligoclase and albite in composition and is twinned in accordance with the albite law. Much of it has been sericitized—to a far greater extent than the potash feldspar. The quartz generally contains sagenitic rutile and shows moderate strain shadows and fractures along which secondary sericite has been formed. The biotite has a somewhat unusual color, verging on apple green. It commonly contains rounded zircon grains with pleochroic halos. A common alteration of the biotite results in a pale mica banded with hematite that has been segregated in the process of alteration. Chlorite and green epidote (pistacite) are other alteration products typically present in the biotite. Primary muscovite is not very common, but two or three flakes can generally be found in every thin section. Indeed, its presence in more than very small proportion indicates that the granite in question is the Silver Plume(?) granite.

Of the accessory minerals, apatite and zircon occur in well-formed crystals. Magnetite forms small evenly distributed grains. Where altered it becomes cloudy, and in the more advanced stages of alteration it changes to limonite.

In summary, the characteristic features of the Silver Plume(?) granite, by means of which it may be distinguished from the Pikes Peak(?) granite are (1) the trachitoid arrangement of lath-shaped feldspar crystals, (2) the light-gray or only slightly pinkish color of the rock, (3) the dominance of microcline over plagioclase, (4) the general presence of greenish biotite, and (5) the moderate content of primary muscovite.

A somewhat gneissoid pink granite, apparently a sheared phase of the Silver Plume(?) granite, is seen in some places, as on the northwestern slope of Finnback Knob and on the southwestern side of West Sheridan Mountain. This rock is similar in some respects to the quartz monzonite gneiss described by Ball, and by Lovering (1929, p. 67) from the Front Range. Mineralogically, however, the gneissic granite resembles the typical granite here identified with the Silver Plume; moreover, it is restricted to areas where the Silver Plume(?) granite predominates or at least forms large bodies. Hence, despite its somewhat gneissoid character, this rock may best be mapped with the Silver Plume(?) granite.

Distribution.—Silver Plume(?) granite forms the dominant rock east of the Mosquito fault in the floor of Evans Gulch, as shown in numerous excellent exposures near the Best Friend mine. The extensive outcrops of pre-Cambrian granites in South Evans and Dyer Amphitheaters and upper Iowa Gulch include some Silver Plume(?) granite. There are also extensive exposures on the south side of Empire Gulch from the neighborhood of the Paddock cabin to the head of the gulch, but here the two kinds of granite appear alternately and generalizations are therefore impossible. Much of the large granite mass exposed west of Empire Hill, extending from Empire Gulch to the southern boundary of the area mapped, is composed of the Silver Plume(?). Similar rock makes up the main granitic masses on the crest of the Mosquito Range from Leadville north to Climax (Butler and Vanderwilt, 1931, pp. 325–328) and has been identified by the writer at Weston Pass, 11 miles south of Leadville.

QUARTZ-MICA DIORITE

On the southwest slope of East Ball Mountain, near extensive exposures of the trachitoid granite that resembles the type Silver Plume granite, are two areas underlain by quartz-mica diorite—a dark-gray rock of granitoid texture. Both are large masses; the biggest exposure has an extent of about 20 acres. There are scattered exposures of similar rock north of the Best Friend mine in the valley of the Evans Amphitheater.

The rock is medium-grained, with a texture similar to that of the Silver Plume granite, except for the lack of characteristic feldspar phenocrysts in trachitoid arrangement. The principal constituents are quartz, a plagioclase feldspar (probably andesine), and biotite. Hornblende is suprisingly scarce and potash feldspar is absent. The quartz, which shows strain shadows, is clearly the last mineral to crystallize. The andesine is much altered to fine, felty aggregates of sericite. Large brown flakes of biotite are intergrown with the quartz and andesine; many crystals are bleached. Zircon and rutile inclusions are present in strikingly large quantities. Other accessory minerals include much apatite in conspicuous well-formed grains, hornblende (now mostly altered), garnet, magnetite, and some pyrite peripherally oxidized to hematite and limonite.

The contact between this dioritic rock and the Silver Plume(?) granite is not exposed. The close association of the two types of rock, coupled with their similarities in texture and in accessory minerals, strongly suggests that the diorite is related to the granite and is either a differentiate of it in place or a small plug separately injected into the pre-Cambrian country rock; hence no distinction was made between these two rocks on the map.

PRE-CAMBRIAN DIKE ROCKS

Basic dikes.—Minette-like dikes of pre-Cambrian age are rare. Two, now largely schistose and converted to highly micaceous, hornblendic rock, occur in areas of Silver Plume (?) granite in the south head of the Empire Amphitheater, where they are separately mapped.

Pegmatites.—The characteristic pegmatites consist of milky quartz, pink or flesh-colored orthoclase or microcline, and books of biotite. A soda-rich plagioclase is a constituent of some veins. In texture the pegmatites grade from pegmatitic to typically granitoid. Biotite books attain a diameter of three inches and a thickness of four inches. Individual masses of potash feldspar reach maximum dimensions of six inches on a side. Dikes of granitoid texture that cut pre-Cambrian granite do not have sharply marked borders.

The form and position of the pegmatites are highly variable. Where they cut pre-Cambrian schists, as near the head of South Evans Gulch, they tend to follow the schistosity and are continuous for long distances, tapering to thin lenses between the schist laminae; elsewhere, as on the north slope of Finnback Knob, they cut across pre-foliation planes of the metamorphic rocks and are short and blunt. Commonly, the more schistose the rock, the more accordant are the dikes with its structure. In the massive rocks their form and extent are even more varied.

Aplite.—Aplitic dikes have much the same distribution as the pegmatites, which they generally cut. In composition the aplites resemble the pegmatites, but it is notewerthy that they generally contain a far smaller quantity of dark minerals.

RELATIONS OF THE GRANITES AND RELATED ROCKS

REASONS FOR SEPARATION

In the Front Range of Colorado, due east of Leadville, the Pikes Peak and Silver Plume granites have been studied with great care and are clearly distinguishable petrographically and texturally, and the Pikes Peak represents an earlier intrusion (Spurr, Garrey and Ball, 1908, p. 58). As distinguishing them is essential to the correct interpretation of the geologic history of the Leadville region, it is desirable to map them separately in this region also.

At Climax, 11 miles north of Leadville, a granite has been recognized that closely resembles both the typical Silver Plume granite (Butler and Vanderwilt, 1931, pp. 325–328) and Silver Plume (?) granite at Leadville. Petrographically similar granite occurs in the Sugarloaf district, 6 miles west of Leadville, and near Weston Pass, 11 miles southeast of Leadville along the crest of the Mosquito Range. In contrast, granite resembling the Pikes Peak granite of the Front Range occurs in the Mosquito Range at Buena Vista, south of Leadville. The area between Buena Vista and Leadville along the crest of the Mosquito Range has not been studied in detail, but the relationships described above demonstrate that both kinds of granite occur within a few miles of the region here described.

It is not surprising, therefore, to find both types in the vicinity of Leadville. It is difficult to distinguish them in the field because rock of intermediate character is of common occurrence, suggesting that the two apparently distinct granites in the vicinity of Leadville are merely facies of one large body. Alternatively, the characteristics of the Pikes Peak (?) granite might possibly be attributed to a high degree of permeation and replacement of pre-Cambrian schists by the intruding granitic magma. This process might then have been followed by intrusion of a more nearly pure magma, represented by the Silver Plume (?). Such an interpretation has indeed been offered for a similar rock in the Sawatch Range (Stark and Barnes, 1931, oral communication).

The writer believes, instead, that there are at Leadville two fairly distinctive granites that have intimate intrusive relations. In view of their similarity to the Pikes Peak and Silver Plume granites of the Front Range, their equivalence may best be tentatively accepted and the two petrographic units distinguished in mapping. Moreover, it seems desirable to recognize the petrographic differences and to draw corresponding boundaries as correctly as possible, so that if future work should prove the distinctness of the two granites, the mapping will already have been completed.

RELATIVE AGES

If the writer's correlation is correct, the coarsely porphyritic granite should be the older of the two types as it resembles the Pikes Peak granite. In the region here studied, however, the field evidence is not entirely conclusive.

On the northwestern side of West Sheridan Mountain the porphyritic Pikes Peak (?) granite is cut by fine-grained granitic and aplitic dikes, the texture and composition of which rather closely resemble those of Silver Plume (?) granite. Likewise, at the head of South Evans Gulch, just east of the Mosquito fault, granitic dikes two feet thick cut coarse porphyritic Pikes Peak (?) granite. The rock of these dikes is a medium-grained pink granite, with elongate plagioclase crystals that are trachitoidally arranged, with their long dimensions parallel to the dike walls. The contact between dike rock and surrounding granite is sharp, and in places the dike borders show distinct chilled zones, evidently because of a marked difference in temperature between country rock and dike rock during the crystallization of the latter. The large size of these dikes and the similarity of the textures indicate that between the emplacement of the granitic country rock and injection of the dike material enough time elapsed to permit complete crystallization and considerable reduction in temperature of the main granite masses. Each mass probably represents the more superficial parts of a deeper intrusive body. If this interpretation is correct the Silver Plume(?) magma of the dikes is much younger than the Pikes Peak(?) granite into which it was intruded, and may represent another or secondary cycle of intrusion.

In Empire Gulch, where both granites are found, the contact between large masses of the two kinds of rock is nowhere clearly exposed. On the northwest slope of Finnback Knob near the valley floor the coarse, porphyritic Pikes Peak(?) granite and the Silver Plume(?) have an almost horizontal contact. The elongate phenocrysts in the latter granite possess their usual trachitoid arrangement but, as they are directed at right angles to the contact, the impression is gained that they represent an earlier structure, cut by the Pikes Peak(?) granite which would therefore be the younger. It must be admitted, however, that this evidence is not conclusive. In the same general region a loose boulder of the Silver Plume(?) granite clearly contains an inclusion, somewhat rounded as though by partial resorption, of the coarsely porphyritic Pikes Peak(?) granite.

These occurrences and the analogous relations of similar rocks in the Front Range indicate that at Leadville also the Silver Plume(?) is the later of the two granites.

AGE OF PRE-CAMBRIAN ROCKS

The age of the pre-Cambrian granitic rocks in this region has not been determined. However, as the granites have been compared with those of the Front Range, the following statement made by Lovering (1929, pp. 73–74) regarding the granites of the Front Range may also apply here:

> The Idaho Springs formation could thus be tentatively correlated with the Lower and Middle Huronian, the Pikes Peak granite assigned to the early Algoman, and the Silver Plume and associated granites to the late Algoman. All these formations would then be included in Algonkian as defined by the U. S. Geological Survey.

PRE-CAMBRIAN STRUCTURE AND PHYSICAL HISTORY

Because the metamorphic rocks of pre-Cambrian age appear in such small and discontinuous exposures, their structure cannot be worked out in detail. At most places schistosity and sedimentary banding are nearly or quite parallel, and both generally have steep dips. In Iowa Gulch near the trail to the Hilltop mine, the schistosity strikes N. 20° W. and dips 60° SW. In the upper part of Iowa Amphitheater the regional strike of the schists is N. 50° W. and the dip is steeply northeastward. In the Dyer Amphitheater the strike is N. 5° W. and the dip 80° SW. The largest schist mass in upper South Evans Gulch has banding that strikes fairly uniformly N. 20° W. and dips 45° NE. The lowest dips were observed in the most northerly exposures—those in the several prospects in upper Evans Gulch north of the Best Friend mine and just east of the Mosquito fault; the strike of the schistosity here averages N. 10° W., the dip is 25° NE. In a few localities the schistosity strikes northeast.

These scattered observations, even though made on isolated inclusions of highly metamorphosed rocks, suggest a regional structure in which bedding and schistosity dip northeast or stand essentially vertical. As there is no agreement between this structure and that of the overlying Paleozoic sediments, it is evident that the dominant pre-Cambrian structure is inherited from a period of diastrophism earlier than that to which the Paleozoic rocks of the Mosquito Range owe their present attitudes—in short, that the structure of the metamorphic rocks is of pre-Cambrian origin. Further, the pre-Cambrian granitic intrusions, though locally transgressing the structure of the schists and gneisses, also domed these schists and gneisses, producing a regional northwest strike and northeast dip in this part of the range.

This conclusion is in general agreement with observations of Lovering (1930, p. 234) and others for the Front Range, and those of Stark and Barnes (1935, p. 478) for the Sawatch Range just west of Leadville. In the Front Range, however, the somewhat varied strike of secondary structures in the schists is chiefly east-northeast or due east. The areas studied by Lovering are so far away that they scarcely bear on the local structure of the area considered in this report, and those studied by Stark and Barnes, in which the schistosity and banding were observed to strike northeast, with the dip northwest, may simply represent a structure, fan-like in ground plan, and with a generally westward overturn. According to the interpretation offered, the pre-Cambrian rocks of this part of the Mosquito Range were folded on northeasterly axes and either subsequently or concomitantly intruded by granites which formed a cupola or group of cupolas with their highest points to the southwest. The region was later subjected to erosion, and the Paleozoic sediments were deposited on an essentially peneplained surface. The subsequent history of the pre-Cambrian schists, gneisses, and granites is in accord with that of the overlying Paleozoic rocks.

PALEOZOIC ROCKS [1]

SAWATCH QUARTZITE

Name.—The name Sawatch quartzite was retained from earlier literature (Emmons, Irving, and Loughlin, 1927, p. 25) for the lower part of a formation formerly also called the "Lower" quartzite. Its use as a formation name is here restricted to the quartzite of Late Cambrian age. The Sawatch is limited to the quartzite, generally white and averaging 105 ft in thickness. The overlying Peerless formation, by contrast, is of Late Cambrian age and consists of 45 ft of light brown or buff calcareous, sandy, shale (fig. 11).

Description.—The stratigraphy of the Sawatch quartzite varies greatly in detail, but certain features are so uniform as to merit mention. The total thickness averages 105 ft but varies somewhat from place to place, being 100 ft at Weston Pass, a short distance south of the area mapped, and 125 ft at Mount Zion, just north of it. The formation as a whole thins southward and eastward.

The basal bed is a conglomerate about 2 ft thick. Its pebbles are well rounded, chiefly of bluish or white quartz, and ½ in. or less in diameter; the matrix is generally composed of fine white quartz grains, pure in most places, but locally somewhat clayey or micaceous.

For some distance, usually about 60 ft above the conglomeratic bed, the formation consists of white, glassy, quartzite, in beds averaging about 3 ft in thickness. Some of these beds weather with a peculiar pinkish cast. It is these white beds that form a most conspicuous white band on cliffs or other bare surfaces, a feature so striking that it may be recognized on West Sheridan Mountain from the top of Mount Elbert, west of the Arkansas Valley and 14 miles away. Under the microscope these beds are seen to consist of slightly enlarged, rounded quartz grains, interlocking somewhat and set in a matrix of sericite.

Approximately the upper 40 ft of the Sawatch quartzite consists mostly of impure gray, buff, and brownish sandstone. Many beds have a calcareous cement and hence become pitted or honeycombed upon weathering. The lower sandstone beds are interbedded with the white quartzite described above, so that outcrops have a distinctive striped appearance (figs. 12, 13). Higher in the sequence, the white quartzite is entirely absent and the buff sandstone is the dominant rock type. Here the beds average 1 ft in thickness, and crossbedding is conspicuous. Because of the solubility of the cement, the individual sand grains weather out, resulting in a gritty surface very different from the smooth faces of the quartzite beds that make up the lower part of the formation.

Relation to adjacent formations.—The contact of the Sawatch quartzite with the underlying pre-Cambrian crystalline rocks is a remarkably flat surface. On the south slope of West Dyer Mountain, on the northwest wall of Dyer Amphitheater (fig. 12), and on the east wall of the Empire Amphitheater, the basal conglomeratic bed of the Cambrian can be traced continuously for a distance of several hundred feet without visible noteworthy depressions in the pre-Cambrian floor on which it was deposited.

The upper limit of the Sawatch quartzite is generally marked by a bed of purple or black quartzitic sandstone, dark-brown where the cement is oxidized. In places where this sandstone is covered or absent, the position of the lime between the quartzite and the overlying Peerless formation can be drawn within five feet by noting the change in character and color of bedrock or chips where the more massive, buff-colored sandy beds or fragments are succeeded upward by thinner, cream-colored shaly beds that alternate with thin limestone layers.

Geologic age and correlation.—Small collections of fossils were made in two localities—from the cliffs at the southeast side of Mount Sherman and from the cliffs on the west slope of Peerless Mountain at the head of Empire Gulch. At both places the material was from loose blocks, but a comparison of lithologic features suggests that the fossils are from the uppermost, sandy beds of the Sawatch quartzite. In discussing the collections from Mount Sherman, C. E. Resser of the U. S. National Museum said:

> The material . . . contains fairly complete specimens of the brachiopod *Dicellomus*, and hence is to be correlated with the lower Upper Cambrian Eau Claire and other formations of that age.

Another small collection from the same locality was referred to Edwin Kirk of the U. S. Geological Survey, who identified the fossils as a species of *Lingulella* and stated that the age indicated is Late Cambrian. On the west slope of West Dyer Mountain a small collection of brachiopods was made in the uppermost, locally calcareous beds of this member. These were identified by Edwin Kirk as *Eoorthis linecosta* Walcott, and referred by him to the Late Cambrian.

Brachiopods related to the forms mentioned have been collected from the Cambrian in Buckskin Gulch, near Alma, on the east side of the Mosquito Range (Patton, Hoskin, and Butler, 1912, p. 51), and a form closely resembling the trilobite *Dikellocephalus minnesotensis* is reported from talus blocks on Quandary Peak, near Alma, by Emmons (1886, p. 60). All these fossils point clearly to the Late Cambrian age of the Sawatch quartzite.

The lower, more strictly quartzitic beds included in the Sawatch may represent the Middle or Early Cambrian, but it is more probable, considering the absence

[1] See also Johnson, J. H., Paleozoic formations of the Mosquito Range, Colorado: U. S. Geol. Survey Prof. Paper 185-B, pp. 15-43, 1934.

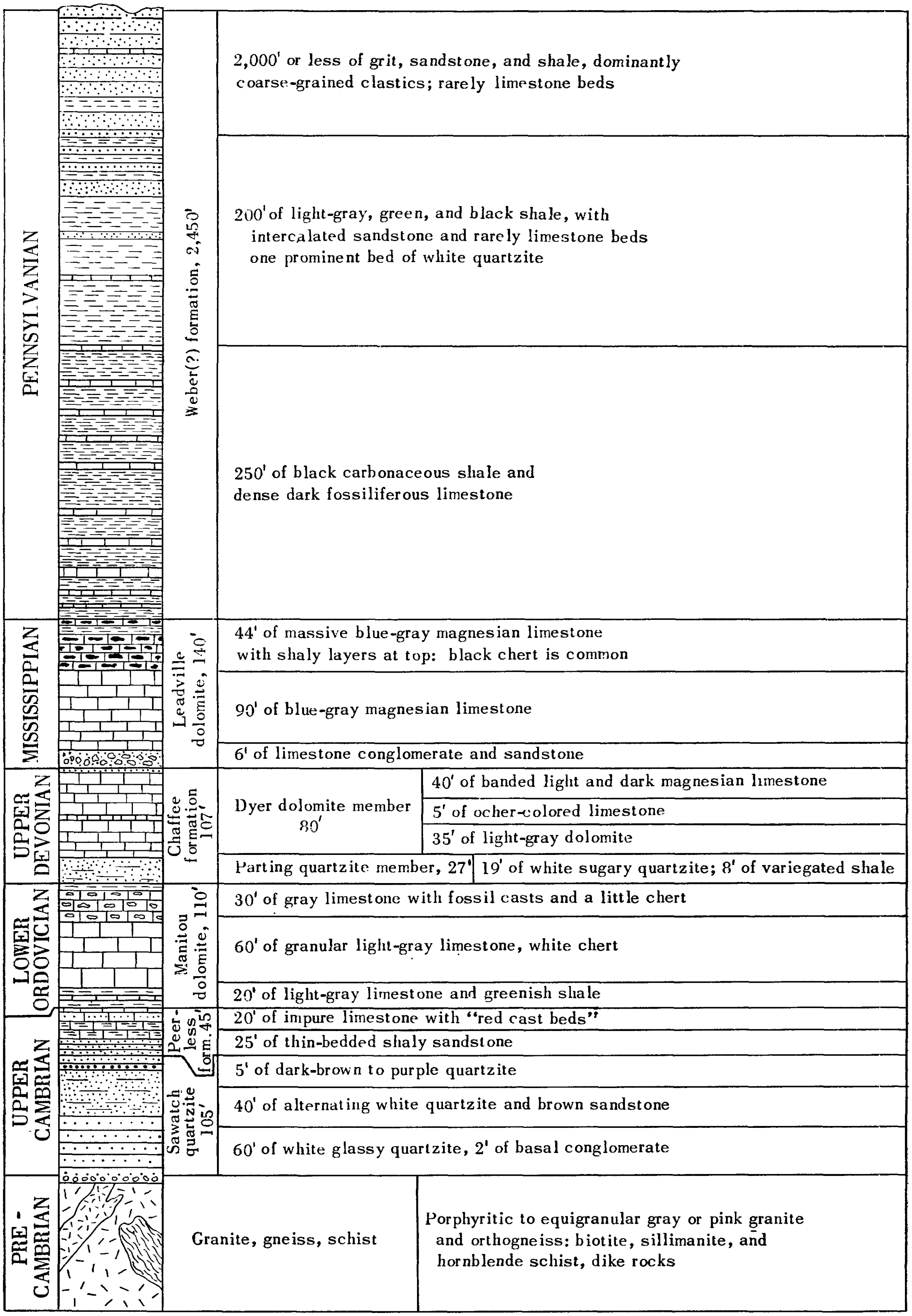

FIGURE 11.—Generalized stratigraphic column of Leadville region; to scale, but full thickness of Weber(?) formation not shown.

FIGURE 12.—Section showing pre-Cambrian and Paleozoic rocks; length of the face shown 1,800 feet; exposure on western wall, Dyer Amphitheater.

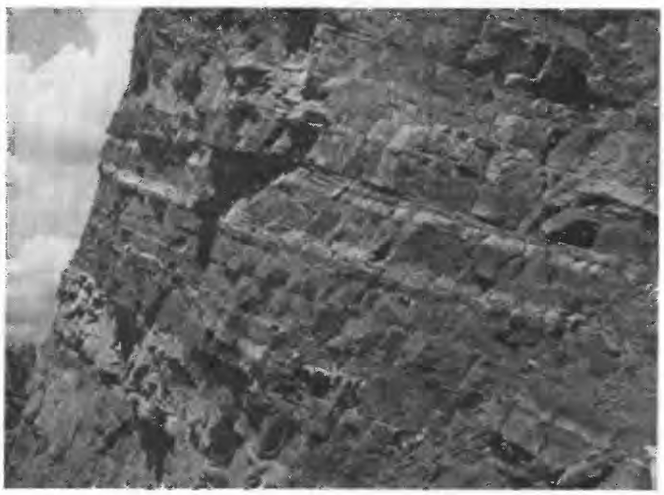

FIGURE 13.—Typically banded white quartzite of Cambrian age.

of marked lithologic breaks separating them from the overlying more sandy beds, that they are of about the same age as the sandy beds and that no deposits were laid down before Late Cambrian time in this part of Colorado.

PEERLESS FORMATION

Name.—The strata above the dark beds of the Sawatch quartzite have been described in earlier reports under the term "transition shales" but, as they are readily distinguished from the underlying quartzite on a lithologic basis, it has proved desirable to recognize them as constituting a distinct formation, the lower limit of which is drawn at the top of the dark quartzite already mentioned. To the shaly, sandy, and calcareous beds thus distinguished from the Sawatch quartzite as here more closely defined, the name Peerless shale member was applied (Behre, 1932, p. 58). This member is now ranked as a formation, The type exposure is on the northwest slope of Peerless Mountain, 7 miles east-southeast of Leadville.

Description.—The Peerless formation is divisible into two parts. The lower part consists of 20 to 30 ft of thin-bedded, shaly sandstone with a few quartzitic layers up to 1 ft thick. The upper part consists of 20 to 25 ft of impure sandy and shaly limestone, largely brick-red, in beds as much as 2 ft thick. Many of these upper beds show fucoidal markings, and very characteristic "red casts." These are circular, ovoid, or disk-shaped bodies suggesting in form irregular pebbles or the "edgewise conglomerate" of many limestones, and stained at their margins with red iron-oxide so that they are conspicuous on weathered surfaces and look like coprolites or like casts of fossils. They are supposedly characteristic of the upper part of the Peerless formation, but they have been found through a thickness of 30 ft of sediments, and thus extend well down into the lower part of this stratigraphic unit.

Despite the lime content of the Peerless formation, no alteration is observed in the region described. At Leadville, in some mineralized ground, leaching by solutions has locally produced a little "dolomite sand" similar to that described on a later page for the Leadville and Manitou dolomites.

The thickness of the Peerless formation ranges from 40 to 55 ft; it is generally about 45 ft.

Relation to adjacent formations.—In contrast to the generally sharp lower boundary already described, the upper limit of the Peerless formation is gradational. The line is drawn somewhat arbitrarily where limestone becomes the dominant rock. At places where, for lack of exposures, the upper boundary is in doubt, a thickness of 45 ft for the Peerless has been assumed—a procedure which experience has shown to be sufficiently accurate for purposes of mapping.

Geologic age and correlation.—The age of the Peerless formation is in doubt. In the area described no fossils have been collected from it. Johnson (1934, p. 20) refers it to the middle or late Late Cambrian on the basis of fossils found in the Alma district. In the Manitou region, intercalated red calcareous sandstone and white limestone beds 105 to 122 ft above the pre-Cambrian are said to contain a Lower Ordovician fauna (Schuchert, oral communication). The lithologic description of these beds is suggestive of the Peerless, but such a lithologic correlation is weak. The possibility is thus opened that the Peerless is of Early Ordovician age. On the basis of the evidence cited by Johnson, however, it will continue to be classified with the quartzite member as of Late Cambrian age.

MANITOU DOLOMITE

Name.—The light-gray highly dolomitic limestone, averaging about 110 ft in thickness, that overlies the Peerless formation was formerly known as the "White" limestone. As its correlation with the Manitou limestone of the eastern slope of the Front Range in Colorado has now been established by Kirk (1931, p. 222), the name Manitou will be used in this report. The term dolomite, however, is preferable to limestone in this report, for the formation consists dominantly of dolomite in the Leadville area. The term Yule limestone, applied by Emmons (1898, p. 1) and later authors, has been discarded for use in the publications of the United States Geological Survey, as Kirk (1931, pp. 225–226) has shown that as originally applied it included rocks of ages at least as diverse as Early Ordovician, Late Ordovician, and Devonian.

Description.—The Manitou dolomite is a moderately uniform, finely crystalline, white, light-gray, or very faintly pinkish rock. Its thickness is somewhat varied, the measured extremes being 93 ft on Dyer Mountain and 150 ft on Horseshoe Mountain. On the east side of the Mosquito Range the thickness is even more varied, being as little as 44 ft on Mount Lincoln (Singewald and Butler, 1931, pp. 392–393). The smaller thicknesses are due to erosion following the Ordovician and preceding the Devonian.

In general the lower 20 ft of the Manitou dolomite contains two kinds of rock. One is a light-gray dolomite, which weathers to buff or faintly pinkish and most of which forms beds as much as 1 ft thick; the other consists of intercalated layers of greenish shale averaging 2 in. in thickness. This subdivision is succeeded by about 60 ft of light-gray, granular dolomite (fig. 14) which weathers to a very light color and forms beds having a thickness of 2 or 3 ft. The texture of these higher beds is sugary because of the fine dolomite crystals of which they are composed. White chert, in layers as much as 2 in. thick, but more commonly in discontinuous beds or nodules, is conspicuous, and a fine tracery or ribbing of silica appears on the weathered surface parallel to the traces of the beds. The uppermost 30 ft of the Manitou is similar to the division last described, except that chert is less plentiful, the color is slightly darker, and conspicuous oolitelike markings, with diameters of a quarter of an inch, stand out as darker blotches on the light-gray surface. These markings, especially, may safely be used as horizon markers of the upper part of the formation.

The microscopic features of the rock have already been described (Emmons, Irving and Loughlin, 1927, p. 28); a brief summary follows. The dominant mass consists of dolomite crystals ranging from 0.02 to 1.0 mm in diameter; the smaller grains are the more common. Some calcite is readily discernible; it tends to surround dolomite grains, indicating that there has been recrystallization after deposition. A little quartz fills interstices among dolomite grains and completely encloses some of them; the presence of cryptocrystalline silica is inferred but not proved. Small quanti-

FIGURE 14.—Typical exposure of Manitou dolomite; note absence of color banding, but presence of crosscutting "sheeted" structure and of faint ribbed markings showing bedding.

ties of minerals resembling sericite and kaolin are also present.

Chemical composition.—Emmons, Irving and Loughlin (1927, pp. 28–29) discussed at length the chemical composition of the Manitou dolomite. Their work is only briefly reviewed here; for more details the reader is referred to the pages cited.

Representative analyses of Manitou dolomite

	(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
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
Total	100.436	100.06

[1] U. S. Geol. Survey Mon. 12, p. 65; W. F. Hillebrand, Analyst.

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

Below are given the ratios of dolomite to calcite recalculated from six analyses that were selected as representative.

Ratio of dolomite to calcite in Manitou dolomite

Dolomite	98.2	92.7	98.5	82.1	81.0	87.0
Calcite	1.8	7.3	1.5	17.9	19.0	13.0

Similar ratios are obtained from microscopic studies.

Alterations.—In some mines at Leadville the Manitou dolomite is seen to be disintegrated into material resembling sand. In this material the separate grains are chiefly rhombs of dolomite. The disintegration is the result of dissolving away the calcite peripheries of interlocking crystals or the intergranular calcitic and possibly dolomitic cement, apparently by ground-water or hydrothermal action or both. This kind of alteration was not observed in the area here described, but may well have occurred in some of the mines that are no longer accessible. Beds thus altered cause serious difficulties in mining.

On the south slope of Printer Boy Hill, near the Lillian mine, another type of alteration has taken place. The altered rock was not observed in place, but the dump furnished specimens. The product is a dense, light gray-green rock, in which lenses of blue-gray cryptocrystalline silica and irregular blebs of white talcose material are conspicuous. Under the microscope with low-power lenses the rock has the general appearance of a typical limestone, except that it is more coarsely granular. Examined under high power, however, it shows large areas of yellowish-brown epidote, generally centered around tiny fractures, and areas of irregular, faintly iron-stained masses of finely crystalline quartz. There are also poorly formed fibers of a light-colored amphibole, probably tremolite. These minerals are all embedded in a matrix of closely interlocking carbonate crystals.

Alteration like that described probably took place only under conditions of medium or high temperature and mineralization was intense. Its occurrence near the magnetite-gold veins of Printer Boy Hill is significant.

Relations to adjacent formations.—As the lower boundary of the Manitou dolomite is not sharply marked against the subadjacent shales of the Peerless formation, the latter are commonly included with the Manitou, thus introducing considerable variation in measurements of thickness made by mining companies.

In places the Manitou dolomite appears to be gradational into the overlying Parting quartzite member of the Chaffee formation. The change occurs through thin, shaly, reddish, or green beds, but more commonly these beds differ sharply from the sandy beds typical of the overlying quartzite. Striking differences in thickness from place to place (fig. 15) and the widespread absence of the Harding sandstone and Fremont limestone, which elsewhere in Colorado lie between the Parting quartzite member of the Chaffee and the calcareous beds of the Manitou, point definitely to an erosional unconformity above the Manitou (Behre, 1932, p. 59).

Geologic age and correlation—The fossils collected from the Manitou dolomite in this region do not furnish conclusive evidence regarding the exact age of all of the beds in this formation. The identification and significance of fossils of supposed Niagaran age (Emmons, 1886, p. 61) reported from California Gulch, just south of Leadville, may well be doubted, as has been pointed out by Girty (Emmons, Irving, and Loughlin, 1927, p. 30). Fossils of Early to Middle Ordovician age are reported by Emmons (1886, p. 62) from the Manitou limestone in the Dyer Amphitheater, and on West Sheridan Mountain and are of greater significance. Edwin Kirk and the writer made a small collection of fossils, largely silicified, on the west slope of West Dyer Mountain; in this collection Kirk identified *Syntrophia sp.*, *Colpoceras sp.*, and *Piloceras sp.* He adds that these fossils are characteristic of the Manitou limestone of Colorado and substantiate its correlation with the Beekmantown of the eastern United States. From his field studies of the type section of Eldridge's Yule limestone on lower Cement Creek in the Anthracite-Crested Butte region, Kirk (1931, p. 225) also concludes that the lower part of the Yule—the stratigraphic equivalent of the "White" limestone [Manitou dolomite] at Leadville—is to be correlated with the Manitou limestone of the section at Manitou Springs, the type locality (Finlay, 1916, p. 6). From two different lines of evidence, therefore, it is clear that the "White" limestone of the Leadville section is of Early Ordovician age.

CHAFFEE FORMATION

It was formerly thought that the Parting quartzite, which at Leadville overlies the Manitou dolomite, was of Ordovician age; hence it was tentatively grouped with the Manitou under the term "Yule formation" (Emmons, Irving, and Loughlin, 1927, pp. 31–32). The lower part of the limestone overlying the Parting (the Blue limestone of earlier reports) was tentatively referred to the Devonian. Later, both the Parting quartzite and the lower part of the Blue limestone of earlier usage were found to be of Devonian age (Behre, 1929, pp. 38–39), and Kirk (1931, pp. 229–230) therefore proposed the name Chaffee formation for the Devonian rocks of the region. Two divisions of the Chaffee are recognized: the term Parting quartzite is retained for the lower member (after the Parting Spur which separates the Dyer and Evans Amphitheaters, 5.5 miles east of Leadville) and the Dyer dolomite (Behre, 1932, pp. 59–60) for the upper member (after its typical exposures at West Dyer, Dyer Mountains, and Dyer Amphitheater, 5 miles east of Leadville, fig. 16).

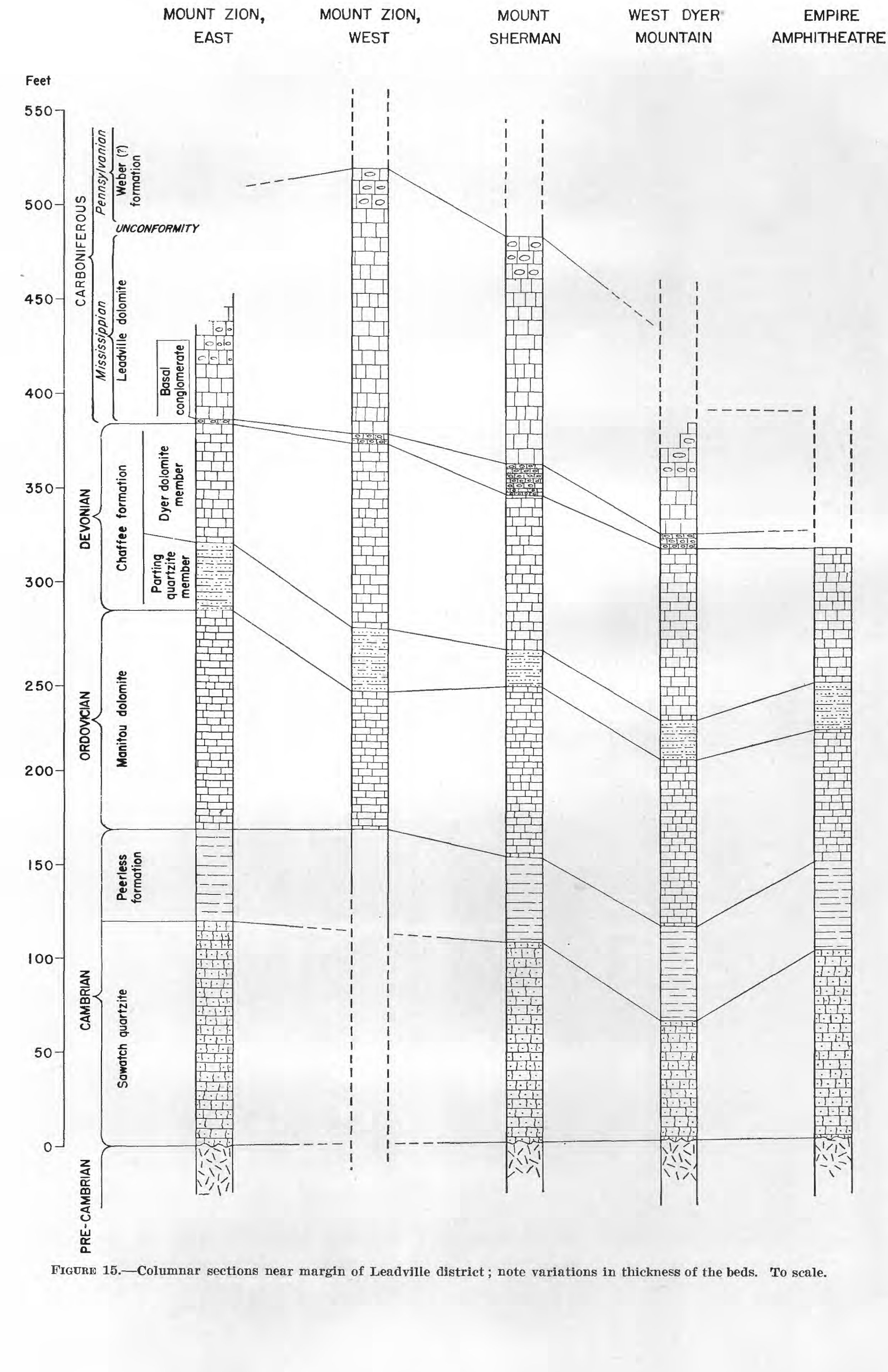

FIGURE 15.—Columnar sections near margin of Leadville district; note variations in thickness of the beds. To scale.

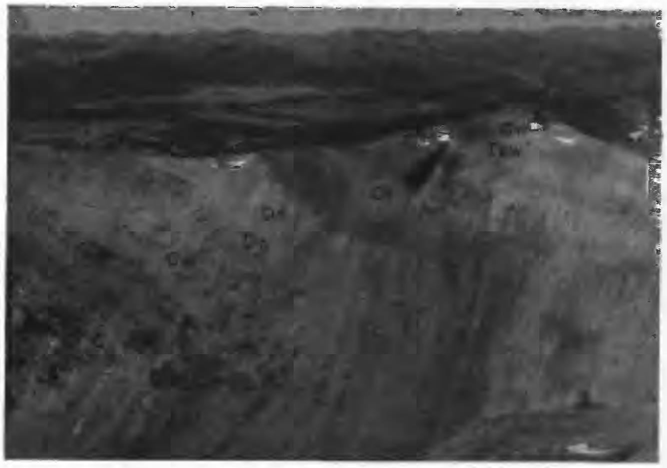

FIGURE 16.—View down upon West Dyer Mountain from Dyer Mountain. *Cl*, Leadville dolomite; *Dd*, Dyer dolomite member of Chaffee formation; *Dp*, Parting quartzite member of Chaffee formation; *Om*, Manitou dolomite; *C*, shale of Peerless formation and Cambrian quartzite; *Tew*, early White porphyry.

The Dyer dolomite corresponds to the lower part of the Blue limestone of earlier reports. These more recent correlations, subdivisions, and names are used in this report.

PARTING QUARTZITE MEMBER

Description.—The Parting quartzite was originally so called because it parted the underlying "White" limestone (now known as the Manitou) from the upper or "Blue" limestone. At Leadville the Parting quartzite is for the most part a sugary, quartzitic sandstone. It varies in color between white and light buff or faintly pinkish gray; the pinkish tone is noteworthy only in contrast with the gray and light yellowish-buff of the overlying and underlying limestones, yet, once recognized, it serves as a distinguishing feature in cliff exposures. Cross bedding is common, and especially conspicuous on weathered surfaces (fig. 17). In detail the sequence is not constant from place to place (fig. 18); usually it consists of alternate sandy and conglomeratic beds. The sand grains are not very well rounded; their mean diameter is about 0.5 mm. Few individual grains in the more coarsely granular layers exceed 1.5 mm in diameter. Sparse flakes of white mica constitute the primary constituent. Locally some beds are highly calcareous, being essentially sandy limestones, and even in the purer sandstone beds calcareous cement is not lacking. Aluminum silicates resembling kaolin contribute to the cement, giving certain beds a strong clayey odor. The most common cementing material, however, is secondary silica; by its deposition the quartz grains have been enlarged and are made to interlock. Glauconite was seen in the lower quartzitic beds on Empire Hill.

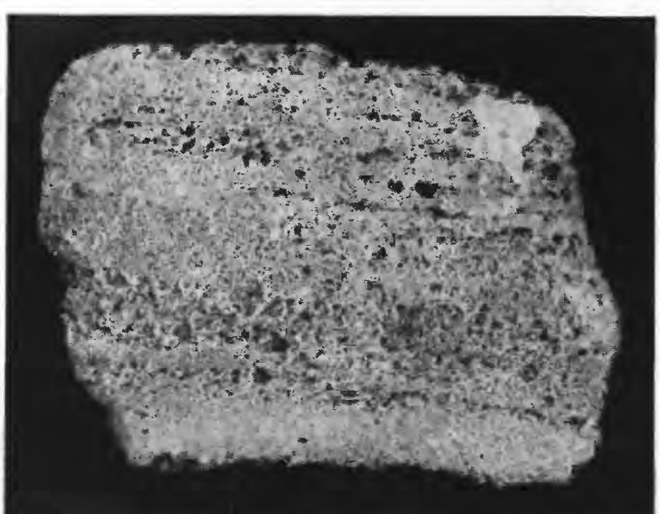

FIGURE 17.—Parting quartzite member of Chaffee formation, showing typical honeycombing on weathering; note suggestions of irregular bedding; length of specimen, 4 inches.

A feature to which attention was directed by Emmons, Irving, and Loughlin (1927, p. 30) but which has otherwise been generally ignored, is the shale that underlies the strictly quartzitic beds in many places. This material weathers so easily that it is generally worn away at the outcrop; as a result a small overhanging cliff is produced by sapping and from it blocks of the overlying quartzite slump or fall down and partly or wholly conceal the shale. The color of these shale beds is highly varied, the most conspicuous hues being brick red and light olive-green. Their total thickness is approximately 2 ft at most places, but is highly varied. They comprise about 1 ft of light greenish-gray shale on the south slope of Mount Zion, 4 miles north of Leadville; 3 ft of brick-red sandy shale on the east slope of West Dyer Mountain in the head of the Evans Amphitheater; probably as much as 5 ft of very poorly exposed red sandy shale on the southeast slope of East Ball Mountain, 5 miles east-southeast of Leadville; and 22 ft (of which the lower 18 ft are brick red and the upper 4 ft light gray-green shale) at Weston Pass, 10 miles southeast of Leadville.

At Weston Pass, as at Aspen (Spurr, 1898, p. 21), the red shale overlying the Manitou dolomite contains fish plates. These fossils were thought by Girty to indicate Devonian age. Somewhat similar fish plates are known from the Ordovician Harding sandstone, which is not present at Leadville but does crop out along the highway west of Trout Creek Pass, 26 miles southeast of Leadville. The presence at Trout Creek Pass of a sandstone containing fish plates but of Ordovician age has caused some uncertainty regarding the age of at least the lower, shaly part of the Parting quartzite member of the Chaffee. The occurrence of fish plates in these two apparently different horizons has been discussed elsewhere (Kirk, 1930, p. 458; Behre and Johnson, 1933, pp. 476–483). In the Gold Brick district (Crawford and Worcester, 1916, pp. 54–55; Kirk, 1931, p. 228) at the northern end of Taylor Park, beds similar to the red shales in question occur well above the highest recognized Ordovician and just below

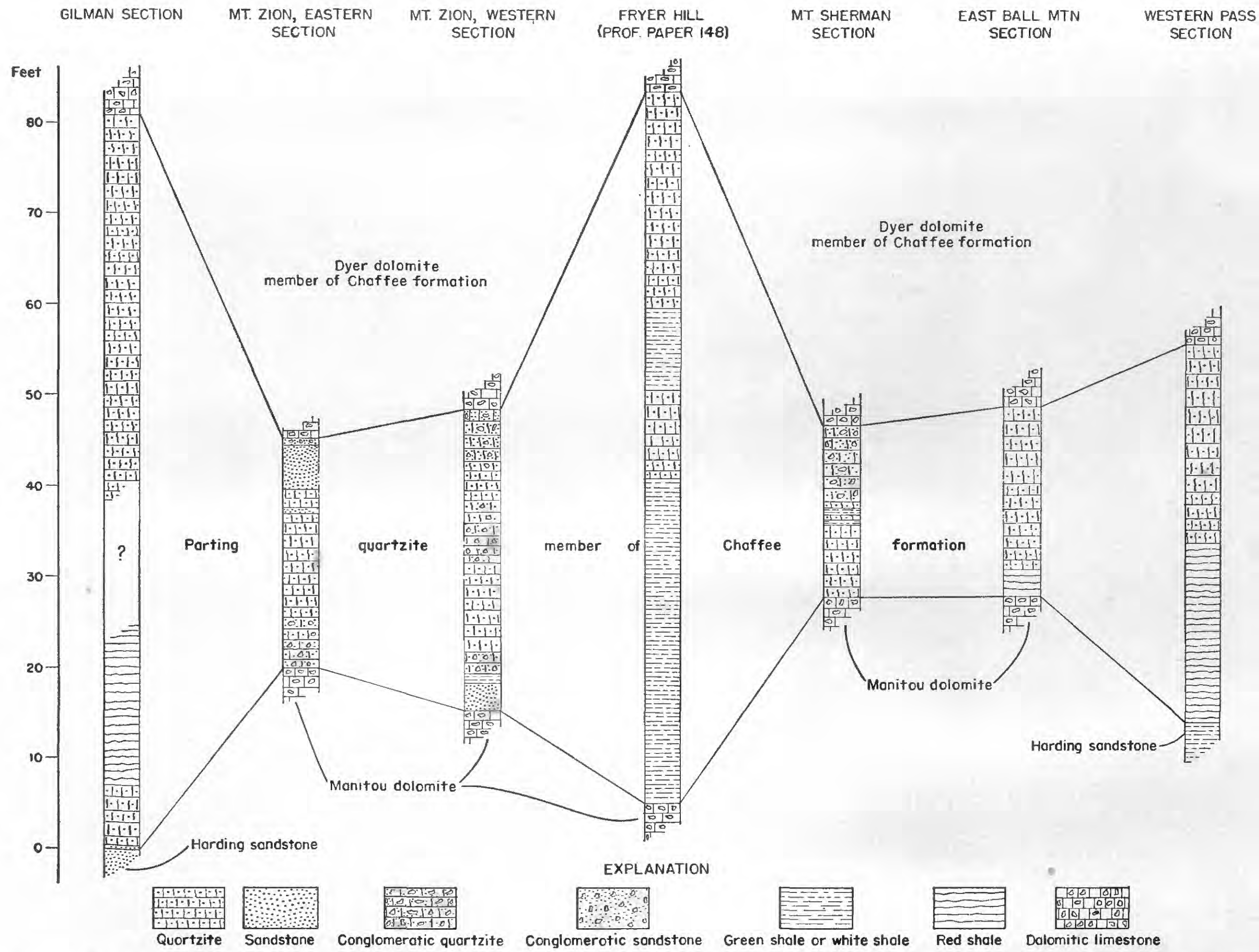

FIGURE 18.—Diagram to show variations in thickness and lithologic character of Parting quartzite member of the Chaffee formation. To scale.

a quartzite which, on the basis of stratigraphic relations and lithology, is almost certainly the Parting; these facts strongly indicate, though they do not prove with absolute certainty, that the variegated shales just under the quartzitic beds of the Parting at Leadville actually should be grouped with the Parting quartzite as part of a stratigraphic unit—the Parting quartzite member of the Chaffee formation.

The thickness of the Parting member is varied, as shown in figure 18, but averages about 27 ft. It is thick on Mount Zion, just north of the East Fork of Arkansas River, thins in the direction of Leadville, and gradually thickens again southward. It is 35 ft thick on Mount Zion, 19 ft on Mount Sherman, 21 ft on West Dyer Mountain, and 25 ft in the Empire Amphitheater. At Weston Pass the thickness is much greater—about 62 ft. These variations may be due to erosion before deposition of the overlying Dyer dolomite member, or to irregularities in the surface on which the beds were deposited and to local irregularities in deposition—such as might be expected in a shore facies; the writer considers the latter explanation, given by Singewald (1931, pp. 407–413), the more probable one.

Alteration.—The siliceous beds of the Parting quartzite member are generally so resistant to the action of solutions that they show neither contact metamorphism nor hydrothermal alteration by mineralizing solutions. The shaly layers at the base, however, are slightly altered, having a mottled color and scattered small sericite flakes. Locally in some of the areas of more intense mineralization, as at Leadville, the rock has been somewhat silicified and slightly replaced by sulfide ores (Emmons, Irving, and Loughlin, 1927, p. 31); in such places the calcareous and clayey matrix has probably been the chief material affected, but the quartz grains also have been sericitized to some extent.

Geologic age.—When the writer began his studies in the Mosquito Range the Parting quartzite was still regarded as being possibly of Ordovician age (Behre, 1929, p. 40) in conformity with the statements in earlier reports on the Leadville district. However, Kindle and Kirk maintained (Kindle, 1909, pp. 11–13; Kirk, 1931, p. 234) that the scanty fauna of the Parting quartzite or its equivalent is of Late Devonian age, and Johnson and the writer found (Behre, 1932, p. 59; Behre and Johnson, 1933, p. 481) that the typical Parting quartzite of the Mosquito Range is separated by an erosional unconformity from the underlying Manitou dolomite. It appears, therefore, that the Late Devonian age of the Parting quartzite is established.

Relation to adjacent formations.—The unconformity between the Manitou dolomite and the base of the Parting quartzite member of the Chaffee has been described above. The upper limit of the Parting is fairly definite, but presents no evidence of an erosion surface; in fact, in the exposures near Leadville, the sandy upper beds of the Parting quartzite grade upward into the overlying Dyer dolomite through sandy limestone, and no definite boundary between the two members can be recognized. Emmons (1886, p. 61) reported an angular breccia in the "Blue" limestone above the Parting quartzite and regarded it as evidence for an unconformity. The locality in which these relations were found by him could not be identified by the writer, but the breccia is interpretable as a limestone conglomerate, such as is commonly associated also with a higher sandstone unit that forms the base of the Mississippian. It is at least possible that erosion during the interval between deposition of the local Devonian and Mississippian rocks may in places have removed the 60 to 80 ft of Devonian strata that commonly overlie the Parting. In such places the succeeding Mississippian Leadville dolomite rests directly on the remaining Parting quartzite. These relations, however, would obviously not afford grounds for separating the Parting from the overlying dolomitic limestone beds of recognizably Late Devonian age.

DYER DOLOMITE MEMBER

Description.—The Dyer dolomite member, which was the lower or Devonian portion of the Blue limestone of earlier reports, in general resembles the upper, Mississippian part of the "Blue limestone," but differs in two conspicuous respects: (1) it is almost free from chert and (2) its color, taken as a whole, is less blue-gray and more light-gray, buff, or yellowish. Two typical sections are given below:

Section of Dyer dolomite member of the Chaffee formation—South Slope of Mount Zion

	Feet
Lower part of Leadville dolomite:	
Dolomitic limestone beds.	
Conglomerate of dolomite boulders with coarse sandstone.	
Dyer dolomite member of Chaffee formation:	
7. Dolomitic limestone beds up to 3 ft thick; banded in dark and light shades of blue-gray	24.5
6. Dolomitic limestone beds, blue-gray, 1 ft or less thick, separated by shale beds 1 to 4 in. thick and greenish or reddish in color	10
5. Yellow, thin-bedded shaly limestone, irregularly cross-bedded	8
4. Shattered, irregularly bedded, slightly sandy limestone	1.5
3. Pinkish dolomitic limestone, in beds 6 in. thick	8
2. Shattered, nodular dolomitic limestone, brown	2
1. Light-gray, blocky dolomitic limestone in beds 1 ft thick	41.5
Total	95.5
Upper part of Parting quartzite member of Chaffee formation:	
Pink, slightly conglomeratic quartzite.	

Section of Dyer dolomite member of Chaffee formation—West Dyer Mountain

	Feet
Lower part of Leadville dolomite:	
Very sandy dolomitic limestone, light-buff in color.	
Dyer dolomite member of Chaffee formation:	
5. Dense, blue-gray dolomitic limestone in massive beds; faintly banded	14
4. Brownish-spotted, gray dolomitic limestone, densely granular; weathers into beds 1 in. thick	37
3. Light blue-gray dolomitic limestone, with platy fracture; weathers to conspicuous ocher color; a good horizon marker because of its conspicuous color	4
2. Massive, light-gray, buff-weathering dolomitic limestone in massive beds	30
1. Very sandy crystalline dolomitic limestone, medium-fine to locally coarse-grained; color light buff	14
Total	99
Upper part of Parting quartzite member of Chaffee formation: Pink, coarsely granular quartzite, locally conglomeratic.	

As indicated in these sections, most of the Dyer dolomite member is light gray or blue gray, somewhat banded dolomitic limestone. The banding is especially conspicuous in the higher beds (fig. 19). Individual bands are generally 1 in. or less thick and are conspicuous on the weathered surface, but far less so in the fresh rock. A few limestone layers bear "fucoid" markings, light on a dark background, or the reverse. The buff or yellow bed near the middle of the Dyer member (No. 5 in first section and No. 3 in second section), which weathers to an ocherous color, is an especially good horizon marker as it is conspicuous at some distance and lies at a fairly constant height above the top of the Parting quartzite.

In general, the dolomitic layers are well recrystallized and relatively impervious like the overlying Leadville dolomite but the Leadville is denser and the crystals are smaller and more closely crowded. The Dyer dolomite is intermediate, with regard to crystal size, between the Leadville and the Manitou dolomites.

Although the calcareous layers are locally shaly and more sandy, the formation as a whole is a dolomite and the impurities are inconspicuous, with the single exception of the somewhat sandy beds immediately overlying the Parting member.

Alteration of the Dyer dolomite is essentially identical with that of the Leadville dolomite as described on pages 37, 38.

FIGURE 19.—Characteristic appearance of Dyer dolomite member (lower "Blue" limestone) of Chaffee formation; note blocky fracture and contrast in color shading between successive beds.

The average thickness of the Dyer member is about 80 ft. It is 98 ft thick on Mount Zion, north of the East Fork of Arkansas River, 78 ft on the east slope of Dyer Mountain, 82 ft on Mount Sherman, and 71 ft in the Empire Amphitheater. At Weston Pass, about 10 miles south of Leadville, it is 75 ft thick, and at Gilman, 20 miles north of Leadville, 78 ft. The thickness thus appears to be fairly uniform along the western slope of the Mosquito Range.

Relation to adjacent formations.—The relation of the Dyer dolomite member to the underlying Parting quartzite member was discussed above. There is no conspicuous discordance to facilitate separation of the Dyer dolomite from the overlying Leadville dolomite, but a lithologic change is everywhere observable—a thin layer of sandstone generally overlain by a limestone conglomerate. This zone, though not conspicuous, has been recognized in this region by the writer wherever he sought it, from Gilman, 20 miles north of Leadville, to Weston Pass, 10 miles southeast of Leadville. The sandstone bed indicates a noteworthy change in sedimentary conditions, and almost certainly the boundary between the Devonian and Mississippian beds should be drawn at its base.

Geologic age and correlation.—At Glenwood Springs the dolomitic limestones were correlated with the Dyer on the basis of stratigraphic relations and lithology, and here Kirk (Personal communication, 1929) found a species of *Fenestella* thought to show Devonian affinities; this agrees with Kindle's earlier conclusion based on an abundant Devonian fauna (Kindle, 1909, p. 9). At Red Cliff a 78-ft zone of gray dolomitic limestone lies between the top of recognizable Parting quartzite and a brown sandstone with associated limestone conglomerate that resembles the beds on top of the Dyer at Leadville. *Syringopora*, with characteristics that are probably Devonian (Kirk, 1931, p. 237–239) was found in the gray dolomitic limestone. From the same horizon at Gilman a small fauna, including *Spirifer whitneyi animanensis*, was collected by Gibson; on this basis these beds likewise were tentatively referred to the Devonian by the geologists of the Colorado Geological Survey (Crawford and Gibson, 1925, pp. 37–38). Finally, *Syringopora* was also found in the Dyer dolomite on west Dyer Mountain at Leadville; this is the only occurrence of fossils in the Dyer dolomite of the Leadville district of which the writer is aware. All these facts support Girty's conclusion (Girty, 1903, pp. 161–162), with which Kirk (1931, pp. 237–239) agreed, that the unit here called the Dyer dolomite is of Late Devonian age and is the stratigraphic equivalent of the Ouray limestone as recognized in the San Juan region by recent authors (Cross and Larsen, 1935, pp. 33–34; Burbank, 1941, pp. 194–196).

The exact age of this fauna was formerly somewhat in doubt, for it was considered early Devonian by some writers and late Devonian by others. The most definite statement on this subject is that of Girty (1900, pt.2, p. 35), who concluded that the part of the Ouray limestone here regarded as equivalent to the Dyer dolomite—

> was deposited certainly no earlier than Middle Devonian time, and that its deposition may have taken place as late as early Upper Devonian time.

Kindle (1909, p. 13) referred the fauna to the Upper Devonian without comment.

LEADVILLE DOLOMITE

Nomenclature.—The term Leadville limestone was formerly used, synonymously with Blue limestone of earlier writers, for all sedimentary rocks in the Leadville district between the Parting quartzite member of the Chaffee formation and the Pennsylvanian Weber(?) formation. Subsequently it was shown that the sequence could be divided into a lower part of Devonian age named the Dyer dolomite member of the Chaffee formation, and an upper part of Mississipian age, the Leadville dolomite (Girty, 1903, pp. 161–162; Behre, 1929, pp. 38–41; Kirk, 1931, pp. 226–227), which in the region around Leadville consists almost entirely of dolomite. The beginning of Mississippian sedimentation is marked by sandy beds or by a conglomerate of limestone or dolomite, or both. The writer follows Kirk in restricting the term Leadville dolomite to the upper part of the Blue limestone of earlier writers—in other words, to rocks of Mississipian age. There are, however, localities where the contact between the Dyer and the Leadville dolomite is not determinable; for such localities the name "Blue" limestone will be applied in its original sense.

Description.—In general appearance the Leadville dolomite is not very different from the underlying Dyer dolomite member of the Chaffee formation. The basal layer is a buff-colored, buff-weathering bed of sandstone 1 to 2 ft in thickness. It consists of well-rounded quartz grains of medium size set in a calcareous matrix; in places the matrix is siliceous and the rock resembles an impure quartzite, but is friable. This bed contrasts sharply with the blue-gray dolomite above and below.

Above the sandstone there is almost everywhere a bed or series of beds, aggregating about 4 ft in thickness, of subangular or poorly rounded limestone or dolomite conglomerate or breccia (fig. 20). The matrix is calcareous sand, weathering to faintly buff. The individual blocks in this conglomerate consist of blue-gray, light gray, dark gray, or almost black dolomitic limestone, probably derived from the Dyer. In size the blocks vary greatly; an average diameter is about 2 in. but there are some blocks 6 in. across; others are much smaller. The average size of the conglomerate blocks varies from place to place. Thus, at the head of Alps Gulch between Ball and East Ball Mountains individual blocks average 5 in. in diameter, whereas on the south slope of Mount Dyer they average only 1 in. across. The general appearance of the breccia is that of a talus agglomerate rather than of cemented reef fragments. It suggests an accumulation of debris at the foot of cliffs composed of Dyer and Manitou dolomites that were being cut by waves during the advance of the Mississippian sea.

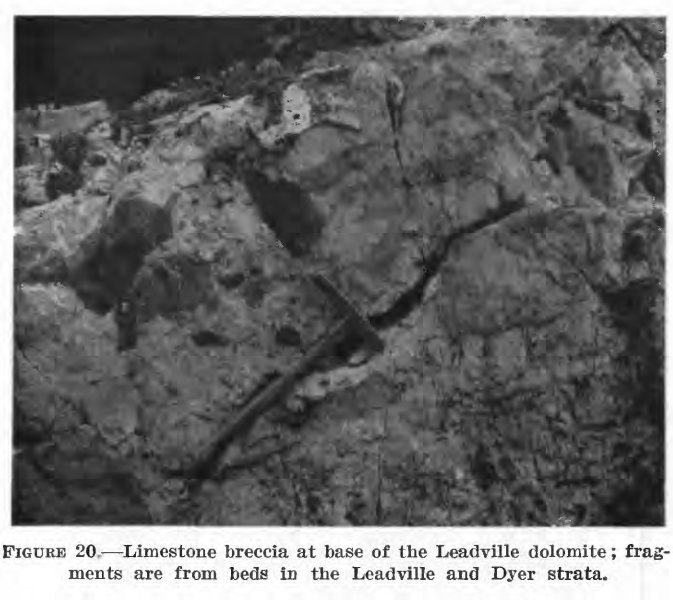

FIGURE 20.—Limestone breccia at base of the Leadville dolomite; fragments are from beds in the Leadville and Dyer strata.

These two zones comprise what for the sake of brevity is here called the basal sandstone of the Leadville dolomite. Although the description given above is generally correct, there are many localities in which one or the other zone is lacking. Moreover, the succession is not strictly adhered to—several beds of conglomerate may be separated by sand lenses, or the conglomerate may appear below, overlain by a very thin bed of sandstone. However, no place was found near Leadville where the base of the Mississippian sequence is not indicated by one or the other kind of rock. Even in the poorer exposures in the immediate environs of Leadville, where alteration has obliterated many of their original features, beds suggesting this horizon were identified by Emmons, Irving, and Loughlin (1927, p. 34), who remarked, "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." The horizon has been identified with certainty both at Gilman, north of Leadville, and at Weston Pass to the south.

The petrology of the overlying layers of dolomitic limestone varies. The average thickness of the beds is between 3 and 6 ft, the lower beds being commonly the thinner. In general the beds are gray. Whether fresh or weathered they have a bluish tint, in contrast with the predominantly light gray or pinkish color of the Manitou dolomite and with the yellowish tones characterizing some of the Dyer dolomite. Banding is not as conspicuous as in the upper part of the subjacent Dyer dolomite. As a rule the rock is finer-grained than in the Dyer, crystal faces rarely showing on the fresh fracture. Some of the uppermost beds, however, especially where near intrusive masses of porphyry, are recrystallized and contain rhombs of carbonate as much as ⅛ in. in diameter. The same uppermost beds on weathering acquire such a peculiar speckling of white and dark-gray areas that they are called "pepper-and-salt" beds by the miners. The speckling is apparently due to an irregular concentration of the sedimentary carbon in the recrystallized carbonate.

Throughout the Leadville dolomite, but especially in the upper beds, there are discontinuous layers of black chert nodules, in contrast with the white chert of the Manitou dolomite. A few faint impressions of fossils have been found in them, but no well-preserved specimens. On weathering, the chert may become dark gray, but more commonly acquires a rusty, ocherous color, in striking contrast to the dark gray of the dolomite. These layers of silica nodules characterize certain stratigraphic horizons and are considered to be the results either of primary deposition or of a diagenetic process.

Locally, there occur discontinuous beds of limestone breccias resembling the breccia at the base of the Leadville dolomite. They seem to represent intraformational conglomerates or sedimentary breccias. Some sections, such as the very complete one in Dyer Amphitheater, contain none of these beds, but one is seen at Iowa Amphitheater and two on Zion Mountain.

Streaks, bands, and blotches of white dolomite are common in the upper part of the Leadville dolomite. In places a porous or cavernous structure is seen, the openings of which are surrounded with white dolomite crystals whose free faces form glistening surfaces. Such altered masses may be as much as 2 ft in diameter. These banded areas of light and dark dolomite are popularly called "zebra rock" (figs. 21–23). The white dolomite of the "zebra rock" is not chemically different

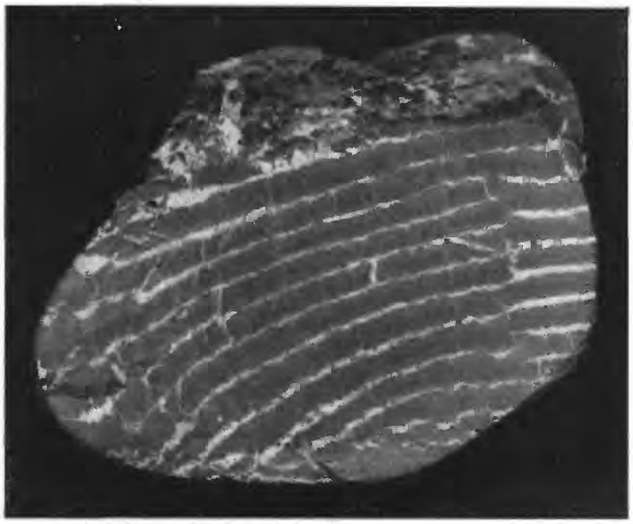

FIGURE 21.—Early stage: blue-gray limestone or dolomite is somewhat fractured, cracks being filled with white dolomite; specimen is 3 inches long.

FIGURE 22.—Intermediate stage: limestone is about 50 percent replaced by dolomite.

from the original blue-gray dolomite and may be merely an alteration product (Emmons, Irving and Loughlin, 1927, p. 33). Possibly it is the result of mineralizing solutions, or of a far-distant phase of contact metamorphism. It is commonly attributed to mineralization and is thought to be a favorable indication in

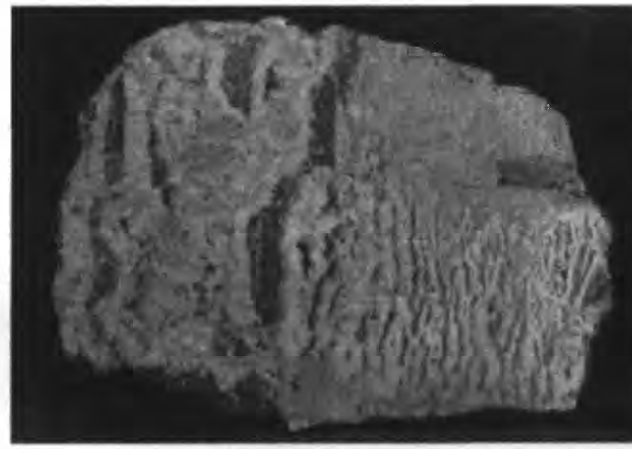

FIGURE 23.—Advanced stage: limestone almost wholly replaced and dark blotches also no longer conspicuous; specimen is 3 inches in length.

searching for ore, but this impression could not be confirmed by the writer. This "zebra rock" is so generally prevalent in the upper part of the Leadville dolomite, that it is discussed here, rather than among the alteration products described on pages 37, 38.

The highest beds of the Leadville dolomite include one or more shaly beds. Thus in the area about the head of Iowa Gulch there is a thin, gray, calcareous shale bed, about 15 ft below the top of the Leadville dolomite. It is varied in thickness but averages about 5 ft. It is overlain by about 13 ft of thin, platy limestone beds, above which is a bed of black shale 3 ft thick, identified as the basal bed of the overlying Weber(?) formation.

Microscopic examination reveals that the calcareous beds of the Leadville dolomite consist of minute closely interlocked dolomite crystals. In the insoluble residues, Emmons, Irving, and Loughlin (1927, p. 33) identified irregular quartz grains, microcline, albite (or oligoclase?), pyrite, and bituminous matter. Minute dark particles seen in thin sections are probably carbon; they are less conspicuous in the light-colored rock and in the white, dolomitic bands of the "zebra rock".

Chemical composition.—The Leadville dolomite is singularly pure. Six analyses have been published; four of them are certainly from the Leadville dolomite, but the other two may be from the Dyer dolomite member of the Chaffee formation. All six have been recalculated and tabulated in the report by Emmons, Irving, and Loughlin (1927, p. 35). Four reveal no calcite whatever and in the two other samples the ratio of dolomite to calcite is 97.9 to 2.1, and 99.9 to 0.1.

Moreover, the rock as a whole is singularly free from insoluble matter, such as silica and clay. Thus, when the six analyses mentioned are recalculated to probable mineral content, and the percentages of the carbonates of calcium, magnesium, iron, and manganese are added, the total percentages of soluble carbonates are, as shown in the following table, much higher than in the Manitou dolomite.

Percentages of chief mineral constituents of Leadville, Manitou, and Dyer dolomites

	Quartz	Silicates	Quartz and silicates	Soluble carbonates
Manitou dolomite, California Gulch	10. 1	4. 1	------	84. 1
Leadville dolomite, Silver Wave mine, Leadville	------	------	0. 55	98. 05
Leadville dolomite, Dugan quarry, Leadville	. 50	. 36	------	98. 46
Leadville dolomote, Glass-Pendery mine, Leadville	. 23	. 09	------	98. 85
Dyer or Leadville dolomite, Montgomery quarry, Leadville	7. 65	. 24	------	91. 55
Dyer or Leadville dolomite, Stephens mine, Leadville	------	------	. 62	99. 59
Leadville dolomite, Iron Hill quarry, Leadville	------	------	. 55	97. 66

The blue-gray color characteristic of the Leadville dolomite is probably caused by organic matter. This conclusion follows from the fact that on being heated the limestone bleaches, even at low temperatures. Moreover, the quantity of organic matter reported in all analyses ranges from 0.025 to 0.26 percent, as against only traces reported in analyses of the Manitou dolomite, a rock of distinctly lighter color. A fetid odor is emitted by much of the rock when freshly broken (especially by the upper, dark-colored beds) indicating an abundance of organic matter. It is striking that a rock with these properties should contain so few fossils, but in this respect it is similar to dark-blue Paleozoic dolomites in Utah and elsewhere.

Alteration.—Emmons, Irving, and Loughlin (1927, pp. 36–37) have given a good description of the alteration product called "dolomite sand." This product is found also in the Manitou and Dyer dolomites, but is more commonly associated with the Leadville dolomite. These authors state that 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 ft below the surface.

Obviously the lack of cementation of the "dolomite sand" causes much difficulty in mining. The study mentioned indicates that the looseness of the "dolomite sand" is caused by the solution of grain edges and of the cementing material in the form of lime, magnesium, and iron carbonates. The solution is attributed to the action of descending waters.

A second kind of alteration, very different from that already mentioned, is marmorization. For this kind of alteration, too, the description applies to all of the limestone and dolomite beds of the region—those of the Peerless formation, the Dyer dolomite member of the Chaffee formation, and the Leadville dolomite. It is most conspicuous, however, in the Leadville dolomite, especially in the upper beds, where they are in contact with a thick sill of early White porphyry. Altered rock of this kind is well exposed in the highest beds of the Leadville dolomite on the cliffs at the head of the Iowa and Dyer Amphitheaters, in the section on West Dyer Mountain, and on the cliff on the south slope of Zion Mountain. The maximum diameter of individual dolomite grains is ⅛ in. (about 0.3 cm). Such alteration was commonly accompanied by a color change, whereby the beds acquired a mottled appearance in which light-gray and dark blue-gray predominate. The fairly general association of marmorized beds with intrusive rocks and, further, their absence in localities where there are no intrusive rocks, point to this alteration as a phase of contact metamorphism.

A third kind of alteration is silicification. In this alteration the texture of the limestone becomes dense and flinty so that the altered beds can scarcely be distinguished from quartzite except with the aid of the microscope; their hardness also is such that most of the rock scratches steel. The color may remain blue-gray, as in the unaltered rock, or more rarely may become a very light gray or white. In extreme alteration, cavities measuring as much as ½ by 1 by 2 in. are produced. Under the microscope the rock mass is seen to be dense and made up chiefly of cryptocrystalline silica, or partly or wholly of crystalline quartz. In the latter case angular quartz crystals, many of which are well-formed hexagonal bipyramids, may be seen in profusion and project into shreds and remnants of carbonates that are still unreplaced. Locally, these crystals form large irregular aggregates of quartz.

So far as observed, silicification was confined to zones of considerable mineralization or at least to the neighborhood of fracture zones along which mineralizing solutions may have passed. Thus, its effects are noted in the drifts and dump material of the Altoona tunnel and other mines on the south slope of Printer Boy Hill, on the south slope of Canterbury Hill between the Chicago Boy and Old St. Louis workings, and near the Oak and associated claims about 1½ miles west of the crest of Empire Hill. Silicified rock is found also near zones of shattering that are not associated with known ore bodies, as east of the ridge that rises northwest of Empire Hill to an altitude of 12,065 ft, and south of the ridge crest connecting Mount Sheridan and Peerless Mountain. A fairly continuous band of blue-gray silicified limestone at the very top of the Leadville dolomite can be traced from the south slope of Empire Gulch near the Mitchell Ranch all the way south to the head of Union Gulch.

A fourth kind of alteration, to which the term "silication" may be applied, is that in which silicates of alkaline earths are developed. Although this alteration represents a relatively smaller increase in silica than does silicification, the temperature required for silication is greater than that for silicification, and hence, as might be expected, the products of silication are found in ground subjected to mineralization at high temperature. In the area described, silication of the Leadville dolomite was observed only on the south slope of Printer Boy Hill, where, it will be recalled, similar alteration had taken place in the Manitou dolomite (p. 29). The product is a tremolite-rich rock which, where originally clayey, contains much sericite also. Locally, epidote was formed. This rock resembles in most respects the altered facies of the Manitou dolomite already described.

To summarize, of the alterations described for the Leadville dolomite, as for other calcareous beds in the section, the formation of "dolomite sand" is attributed to leaching by downward-moving solutions; marmorization is probably a result of contact metamorphism, using this phrase in its strict sense; whereas silication and silicification are probably produced both by hydrothermal alteration through the action of mineralizing solutions and by contact metamorphism near the intrusive sills and dikes so abundant in the region.

Variations in thickness.—Like the Manitou but unlike the Dyer, the Leadville dolomite varies somewhat in thickness. Over much of the area where it is exposed, some of the upper beds have been removed by erosion, but where the Leadville dolomite is overlain by recognizable lower beds of the Weber(?) formation and the entire Leadville is represented, the range in thickness of the formation is indicated by the measurements listed below.

Thickness of Leadville dolomite at selected localities on west slope, Mosquito Range

	Feet
Gilman, 22 miles north of Leadville	125
Mount Zion, 3 miles north of Leadville	146
West Dyer Mountain, 5 miles east of Leadville	154
Mount Sherman, 6.5 miles southeast of Leadville	124
Weston Pass, 10 miles south of Leadville	160

Obviously there is no uniform decline in thickness in any definite direction. Existing differences may be attributed to changes in rate of accumulation of sediments, to minor irregularties of the sea bottom, or to widespread but irregular erosion at the close of the Mississippian epoch.

On the figures given, the average thickness of the Leadville dolomite is estimated to be 140 ft. If to this is added the 80 ft of Dyer dolomite, a total of 220 ft is obtained, or about 20 ft more than the average thickness given for these two stratigraphic units by Emmons, Irving, and Loughlin (1927, p. 32).

Relation to adjacent formations.—The contact between the Leadville dolomite and the underlying Dyer dolomite member of the Chaffee formation has been described as marked by the basal sandstone of the Leadville. The upper boundary of the Leadville dolomite is at the base of a black, pyritic shale, averaging about 5 ft in thickness; above it limestone beds are rare or absent, and clastic rocks are the rule. The boundary between this shale and the underlying limestone is sharp. The black shale does not truncate the subjacent limestone beds, nor is there any other evidence of any very irregular pre-Pennsylvanian erosion surface above the Leadville in this region. At Red Cliff and Gilman, however, erosion and weathering are found to have affected the top of the Leadville dolomite before deposition of the overlying Pennsylvanian Weber(?) formation (Johnson, 1934, p. 27).

Geologic age and correlation.—In the course of this field work no fossils were collected that could with certainty be referred to the Mississippian, but fossils collected by Emmons (1886, p. 66) from the extreme upper part of the Leadville dolomite were found either in the limestone or in chert nodules scattered over the surface. The fauna as listed by Girty comprises a coral, five brachiopods, two pelecypods, and a gastropod. From a study of the Leadville dolomite here and elsewhere in Colorado, Girty (1903, pp. 221–223, 228–229) concludes that it is of Mississippian age and is equivalent to the Mississippian of Crested Butte, Aspen, and Salida, which is "probably chiefly upper Kinderhook and lower Burlington" in age. With these findings Johnson (1934, p. 27) concurred.

WEBER(?) FORMATION

NOMENCLATURE

The beds of shale, sandstone, and conglomerate that overlie the Leadville dolomite in the area mapped were correlated by Emmons with the Weber quartzite as exposed at Weber Canyon, Utah. As a result, this formation, especially the coarser part, is commonly known by the local miners as the "Weber grits." During the past decade the beds included in the "Weber shales" and "Weber grits" as defined by Emmons have been studied with much care, but the results of these studies have not yet been fully assembled. Probably a new name will eventually be applied to the rocks of Pennsylvanian age that overlie the Leadville dolomite. In the absence of such a name the old term, to which the mining public is accustomed, is retained, followed by a question mark to indicate doubt as to the correctness of this correlation.

The Maroon formation, which overlies the Weber(?) formation in the region north and south of Leadville (Stark, Johnson, Behre, and others, 1949, pp. 42–47), has been completely eroded from the area here described and is therefore not discussed.

DISTRIBUTION

Whereas the older formations are thin, and complete sections are exposed at many places in the area, the Weber(?) formation, though very thick, has been largely destroyed by erosion. The most complete sections are in three localities. One is the ridge crest extending from the head of Birdseye Gulch westward to and somewhat beyond Prospect Mountain; west of Prospect Mountain the glacial cover conceals the bedrock, but a fairly continuous section may be studied in the Board of Trade and Isabelle Amphitheaters. Another is on the east slope of the Mosquito Range between Mount Evans and Mosquito Peak. South of this place the Weber(?) has been removed, except for the third locality—that on Empire Hill, on the slope toward Weston Gulch.

DESCRIPTION

In general the Weber(?) formation (Johnson, 1934, pp. 28–42) as it appears near Leadville consists of five kinds of rock:

1. A very coarse to medium-coarse arkosic grit. The pebbles are chiefly quartz, but rounded and subangular feldspar fragments as much as an inch in diameter are also seen; many fragments are fresh and still exhibit good cleavage. There is much cross bedding and, although sorting is commonly poor, in the cross-bedded strata the lower parts of all the beds are the coarser. Shale fragments are scattered through the conglomerate. Their color ranges from light to dark gray, but is generally a light gray, commonly with a greenish tint. Surfaces of these fragments sparkle with mica flakes. Diffusion banding is locally conspicuous (fig. 24).

2. A fine-grained arkosic sandstone. This is a true sandstone except for a few quartz pebbles as much as ¼ in. in diameter. This rock is more even bedded than facies 1, and cross bedding is rare. As in the other facies found in the Weber(?), mica is a conspicuous constituent. The sandstone is light to medium gray and generally acquires a rusty-yellow hue on weathering. Near Leadville, arkosic sandstone probably makes up more of the formation than any other facies.

3. Micaceous shales. These shales are very rich in mica and range in color from olive green to chocolate brown or black. On weathering, the rock becomes gray or rusty brown, depending largely on the extent to which the mica is decomposed. Much of the dark color is due to carbonized plant stems, still faintly visible. The mica flakes reach a maximum dimension of ½ in. The other materials are quartz and feldspar grains and a little clayey matter. In rock of this facies the fracture is very regular and slabby, parallel to the surface of the conspicuous mica flakes and to the bedding. The mica glistens conspicuously on the bedding planes.

FIGURE 24.—Diffusion banding of limonite, commonly seen in grits of the Weber(?) formation; note also ellipsoidal parting.

4. Impure shales, faintly calcareous, buff, light gray, or dark gray. Rock of this kind breaks easily parallel to the bedding with a slightly irregular parting, varying from papery to platy; in some beds the fracture is almost conchoidal. A fresh surface effervesces slightly with acid, but its odor is clayey, and the rock is distinctly a shale. On weathering the color if light changes to a rusty brown; if dark it fades slightly.

5. Shaly or pure, dense, blue-gray limestone. Clay, quartz, feldspar and mica are present in varied but small quantities. The beds are thin, rarely exceeding 2 ft in thickness. The fracture is conchoidal and the freshly broken rock emits a fetid odor. Locally this facies is fossiliferous. On weathering the color alters to light gray, faintly rusty gray, or light olive-green. These limestones are said to be distinguishable from other limestones in the Paleozoic section by their nonmagnesian composition. Analysis of a blue-gray granular limestone specimen collected just west of the gap between Little Ellen Hill and West Dyer Mountain is representative of the more limy beds.

Analysis of magnesian limestone typical of the Weber(?) formation

[J. G. Fairchild, Analyst]

Soluble constituent	Percent	Insoluble constituent	Percent
CaO	29.83	SiO_2	60
MgO	19.85	Al_2O_3	16
FeO	1.84	Fe_2O_3	4
MnO	.28	TiO_2	None
CO_2	46.18	CaO	None
P_2O_5	.06	K_2O	3
Cl	.09	$H_2O\pm$	8
Na_2O	.08	Organic matter	5
(Ba, Sr)O	None	FeS_2	2
Insol	1.78		
H_2O-	.09	Total	98
Total	100.08		
Less O=Cl	.02		
Total	100.06		

The Weber(?) formation possesses some unusual lithologic features. Almost all of the sandstone beds are predominantly micaceous, not unlike the micaceous sandstone of Pennsylvanian age in the Appalachian region. This facies has frequently been mistaken for porphyry, especially in underground exposures; this error is no doubt caused by the conspicuous mica and the not uncommon feldspar grains. In all of the rocks studied with the aid of the microscope, however, the large mica flakes are clearly products of sedimentation and not of igneous action or of alteration. They are fresh or slightly iron-stained and do not cross the boundaries of other minerals, as is usually the case with secondary micas. Their sources were obviously the rocks of the pre-Cambrian "complex."

Clearly a common lithologic facies of the Weber(?) formation is mineralogically very similar to an igneous rock rich in quartz and lean in feldspar, as it contains mica and quartz in abundance and even some feldspar grains. Where the quartz and feldspar are not well rounded and the rock is in massive beds, this facies of Weber(?) makes mapping in regions of complicated structure and alteration difficult; the Weber(?) may be confused with some of the more coarsely crystalline late Cretaceous Tertiary porphyries of the Gray porphyry group described below, or with rocks of pre-Cambrian age. The rock resembles in many respects the "recomposed granites" described by geologists in the Lake Superior region, and it is identified with considerable difficulty (Grant, 1893, pp. 50–51).

Although most of the quartz particles are somewhat rounded, well-rounded ones are rare and some beds contain sharply angular grains measuring as much as 0.2 by 0.3 mm. The cause of the angularity is not known. There are no associated glass particles to indicate that this is tuffaceous rock and that the angular particles were formed by a volcanic explosion. Perhaps the angularity is a result of physical disintegration of rock in which the quartz crystals had already been shattered by shear, such as might be expected in the pre-Cambrian rocks and as is actually seen today in pre-Cambrian granites and schists of the Mosquito Range; such material, if not transported very far, would retain much of the originally angular form of its grains.

In the Leadville district, the fossil collections are not sufficiently complete, and the vertical distribution of faunas is not well enough known to permit definite subdivisions of the Weber(?) formation. As no continuous section can be measured, there is some uncertainty as to the correct sequence. Of the three sections mentioned above, undoubtedly the oldest Weber(?) is that exposed on the crest and west slope of Mount Evans, where it directly overlies the Leadville dolomite without angular uncomformity. Next in age is probably the section on the south slope of Empire Hill. The youngest part represented in the measured sections is thought to be that in the Board of Trade and Isabelle Amphitheaters. If the stratigraphic relations of these three sections are correctly interpreted, three lithologic divisions, here regarded as members, may be recognized in the Weber(?) formation as exposed close to Leadville. (See also Stark, Johnson, Behre, and others, 1949, pp. 33–41.)

1. The lowest member of the Weber(?) formation ranges in thickness from 120 to 375 ft. It is composed chiefly of beds of dense, fetid, fossiliferous blue-gray limestone, alternating with black, carbonaceous shaly strata that contain plant matter. Locally there is a bed of quartzite about 3 ft thick at the base of the Weber(?), but more generally the lowest unit consists of 35 ft of black shale, rich in pyrite, papery in fracture, with occasional chert concretions and plant fibers. The base of this shale forms the boundary with the Leadville dolomite. This shale facies causes much trouble to miners by caving from the roof. A zone of this unit, a few feet thick, occurs at many places directly overlying the Leadville dolomite and just under a thick sill of early White porphyry; such relations are seen in the Continental Chief mine at the head of Iowa Gulch.

Plant fossils were collected on Mount Evans from two shaly beds situated respectively 107 and 128 ft above the base in this lowest member of the Weber(?). They were submitted to David White and C. B. Read of the U. S. Geological Survey, who identified the following forms:

Sphenopteris aff. *cheathami*	*Stigmaria* sp.
Sphenopteris cf. *microphylla*	*Lepidostrobus* sp.
Diplotmena(?) sp.	*Cordaites* sp.
Neuropteris cf. *dluhaschi*	*Cordaianthus* sp.
Neuropteris cf. *heterophylla*	*Cordaicarpus* sp.
Neuropteris cf. *gigantea*	*Dicranophyllum*(?) n. sp.
Calamites sp.	*Ginkophyllum* n. sp.
Asterophyllites sp.	

In the same locality, 246 ft above the base of the Weber(?) formation, the following invertebrate fossils were collected and identified by J. H. Johnson:

Cleiothyridina pecosi var.	*Spirifer opimus*
Composita subtilita	*Pleurophorus subcostatus*
Composita sp.	*Schizodus* sp.
Lissochonetes geinitzianus	*Yoldia glabra*
Dictyoclostus coloradoensis	*Orthoceras* sp.
Productus sp.	

On the south slope of Empire Hill, in gray, thin-bedded limestone, J. H. Johnson collected and identified the following fauna:

Archaeocidaris sp.	*L. cora* var. *nodosus*
Lophophyllidium profundum	*Productus coloradoensis*
Fistulipora sp.	*Dictyoclostus?* n. sp. aff. *semistriatus*
Orbiculoidea sp.	*Leptalosia spondyliformis*
Cleiothyridina pecosi?	*Spirifer opimus* var.
Chonetes geinitzianus	*Euphemites carbonarius*
Composita subtilita	*Deltopecten* aff. *D. scalaris*
Juresania nebraskensis	*Enchostoma* sp.
Derbya crassa	*Phillipsia* sp.
Linoproductus aff. *L. cora*	

At Weston Pass in similar beds a small fauna was collected and identified by J. H. Johnson, who lists the following forms:

Lophophyllidium profundum	*Composita subtilita*
L. profundum var. *sauridens*	*Marginifera ingrata*
Chonetes geinitzianus	*Productus cora*
Phricodothyris sp.	*Spirifer opimus*
Platyceras sp.	*Phillipsia major*

2. The next higher of the three members here recognized in the Weber(?) formation is predominantly shale. Limestone beds are rare and sandstone and

grit are more abundant. Layers of light-gray, greenish, brown, and black shales alternate with black micaceous sandstone, light-gray sandstone, and gray grit. The shales contain rare plant fibers, too poorly preserved for identification. No other fossils have been found. The thickness of the member in the measured sections at Leadville ranges from 150 to 250 ft.

An especially conspicuous part of the middle member is a white, massive, pure quartzite, distinguished lithologically from the Cambrian quartzites and the Parting quartzite member of the Chaffee formation only by the presence of a few mica flakes. This quartzite is well exposed on the west slope of Dyer Mountain and on the north slope of Long and Derry Hill south of the Clear Grit mine. With due allowance for intervening intrusive bodies, the quartzite is computed to lie 125 to 150 ft above the base of the Weber(?). With further detailed field work, this quartzite may come to be generally recognized in the sections at Leadville and to be regarded as the base of the middle member of the Weber(?) formation as here defined.

The two members described above probably make up what Emmons (1886, p. 67) called the "Weber shales." The coal beds mentioned by Emmons do not extend into this area, but probably some of the black shale beds are a stratigraphic equivalent.

3. The uppermost of the three members into which the Weber(?) formation is here divided consists of intercalated grit, sandstone, and shale beds. Though argillaceous beds are present, this member consists dominantly of coarser clastics; conglomerate horizons are common and sandstone makes up by far the largest part. Many of the characteristic features of shoreline or continental accumulation are seen; ripple marks, rill marks, and crossbedding are conspicuous. Some of the sandstone is well consolidated and essentially quartzitic. Beds rich in calcium carbonate are scarce, but a few singularly persistent layers of blue-gray, fetid limestone containing marine fossils can be traced for some distance on Prospect Mountain. The maximum thickness of this upper member in the Leadville district has not been determined. On Prospect Mountain the lower part of the Weber(?) formation is not exposed, but the thickness of the part of the upper member that was measured by Johnson, was found to be 872 ft; the entire member is here probably about 1,300 ft thick. Emmons (1886, p. 68) gives 2,500 ft for the thickness of the "Weber grit," which is the approximate stratigraphic equivalent of the unit here described. This estimate was accepted by Patton, Hoskin, and Butler for the Alma region, on the eastern side of the Mosquito Range (Patton, Hoskin, and Butler, 1912, p. 56).

Because of the uncertainties concerning the boundaries of the three members in the Leadville region, the whole of the Weber(?) formation, except for certain thin but conspicuous limestone beds, is represented on the geologic map (pl. 1) by a single pattern.

ALTERATION

Several products result from the alteration of the Weber(?) formation, depending in part on the original composition of the rock, in part on the type and intensity of alteration. Some beds that were originally sandstone have been altered to quartzite. A good example is the white quartzite described on this page. Much if not all of this alteration is a result of dynamic metamorphism.

The originally shaly beds have been compressed and in places somewhat recrystallized, with the growth of secondary mica—chiefly biotite. The result is a dark gray-green rock suggestive of a schist, but retaining a distinct clayey odor; the schistose appearance is attributable chiefly to the large proportion of mica in the original sediment. Effects of this type of alteration are commonly seen near sills and dikes, as strikingly demonstrated in the head of the Isabelle Amphitheater. Some of the black shales are bleached in the neighborhood of the thicker sills. In the thin bands of shale included in the sill of early White prophyry that forms the ridge between Dyer Mountain and Mount Sherman, the bleached areas show the faint outlines of chiastolite, still only in the incipient stage of formation.

A fairly common result of alteration of both shale and sandstone is the formation of microscopic mica flakes in the feldspar grains. Secondary sericite fills fine cracks that cross the quartz grains.

The changes in the limestones are by far the most conspicuous. They are best seen in the thin limestone lenses above the intrusive sill that forms the floor of the Isabelle Amphitheater. The alteration—probably a contact metamorphism—yields three products visible to the naked eye. One is a dense jasperoid, similar to that resulting from silicification of the Leadville dolomite (p. 37). The second product is marmorized limestone, commonly somewhat bleached from blue-gray to a light-gray color. The third is a silicate rock formed under much the same circumstances as the other two products, but apparently showing the effects of higher temperatures. It is peculiarly mottled—the gray rock contains very light gray lenses or spherical masses largely composed of needles or fibers of tremolite and actinolite, or cores of greenish-gray epidote. Under the microscope epidote (zoisite), tremolite, actinolite, diopside, sericite, and secondary quartz and carbonates (calcite?) are conspicuous. The extreme of this type of alteration produces a very friable olive-green rock composed wholly of the secondary silicates and containing radiating sheaves of bladed tremolite crystals 1 in. (2.5 cm) long.

Limestones and dolomites containing substantial percentages of clay are altered to a hornfelslike rock—

dense, dark, hard, and made up chiefly of very finely granular quartz, sericite, and epidote, and scattered, lesser amounts of calcite.

The Weber(?) formation is stratigraphically the highest bedrock formation in the area mapped. Its upper limit is unknown, as the overlying Maroon formation is not found in this area.

GEOLOGIC AGE AND CORRELATION

Correlation of the Weber(?) formation at Leadville with the Weber quartzite at the type locality, Weber Canyon, Utah, is at best doubtful (Girty, 1903, pp. 171 and 210). Certainly, much of the Weber(?) at Leadville is of Pennsylvanian age, but more exact age assignment is not yet possible. This subject has received careful study by J. Harlan Johnson (1934, p. 33), who reports as follows:

> The fossils obtained indicate that the lower and middle zones of the Weber(?) formation are of Pennsylvanian age and equivalent to the middle Pottsville and part of the upper Pottsville of the East. No equivalent of the lower part of the Pottsville was observed.
>
> In Colorado the Weber(?) is the equivalent of the lower part of the Sangre de Cristo formation of the Sangre de Cristo region, a portion of the Hermosa formation of southwestern Colorado, and at least some of the lowest part of the Fountain formation of the Colorado Springs region. It is also equivalent to part of the Magdelena group of northern New Mexico.

MESOZOIC(?) AND CENOZOIC IGNEOUS ROCKS

SUMMARY

The igneous rocks that are younger than the pre-Cambrian in the area here described are either wholly or mainly Tertiary and only possibly in part late Cretaceous and early Pleistocene in age. They are primarily intrusive, although locally a few of the intrusions apparently broke through to the surface. These rocks fall into three natural divisions, based partly upon petrographic features, and partly upon the time of intrusion. By far the greater part belong to the first two divisions, a series of intrusive porphyries whose geologic relations to faults show that they are of very late Cretaceous or early Tertiary age. Later in the Tertiary or in early Pleistocene time came plugs, explosive pipes, and dikes, in part of porphyry and in part of explosive agglomerates.

The earliest of the three divisions comprises the white porphyries, so called because of their light color. The earlier main body of the white porphyries, designated below as "early White porphyry" for the sake of clarity, forms a series of conspicuous, remarkably extensive sills. In the course of these studies, it has been found that certain dikes, closely similar petrographically to the early White porphyry, were intruded considerably later; these are called by the informal term the "later white porphyry."

The second division, the Gray porphyry group, includes darker rocks of more coarsely porphyritic texture, slightly younger than the early White porphyry but belonging to the same orogenic and intrusive epoch. They form many dikes and occasional plugs but are most conspicuous as sills. One facies is of explosive origin. Six varieties of the Gray porphyry group have been distinguished. They are the Lincoln, Sacramento, Evans Gulch, Johnson Gulch, and Iowa Gulch porphyries, and an unnamed quartz diorite porphyry.

Rocks of the third division contain inclusions of the early White porphyry and of the Gray porphyry group, and are therefore younger than all the other igneous rocks of the area, with the possible exception of the later white porphyry. This division comprises plugs of quartz latite exposed south of Iowa Gulch, and pipes of rhyolite agglomerate which are present in the central Leadville district but do not crop out in the marginal areas, though dikes and plugs of agglomerate are exposed in several of the mine workings. Both the quartz latite and the agglomerate are known to be considerably younger than the ore deposits of the district, whereas all the other porphyries, with the possible exception of the later white porphyry, antedated ore formation.

THE WHITE PORPHYRIES

GENERAL DISCUSSION

The term White porphyry is so well fixed in local mining parlance and in the literature that it is retained here for the older of the two white porphyries. The two porphyries, the early White porphyry and later white porphyry, although of very different ages, do not differ greatly petrographically and are not easily distinguished without the aid of the microscope. In the field, structural evidence is generally the best criterion for distinguishing between them and therefore they are grouped together here, though the contrasts between the two are emphasized on page 46. Because of the difference in age between these two lithologically very similar rocks, they are designated the early White porphyry and the later white porphyry. "White porphyry," where used without a modifying adjective, should be understood to mean the older rock of the type to which that term was originally applied.

EARLY WHITE PORPHYRY

DESCRIPTION

The petrographic character of the early White porphyry has been well described in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 44–46) but a résumé is given here for the convenience of the reader. Megascopically it is a snowy white to very light gray rock of stony to finely granular groundmass that rarely attains the coarseness of a sugary texture (fig. 26). The parting may be massive or columnar but is generally platy (fig. 25). Phenocrysts are generally so few that the rock barely qualifies as a porphyry. The few phenocrysts consist of small crystals, rarely 0.1 in. (0.25 cm) in maximum dimension. Quartz, plagioclase, and black pseudo-hexagons of biotite are about equally plentiful as phenocrysts; no orthoclase phenocrysts are seen.

Under the microscope several varieties of porphyry can be distinguished; the chief differences are variations in the coarseness of the grains that make up the groundmass, which constitutes about 95 percent of the rock. In some facies the quartz grains are as much as 2 mm in average diameter; in others they are 0.5 mm or less wide. In general, the coarser-grained groundmass occurs in the thicker sills, and especially near the middle of such sills, as might be expected. In the least altered facies

FIGURE 25.—Typical early White porphyry outcrop; note characteristic platy parting; Mount Sheridan.

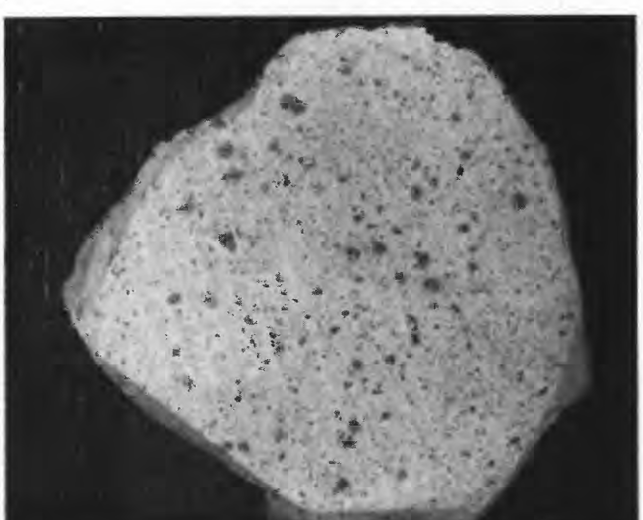

FIGURE 26.—Early White porphyry, slightly altered; dark spots are bluish quartz areas, length 3½ inches.

most of the groundmass consists of quartz, though a few rounded grains show oligoclase twinning and extinction angles. A few orthoclase grains and rare small shreds of biotite are found. Other, rare, accessory minerals are magnetite, zircon, apatite, rutile, and hornblende.

The phenocrysts are generally well formed. This is especially true of the quartz, which has sharp euhedral outlines—entirely unlike the quartz phenocrysts of some of the Gray porphyry group, which are commonly rounded or embayed. Typically the quartz crystals contain numerous fluid inclusions. Quartz phenocrysts generally make up 1 to 2 percent of the rock, but in some places they amount to as much as 7 percent; where the quartz content is so large, however, fingers of quartz extend from the phenocrysts out into the groundmass, strongly suggesting secondary enlargement.

Well-formed biotite phenocrysts constitute from 1 to 2 percent of the rock. They are generally very dark where unaltered, and contain inclusions of apatite and rarely of zircon.

The feldspar phenocrysts are generally oligoclase. They are scarce and generally altered, so that their actual composition is commonly not determinable.

CLASSIFICATION

A consideration of representative chemical analyses of the early White porphyry, together with petrographic study, led Emmons, Irving, and Loughlin (1927, p. 45) to classify the porphyry as a leucocratic granodiorite porphyry. A careful study of the less altered rocks available to the writer in the area here discussed confirms this classification. The light color of the rock and lack of dark minerals, even in the least altered rock, are astonishing.

ALTERATION

Unlike the porphyry in the immediate vicinity of Leadville, most of the early White porphyry in this area is not so intensely changed as to prevent identification of the original minerals. (See figs. 26–30.) Especially striking megascopic features are the rounded patches of bluish-gray quartz, averaging 0.1 in. (2.5 mm) in diameter, and, even more commonly, the "eyes" of sericite, some hollow and druselike, measuring as much as 1 in. (25 mm) in maximum dimension (figs. 26, 29, 30).

Under the microscope, the mica phenocrysts are seen to be partly converted to carbonate; they are very largely sericitized, commonly with the segregation of iron oxides. The feldspar phenocrysts are heavily sericitized. But the outstanding change, best interpreted as a form of hydrothermal alteration after solidification of the rock (Emmons, Irving, and Loughlin, 1927, p. 45), is the general silicification of the ground-

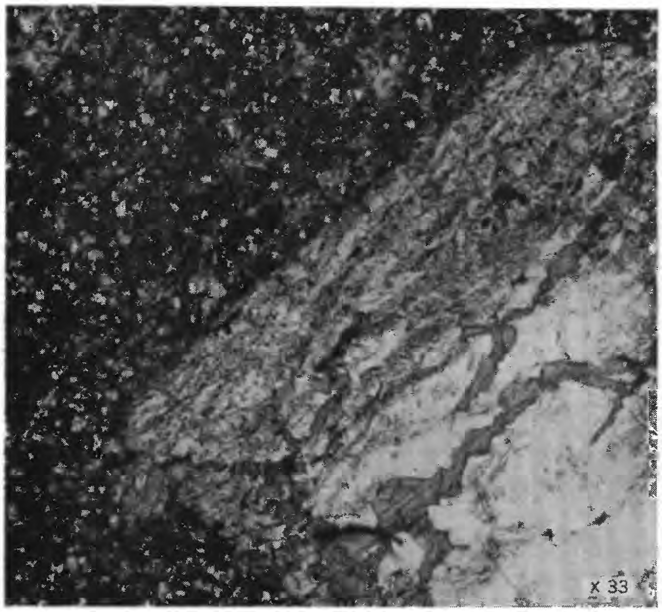

FIGURE 27.—Early White porphyry, almost unaltered. Shows part of one oligoclase phenocryst and the finely granular quartz groundmass, partly invaded by carbonates. × 33; crossed nicols. From sill on Dyer Mountain, west of Liddia fault.

mass, a process concurrent with the widespread sericitization. Fingers of quartz extend outward from the quartz phenocrysts, and the quartz crystallites of the groundmass assume spiderlike interpenetrating forms. Epidote, chlorite, and a material resembling kaolinite are other alteration products. Their proportions, however, are small except in the most highly altered rock. A characteristic feature of the early White porphyry is the dendritic growth of manganese dioxide on joint faces, from which this rock is sometimes designated "forest rock" by miners.

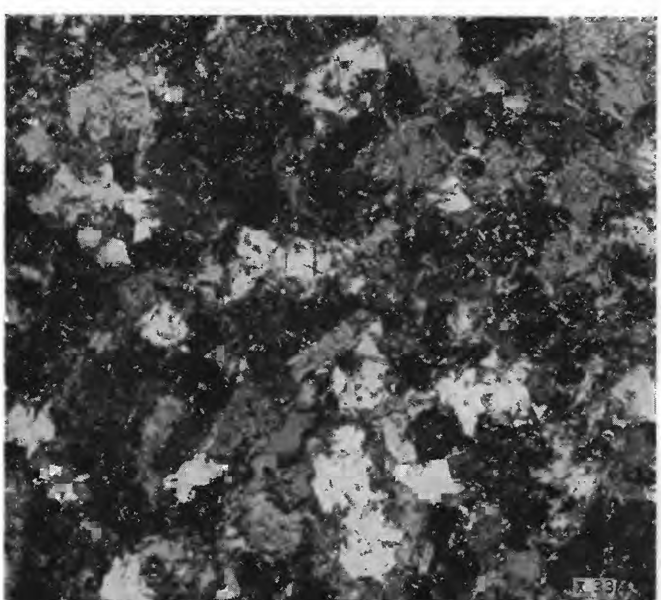

FIGURE 28.—Alteration (silicification) typical of early White porphyry; note extensive development of coarse secondary grainlets of quartz, with inclusions, and absence of true phenocrysts. × 33; crossed nicols. From Great Eastern shaft, near Lake Isabelle.

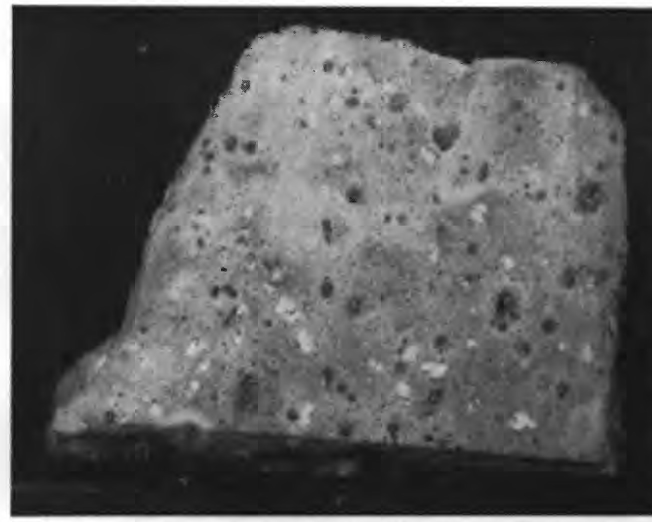

FIGURE 29.—White porphyry, altered with mottling; quartz areas enlarged; darker, vaguely outlined areas are light buff to brown; length $3\frac{1}{2}$ inches.

FIGURE 30. White porphyry, with vug formation; vugs bear small crystals of quartz and sericite; length of specimen 3 inches.

STRUCTURE AND DISTRIBUTION

With very rare exceptions, the early White porphyry is limited to sill-like bodies. It forms several prominent fairly continuous sills in the Cambrian quartzite. A prominent sill within Cambrian quartzite can be traced from near the Best Friend mine in the Evans Amphitheater southward to the western slope of Peerless Mountain, a distance of nearly 5 miles. More conspicuous yet is a very thick sill that directly overlies the Leadville dolomite, a thin strip of 30 ft or less of grits and shales of the Weber(?) formation locally intervening. This sill extends the entire length of the eastern edge of the area mapped—a distance of nearly 7 miles; it appears also as far west as the town of Leadville, and its continuity northwestward is suggested by a thinner sill, slightly lower in the stratigraphic sequence, on Canterbury Hill. On Mount Sherman it attains its maximum thickness of more than 1,000 ft. Locally such sills may be transgressive, as is well shown by the relation between Cambrian quartzite and the early White porphyry on the eastern wall of Iowa Amphitheater, 1/5 mile north of where the South Dyer thrusts cuts across the Cambrian strata.

Southeast of Mount Sherman is a long spur lying east of the area here mapped and referred to by Emmons as White Ridge. Here, also, the early White porphyry is very thick. Emmons assumed that the main feeder for the several sills of early White porphyry was in this locality.

In the pre-Cambrian rocks there are irregular forms and large dikes of White porphyry instead of the sills so commonly seen elsewhere (fig. 31). Good examples of these forms are seen on the southern slope of East Ball Mountain, near the eastern side of the mouth of the Dyer Amphitheater.

FIGURE 31.—South Dyer Mountain from West Sheridan Mountain; note complex structural relations of intrusive bodies (white in photograph) cutting pre-Cambrian granite.

LATER WHITE PORPHYRY

DESCRIPTION

The later white porphyry is discussed here despite the marked difference in age because of its close lithologic similarity to the early White porphyry. In hand specimens the later white porphyry generally resembles the early White porphyry (fig. 32), but it contains a few distinct feldspar phenocrysts as much as 4.5 mm (0.2 in.) long, and very rarely a quartz crystal or a flake of brown mica is visible. The groundmass is white, light cream, or very light gray, similar to that of the early White porphyry; its texture is slightly more dense, as a rule, than that of the early White porphyry. Commonly the rock has a peculiar tendency to break into slabs 1/2 in. thick.

Under the microscope (fig. 33) the few feldspar phenocrysts commonly appear considerably altered but approximate oligoclase in composition; they are well formed. Quartz phenocrysts are far more scarce, as are shreds of biotite. Altogether, the phenocrysts no-

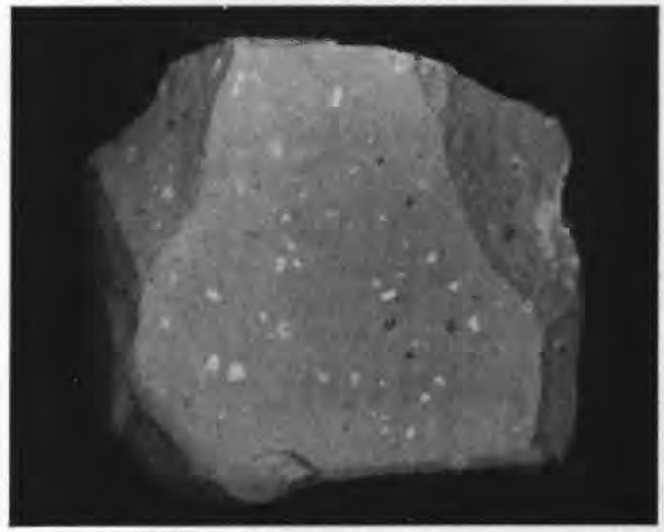

FIGURE 32.—Typical later white porphyry; phenocrysts more common in this specimen than usual; length 3 inches.

where make up more than 5 percent of the rock, and generally much less.

The groundmass is conspicuously fine grained. Some of the grains are orthoclase and others are plagioclase (oligoclase-albite). Apatite crystals, grains of magnetite, zircon, and secondary pyrite are rare. By far the most abundant recognizable constituent is quartz, in tiny granules generally 0.02 mm or less in diameter and having peculiar amoeboid forms strongly suggestive of later enlargement by hydrothermal action. The same process doubtless accounts for numerous very small flakes of sericite seen in some thin sections. Local, highly irregular veinlets of quartz with wavy extinction, may represent remnants of flow lines.

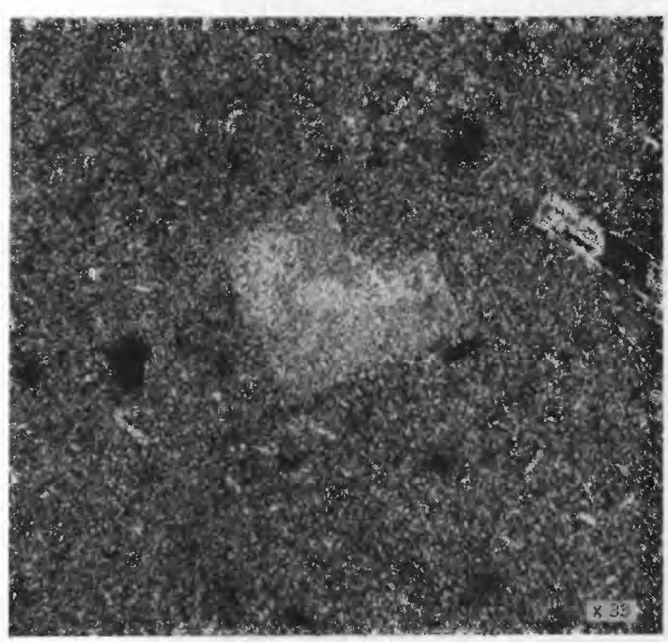

FIGURE 33.—Later white porphyry. The fine-grained groundmass bears one phenocryst of kaolinized feldspar. × 33; crossed nicols. Dike on East Ball Mountain.

It may therefore be inferred that the rock has been considerably altered. Biotite and feldspars have been converted into sericite and even into carbonates. The smaller quartz grains in the groundmass have undergone little if any change since their crystallization, except marginal enlargement and a slightly undulatory extinction.

Although uncertainty exists as to some of its constituents, the rock can best be classed as a rhyolite porphyry. It strongly resembles the rhyolite described in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, p. 59) and on pages 59–60 of this report, but it is not agglomeratic like the other rock and has no flow lines. The rock also closely resembles the later white porphyry of the Alma district (Singewald and Butler, 1931, p. 396), with which it is probably identical.

In the absence of positive evidence, this porphyry is not here correlated with the rhyolite, despite the similarity. As shown by structural relations, it is, like the rhyolite, younger than the rocks of the Gray porphyry group; however, unlike the rhyolite, it is pyritized locally, from which the inference is possible that it antedated all ore deposition, whereas the rhyolite at Leadville encloses ore fragments that were torn off by the intrusion subsequent to ore deposition.

DISTRIBUTION

Typical later white porphyry is best displayed in dikes on the eastward slope of Finnback Knob, the 13,405-ft hill due west of Peerless Mountain. Here one mass has an almost cylindrical form and is suggestive of a ring-dike surrounding an area of pre-Cambrian granite 500 ft across; from this mass a dike projects half a mile with an almost constant strike southwestward up Finnback Knob. Other dikes are exposed on East Ball Mountain, and in Evans Amphitheater near the Best Friend mine.

In the Diamond shaft and in Empire Gulch a rock was found that is said to resemble the rhyolite (Emmons, Irving, and Loughlin, 1927, p. 44) but is here classed with the early White porphyry.

DISTINCTIVE FEATURES

The later white porphyry is easily distinguished from rocks of the Gray porphyry group by its lighter color, its lack of ferromagnesian minerals, and its prevailingly finer texture, but its distinction from the early White porphyry is very difficult. Its most common and conspicuous phenocrysts are plagioclase and scarce quartz crystals, whereas in the early White porphyry dark mica and quartz are fully as abundant as the feldspar phenocrysts. Moreover, the groundmass of the later white porphyry is somewhat more dense, so that a coarsely granular groundmass strongly favors the conclusion that the rock in question is early White porphyry rather than the younger rock. Further, there is a tendency for the later white porphyry to break into thin sheets, evidently controlled by a hidden flow structure; a faintly sheetlike fracture is also locally observed in much of the early White porphyry, but the sheets are thin, conchoidal spallings, rather than flat slabs. Both porphyries have dendrites of manganese dioxide.

Under the microscope the fine groundmass and the lack of moderately large quartz phenocrysts furnish conspicuous contrasts with most of the early White porphyry. Both rocks are likely to be somewhat altered, but the later White porphyry, at least in its groundmass, is relatively unchanged.

GRAY PORPHYRY GROUP

GENERAL FEATURES

CLASSIFICATION AND NOMENCLATURE

As originally used by Leadville mining men the term "Gray porphyry" was applied to all grayish, conspicuously porphyritic intrusive rocks younger than pre-Cambrian. Emmons (1886, pp. 74–86), however, restricted the term to one of the several varieties of porphyry belonging to the Gray porphyry group and applied new names to the other members of the group. Later (Emmons, Irving, and Loughlin, 1927, pp. 46–51) these rocks were again reclassified, and given the name "Gray porphyry group." On the general maps virtually no subdivisions were made, but on the more detailed maps of the area immediately surrounding Leadville at least two varieties were distinguished.

In the present investigation field mapping was necessarily based upon megascopic rather than upon microscopic characters. From the collections, representing a relatively small number of outcrops, several subdivisions designated by Emmons, Irving, and Loughlin could be distinguished, in addition to other kinds of rock obviously closely related. The subdivisions here recognized are designated by their type locality, and have been named as follows: the Iowa Gulch, Lincoln, Sacramento, Evans Gulch, and Johnson Gulch porphyries. The Iowa Gulch porphyry alone was a new designation. (See Behre, 1939, pp. 64–65.) The Mount Zion porphyry was not recognized in this immediate region, though it is possible that some of what is here mapped as Evans Gulch porphyry is actually Mount Zion porphyry. In the following discussion each of the five subdivisions is briefly described. The classification adopted is based primarily upon textural features (with due allowance for such factors as rapidity of cooling) and upon mineralogic composition, especially the proportions of the more common minerals and the prevalence of distinctive crystal forms. As an aid to field recognition, the bases for such distinctions, especially as observed in the hand specimen, are given for each class and typical hand specimens are illustrated in figures 34–37 and 39–40.

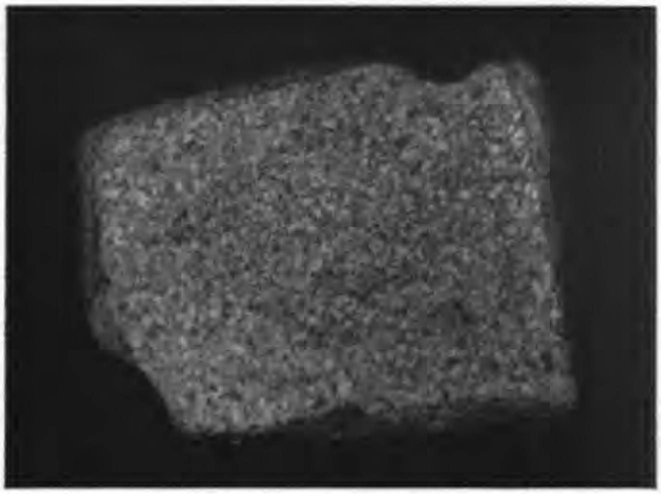

FIGURE 34.—Evans Gulch porphyry, showing relatively finely crystalline, equigranular texture; length of specimen, 4 inches.

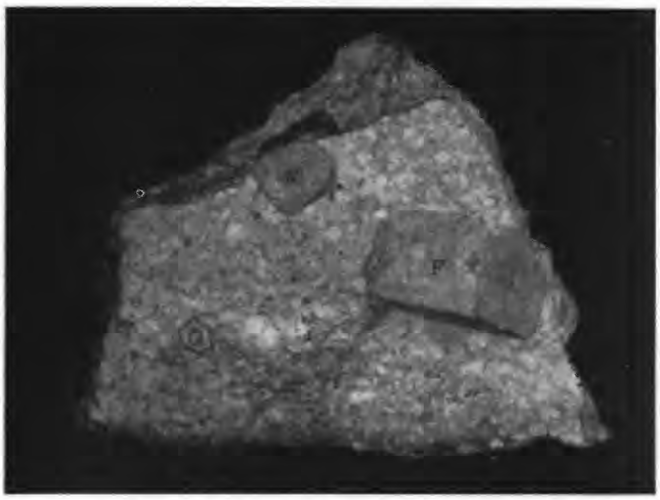

FIGURE 35.—Lincoln porphyry showing orthoclase (*F*) and quartz (*Q*) phenocrysts; length of specimen 3½ inches.

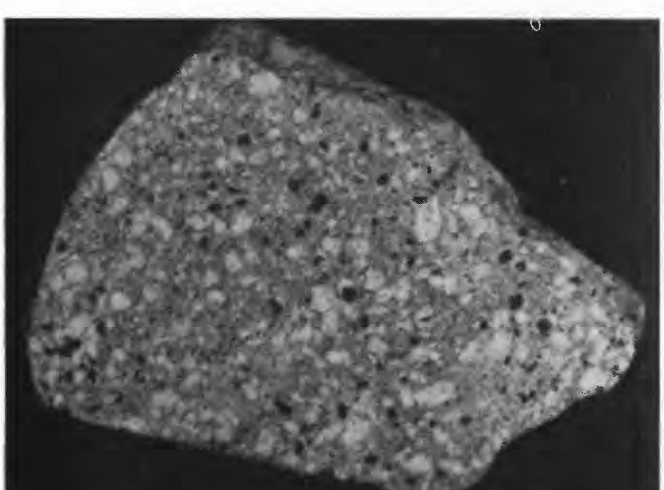

FIGURE 36.—Sacramento porphyry; note more coarsely crystalline texture and darker color; length of specimen 4 inches.

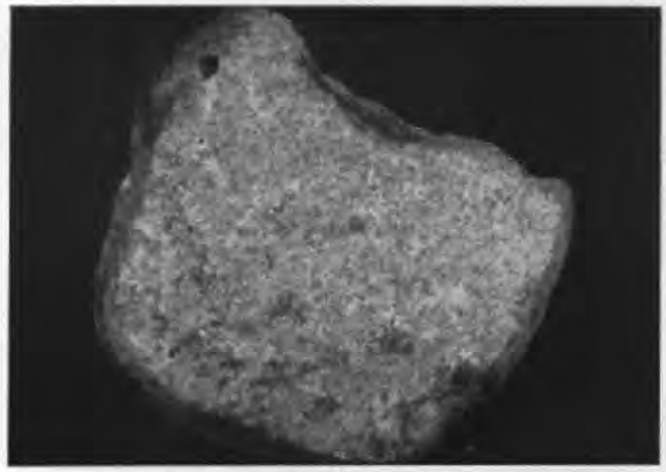

FIGURE 37.—Iowa Gulch porphyry, finely crystalline facies; dark spots are chiefly dendrites of manganese dioxide; length of specimen 3 inches.

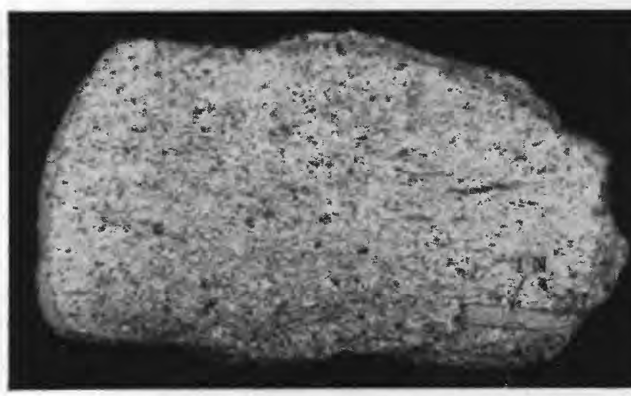

FIGURE 38.—Little Union quartz latite, showing inclusions (*IN*); length of specimen 4½ inches.

FIGURE 39.—Iowa Gulch porphyry, showing flow banding in dense, stony phase; length of specimen 4½ inches.

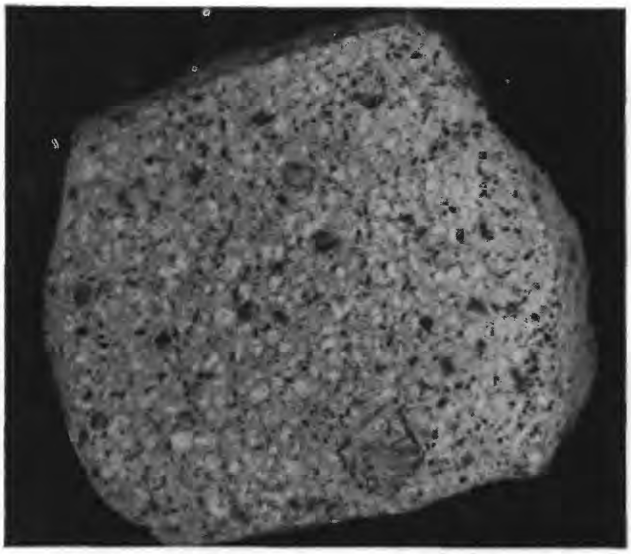

FIGURE 40.—Johnson Gulch porphyry; note euhedral phenocrysts resembling those of Lincoln porphyry; length of specimen 3½ inches.

However, the difficulty in applying any detailed classification to the Gray porphyry group, such as the one here followed, can scarcely be overemphasized. This difficulty is the result of two facts. First, all of the porphyries have been highly altered, at least locally; feldspars are sericitized and carbonatized, amphiboles and micas are changed to chlorite or to sericite, and most of the original constituents have been partly replaced by quartz. Second, there appear to be gradations from one rock type to another. Yet, for a proper understanding of the regional structure and of the age relations between these rocks, correct interpretations of the field relations are necessary, and such interpretations in turn must be based on the actual or probable identity and classification of some units of the Gray porphyry group. The difficulties mentioned and the resulting uncertainties should be borne in mind in studying the maps presented herewith.

STRUCTURE OF THE PORPHYRIES

Unlike most of the early White porphyry, which occurs almost wholly in sills, the bodies of the Gray porphyry group represent almost all of the more common forms of intrusion. The sill of Lincoln porphyry on Little Ellen Hill and that of Sacramento porphyry along the crest of the range to some extent resemble laccoliths in their abrupt thickening and thinning, though the small ratio of thickness to length differentiates them from the common conception of a laccolith. The most abundant and the most conspicuous form, however, is the true sill, varied in extent, thickness, and lithologic features. In a few places, as at a sill-like body of Johnson Gulch porphyry on the northeastern slope of West Sheridan Mountain, the intrusion is inclined to the bedding though at only a small angle. In addition to the Breece Hill stock and two poorly defined stocks in the Adelaide Park and Breece Hill areas, which are already known (Emmons, Irving, and Loughlin, 1927, p. 54) only one other plug or stock has been recognized. It is partly exposed in Iowa Gulch, near the Mansfield shaft. Dikes are common, especially in Iowa Gulch, where they trend about due north and seem to stand vertical; they are chiefly of the Johnson Gulch type and evidently follow fissures or faults of moderate displacement.

LINCOLN PORPHYRY

DESCRIPTION

The Lincoln porphyry, a variety of the Gray porphyry group, named from Mount Lincoln on the eastern side of the Mosquito Range, was first described by Emmons (1886, p. 79). In his original description Emmons gave as the outstanding characteristic the very large euhedral orthoclase phenocrysts and mentioned also the conspicuous quartz crystals that it contains.

The typical Lincoln porphyry (fig. 35) is a light-gray rock with a deep pink or very pale lavender cast, brownish where weathering has been intense, and locally bleached to white or very light gray by hydrothermal alteration. The pinkish groundmass is studded with conspicuous well-formed orthoclase crystals (fig. 35), some as much as 7.5 cm (about 3 in.) in length. These crystals commonly show zonal inclusions and Carlsbad twinning; they weather out of the rock so readily that they form a conspicuous part of the residual soil. Another noteworthy feature is the presence of numerous quartz phenocrysts; many of these are almost perfect hexagonal bipyramids and exceptionally large, with a maximum length of 1 cm (about 0.4 in.). Their appearance suggests high-temperature quartz. There are also phenocrysts of plagioclase and a few small books, plates, or shreds of brown biotite which in natural exposures are largely oxidized and spread a brown stain into the adjacent minerals.

Under the microscope(fig. 41) the orthoclase phenocrysts are seen to enclose fine, dustlike inclusions of red iron oxide, to which they owe their color, and zonally disposed mica crystals. Plagioclase phenocrysts make up about 30 percent of the volume of the rock. They average about 4 mm (approximately 0.15 in.) in length. Both albite and Carlsbad twins are common. In samples collected from different localities the composition of the plagioclase ranges from oligoclase-albite to andesine, the latter being by far the more common. In general, the more albitic phenocrysts are formed in the lighter-colored facies of this porphyry—for example, the sill on Little Ellen Hill.

The quartz phenocrysts also show a great range in size, the average being about 5 mm. The excellently euhedral forms, while not universal, are nevertheless highly characteristic of the Lincoln porphyry; embayments, inclusions of the groundmass, and rounded outlines are relatively rare. Characteristically the quartz phenocrysts are surrounded by a halo of very small

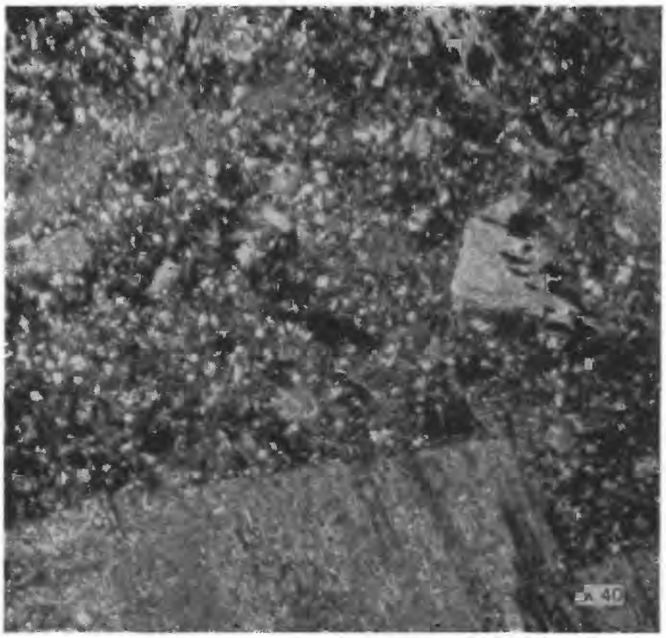

FIGURE 41.—Lincoln porphyry. The edge of one of the typical large orthoclase phenocrysts is visible in this section. Note section of altered oligoclase-albite, and shreds of bleached biotite. × 40; crossed nicols. East slope of Little Ellen Hill.

crystals in the microgranitic groundmass, which becomes even finer grained than elsewhere, as though from mutual reactions that affected crystallization.

Hornblende and biotite are present, but hornblende is rare and seldom makes up as much as 1 percent of the rock. The mica shreds and plates average about ½ mm in diameter and rarely attain 5 mm. Inclusions of apatite, rutile, zircon, and an unidentified trichitic mineral (rutile?) are common. The unaltered mica is brown, but commonly has been converted to an emerald-green mineral by hydrothermal action. The first products of later alteration are a bleached mica and magnetite, some of which, at least, is titaniferous; products of more advanced alteration are chlorite, epidote, and calcite, formed in the order named. Especially conspicuous among these products are yellowish-green, highly pleochroic epidote and the light-green chlorite; the latter gives anomalous deep-purple interference colors under the polarizing microscope. Most of the hornblende crystals are greatly altered; as in the case of the biotite, the commonest products are epidote, chlorite, and calcite.

Accessory primary minerals comprise magnetite, apatite, sphene, rutile, and zircon. The magnetite generally occurs in euhedral crystals, it is uncommon compared with its occurrence in the other rocks of the Gray porphyry group. Apatite is abundant in crystals as much as 3 by 1.5 mm (approximately 0.12 by 0.06 in.) in section, commonly as inclusions in the feldspar and biotite crystals. The apatite shows anomalous biaxial interference figures. Sphene forms rims partly surrounding magnetite and interstitial aggregates between biotite crystals. Zircon and rutile occur chiefly as inclusions, commonly in the biotite. A little pyrite appears to have been introduced locally after the solidification of the rock.

The groundmass consists almost wholly of quartz and an alkalic feldspar whose optical properties resemble those of albite or oligoclase-albite, accompanied by small amounts of chlorite (after biotite) and of the accessory minerals mentioned above. The ratio of the two chief constituents, quartz and plagioclase, is about 6:1. The grains are small, few exceeding 0.08 mm in diameter and the average is only about 0.03 mm. Part of the quartz is in euhedral crystals, but by far the greater part forms irregular grains from which projections extend among the other particles. Inclusions are common in this more finely granular, later quartz, though they are almost wholly lacking in the quartz phenocrysts. The feldspar forms tiny crystals of rhombic outline and slender laths approximating a composition of Ab_9An_1.

CLASSIFICATION AND DISTINCTIVE FEATURES

The classification of the Lincoln porphyry has been thoroughly discussed by Emmons, Irving, and Loughlin (1927, pp. 47–48). They demonstrated that the rock is chemically intermediate between granodiorite and quartz monzonite, but the rocks studied in arriving at that classification were somewhat altered. In the adjacent Breckenridge district similar rock (which, however, does not contain the conspicuous quartz phenocrysts of the Lincoln porphyry at Leadville) was regarded by Ransome (1911, pp. 44–50) as a quartz monzonite. Considering the somewhat more alkalic composition of the plagioclase phenocrysts in the rock typical of the region here mapped, as compared with that hitherto regarded as typical and described by Emmons, Irving, and Loughlin, 1927, it seems proper to call the Lincoln porphyry a quartz monzonite, following Ransome, rather than a granodiorite as suggested by Emmons and his associates. Hence the Lincoln porphyry does not differ noticeably in composition and classification from most of the other rocks of the Gray porphyry group found in the Leadville district.

Megascopically, the generally pinkish hue and the lighter coler of the groundmass in the unaltered rock are especially characteristic, in comparison with the Sacramento, Johnson Gulch, and Evans Gulch porphyries. Important also is the fact that none of the rocks of the Gray porphyry group except the Johnson Gulch porphyry have the large phenocrysts of orthoclase that characterize the Lincoln porphyry; even in the Johnson Gulch porphyry these phenocrysts are scarce. The quartz in the other varieties of the Gray porphyry group also is rarely in the large and well-formed bipyramids so common in the Lincoln porphyry.

Under the microscope the general lack of the irregular embayed quartz phenocrysts, such as characterize most of the other rocks of the Gray porphyry group, is striking and consistent with the preponderance of euhedral quartz phenocrysts in the Lincoln porphyry. The rock differs from the Evans Gulch porphyry in the conspicuous rarity of hornblende. Finally, the groundmass is more finely crystalline than in most of the other rocks of the Gray porphyry group.

All the above features are relative, and gradations from one rock variety to any other are common. This is especially true of the Johnson Gulch porphyry, which in some facies strongly resembles the Lincoln porphyry and is virtually indistinguishable from it where somewhat altered.

ALTERATION

Where the rock is altered partial replacement by sericite is common, and is most marked in the feldspar phenocrysts; here the sericite forms isolated, tiny flakes, with greatest dimensions parallel to the cleavage of the host mineral. In more advanced stages the sericite increases in quantity and finally constitutes a solid aggregate preserving the forms of individual feldspar crystals and even clearly outlining the twinning lamellae of plagioclase. In the most thoroughly altered phenocrysts calcite encroaches upon and replaces the sericite. In the biotite the process of alteration begins with bleaching, followed by the formation of chlorite and epidote. The groundmass undergoes very little alteration, on account of the abundance of quartz, but its feldspar, like that of the phenocrysts, is replaced by sericite. Limonite has been formed from pyrite through oxidation and is conspicuous at some localities.

DISTRIBUTION

The typical Lincoln porphyry occurs on Mount Lincoln near Alma, just east of the crest of the Mosquito Range. Emmons (1886, p. 80) mentions the occurrence of Lincoln porphyry on Buckeye Peak, 7 miles north of Leadville, and in places along the Eagle River still farther north. A rock very similar mineralogically but with the texture of a coarsely porphyritic granite has been described from the Twin Lakes region, about 13 miles southwest of Leadville (Howell, 1919, pp. 47–51; Stark and Barnes, 1935, pp. 474–475).

Typical Lincoln porphyry is well exposed at the head of Birdseye Gulch and in the east wall of the amphitheater in which the Board of Trade mines are located (pl. 1). These exposures are parts of a group of sills several hundred feet above the base of the Weber(?) formation. Two such sills are exposed on Little Ellen Hill. The sequence of sedimentary rocks and sills on the spur that separates Birdseye Gulch from the Board of Trade Amphitheater is like that on Little Ellen Hill, and the sill of Lincoln porphyry seen on the edge of the spur mentioned is probably continuous with the lower sill on Little Ellen Hill beneath the alluvial and glacial deposits of Upper Evans Gulch. In these localities the rock possesses all the characteristics of typical Lincoln porphyry.

SACRAMENTO PORPHYRY

NAME

No exposures of fresh, recognizable Sacramento porphyry were studied in the field work connected with Professional Paper 148. The rock was first described by Emmons (1886, pp. 81–82), who gave Gemini Peaks overlooking the Sacramento Amphitheater as the type locality. Emmons distinguished the Sacramento porphyry from his Gray porphyry (the Johnson Gulch porphyry of Professional Paper 148) by its higher percentage of plagioclase, and the noteworthy quantities of hornblende. These are generally good criteria. Moreover, where not too greatly altered, the rock is a rock unit distinct from the other members of the Gray porphyry group. Therefore the name is retained, and the Sacramento porphyry is distinguished on the map.

DISTRIBUTION

On Gemini Peaks, midway between Mount Sherman and Dyer Mountain, a part of a thick sill of Sacramento porphyry is exposed above a thin strip of the Weber(?) formation. On Mount Evans the entire thickness of the sill is exposed (fig. 42), and also some of the overlying Weber(?) strata; both floor and cover of this large sill are here visible. Still farther north the sill fingers out into several thin sheets. The maximum thickness of the sill is about 750 ft, on Dyer Mountain. Two miles farther north, on Mount Evans, the thickness is 500 ft, and on Gemini Peaks, due to erosion, but 300 ft of it is preserved. Apparently Emmons' (1886, p. 81) estimate of 1,000 ft maximum for this sill is too high. The general form of this body is almost laccolithic, with a surface slope of 6° in places. Similar rock is common in several igneous bodies in Iowa Gulch. In

FIGURE 42.—Sills on Mount Evans, from Evans Amphitheater; sediments included are shales and sandstones of the Weber(?) formation. Explanation: *Cw*, Weber(?); *Pz*, Paleozoic sediments; *Tew*, early White porphyry; *Ts*, Sacramento porphyry.

fact, in the area here described, the Sacramento porphyry is probably the most widespread representative of the Gray porphyry group.

DESCRIPTION

To the unaided eye the fresh rock (fig. 36) presents a light gray-green appearance; it is white or very light gray where bleached, or darker gray with faintly reddish-brown areas where mineralized and partly oxidized. Visible in a light-gray groundmass are numerous white plagioclase phenocrysts averaging 3 mm (about 0.12 in.) in diameter, very scarce pinkish orthoclase crystals of about twice that size, phenocrysts of glassy quartz 2 mm (about 0.08 in.) in diameter, booklets of biotite generally about 2 mm in maximum dimension, and rare needles of dark-green, largely altered hornblende. They are set in what to the unaided eye seems to be a stony groundmass.

Under the microscope (fig. 44) the outstanding phenocrysts are seen to be crystals of plagioclase, ranging in composition from andesine to oligoclase and varied somewhat even within a single body of rock. Albite and Carlsbad twinning, zoning, and euhedral crystals are common. In these plagioclase phenocrysts alteration is especially far advanced; it is generally represented by sericite replacing twinned feldspar, one of a pair of twins frequently showing far more extensive replacement than its neighbor. In other crystals the altered parts are peripheral. Calcite is another common secondary product of the feldspar, and secondary quartz and epidote are observed in some rocks. The plagioclase phenocrysts make up 20 to 35 percent of the total volume of the rock. Much of the rock, however, is so thoroughly altered that the exact identification of the feldspar is impossible.

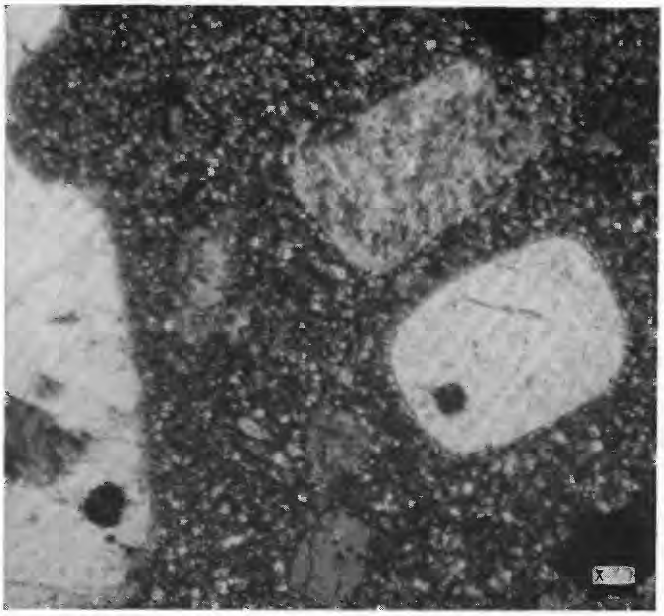

FIGURE 43.—Typical Johnson Gulch porphyry, showing characteristic corrosion of the large quartz phenocryst by the feldspathic groundmass.

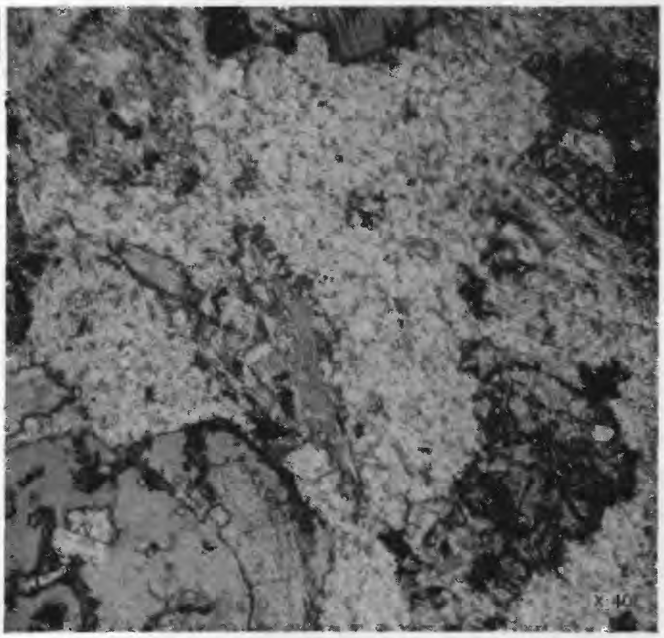

FIGURE 44.—Sacramento porphyry. Main phenocrysts are altered andesine-oligoclase; also present are hornblende and biotite. × 40; plain transmitted light. Board of Trade Amphitheater.

Orthoclase, a rare constituent in the hand specimen, is practically absent in the thin-sections examined. Indeed, its absence or extreme scarcity may be regarded as especially characteristic of the Sacramento porphyry. Visible quartz makes up about 5 percent of the rock volume. The mineral occurs as grayish individuals containing tiny liquid inclusions; the individual grains show strain shadows, and where shattered they are recemented with sericite. They are rarely euhedral and most commonly occur in characteristic amoeboid forms with embayments or inclusions of the groundmass. Typically the groundmass around such quartz individuals is aggregated into a fine-grained border suggestive of a chilled selvage and characterized by a spherulitic or aggregate extinction.

The greenish biotite occurs in flakes and books. It has commonly been converted to chlorite, epidote, and more rarely to calcite, and even where not altered to other minerals it is considerably bleached. It is especially conspicuous because of its abnormal purple interference colors.

Some facies of the Sacramento porphyry contain hornblende, though the mineral is highly altered. Probably much of the chlorite scattered through the rock in small quantities represents altered hornblende. Indeed, so intense was the alteration of the dark minerals that the presence of an amphibole, in contradistinction, can only be ascertained where a basal section with characteristic outline is still preserved.

Under the microscope the groundmass is seen to be made up of minute crystals of alkalic feldspar—orthoclase and albite or oligoclase-albite—which locally show rhombic cross sections. Quartz is also seen in the groundmass as irregular grains, with clearly marked faces, or extending in fingerlike rods between neighboring phenocrysts of quartz and plagioclase. Commonly the groundmass is not greatly altered, but where altered its feldspars are replaced by sericite.

Among accessory minerals, magnetite (commonly limonitized) and apatite appear as euhedral crystals. Zircon and rutile are present, but the latter is very rare.

CLASSIFICATION

The distinctly alkalic composition of the plagioclase in the phenocrysts and groundmass of the Sacramento porphyry, and also its content of free quartz, place this rock among the granites and monzonites. On the other hand, the relatively small quantities of orthoclase clearly puts it among the monzonites rather than the granites. In view of its moderate amount of quartz the rock is best placed among the quartz-monzonites.

DISTINGUISHING FEATURES

The Sacramento porphyry is distinguished from other similar rocks of the Gray porphyry group by the following megascopic features: It is coarser and less equigranular in texture than the mineralogically similar Evans Gulch porphyry. Its mica grains are more nearly euhedral. Even the larger feldspar grains of the Evans Gulch porphyry do not exceed 3 mm (about 0.12 in.) in length, whereas lengths of 5 mm (about 0.2 in.) are fairly common in the Sacramento porphyry. By corollary, the groundmass is more sharply marked off from the phenocrysts in the Sacramento porphyry, whereas the Evans Gulch porphyry would at first sight be designated a fine-grained granitoid rock rather than a porphyritic rock. From the Johnson Gulch porphyry the Sacramento porphyry is distinguished chiefly by the lack of large orthoclase phenocrysts; where present all its orthoclase has dimensions no greater than those of the plagioclase, whereas the Johnson Gulch porphyry contains conspicuous though rare euhedral crystals, 2 cm or more in length. The relative abundance of ferromagnesian minerals and the relatively small proportion of orthoclase phenocrysts and of characteristic euhedral quartz distinguish the Sacramento porphyry from the typical Lincoln porphyry.

EVANS GULCH PORPHYRY

NAME

The Evans Gulch porphyry (fig. 34) is named from its typical occurrence in Big Evans Gulch. It closely resembles the Mount Zion porphyry first recognized by Emmons, but, as pointed out in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 50–51), it is distinguished by its lower content of silica and of free quartz, coarser and more nearly equigranular texture, and larger proportion of dark minerals. Probably no Mount Zion porphyry occurs in the area here described, but possibly some of the highly altered rock on the south slope of Prospect Mountain, here mapped as Evans Gulch porphyry, should be grouped with Emmons' Mount Zion porphyry.

DISTRIBUTION

In plate 13 of Professional Paper 148 only a small area of Evans Gulch porphyry was indicated. In plates 6 and 13 of Monograph 12 two areas were shown to contain this variety of rock; in both places the porphyry is relatively unaltered and definitely identifiable and was believed by Emmons to occur in dikes. More recently two other large bodies of this rock have been discovered. One of them lies in the Board of Trade Amphitheater and the other in upper Evans Gulch and the adjoining region. All outcrops now recognized are known to be parts of sills. Fairly good exposures of one such sill are seen in the bottom of Evans Gulch, some 2,500 ft upstream from the upper end of the two large Leadville reservoirs; still others are in the floor and wall of the amphitheater in which Lake Isabelle lies. A rock tentatively identified as Evans Gulch porphyry forms two thin sills in the Leadville dolomite between Ball and East Ball Mountains and thence southward to U. S. Land Monument Alpha, and several sills within the Weber(?) formation along the crest of the range between Mount Evans and Mosquito Pass.

DESCRIPTION

The rock superficially resembles a fine-grained granite or quartz diorite (fig. 34). None of the crystals exceeds 2 mm (about 0.08 in.) in diameter, and there are no very conspicuous phenocrysts. Its color ranges from light pinkish-gray to light greenish-gray. Characteristic phenocrysts are dark amphibole needles, hexagonal flakes of dark mica, numerous white plagioclase crystals, and thinly scattered quartz grains.

Under the microscope the feldspar phenocrysts (fig. 45) prove to be oligoclase-andesine. They make up about 25 percent of the rock. They are generally altered to sericite or less commonly, epidote and calcite or a related carbonate or to a kaolinlike mineral.

Quartz phoncrysts make up less than 5 percent of the rock, with local variations in abundance. Very few exceed 0.5 mm (0.02 in.) in length. Phenocrysts of orthoclase are few, and much less altered than the plagioclase. Two conspicuous dark minerals—brownish-green biotite and green hornblende—are abundant, but likewise greatly altered, commonly to chlorite.

Other primary minerals include euhedral apatite, cubes or octahedrons of magnetite, and fine grains of rutile and zircon. The groundmass is generally so fine grained that the phenocrysts are sharply marked off from it, but is completely crystalline. Indeed, because the phenocrysts are so small there is far less contrast between groundmass and phenocrysts than in any other member of the Gray porphyry group. The groundmass consists of quartz and alkalic feldspar intergrown

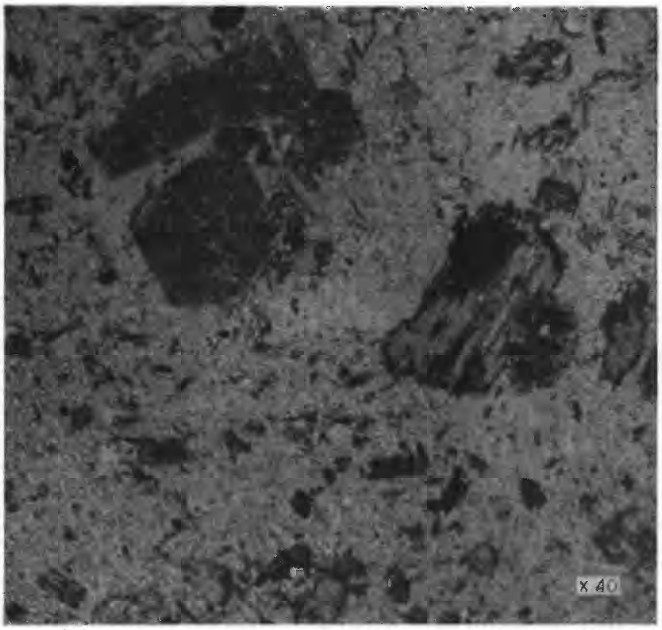

FIGURE 45.—Evans Gulch porphyry, kaolinized and chloritized. The relatively equigranular texture, the numerous cloudy feldspar phenocrysts and the numerous hornblende laths (not shown) and mica plates are typical. × 40; plain transmitted light. Sill on northeast slope, Little Ellen Hill.

in tiny grains and microlites, and small amounts of the alteration products mentioned.

There is little that is distinctive in the alteration of the Evans Gulch porphyry. Because it lacks conspicuous phenocrysts, the altered porphyry acquires a sugary texture. Alteration of the plagioclase proceeds along twinning lamellae, and produces sericite and calcite. The dark minerals are much changed, mostly to chlorite having peculiar purplish interference colors, and to epidote; even where the rest of the rock is not affected, the biotite is likely to be bleached. Alteration commonly produces a grayish-green rock in which the feldspar appears as white spots.

CLASSIFICATION AND DISTINCTIVE FEATURES

The intermediate to sodic composition of the plagioclase and the low content of orthoclase show the rock to be rather silicic though less so than granite porphyry. In view of noteworthy though subordinate quantities of potash feldspar, the Evans Gulch porphyry is best classed as a quartz-monzonite porphyry.

Chemically as well as mineralogically, this rock is closely related to the Johnson Gulch porphyry, but it is finer grained and contains a larger percentage of hornblende. The Evans Gulch porphyry nowhere forms very thick sills; it may represent merely a textural facies of the Johnson Gulch porphyry, though it is perhaps also slightly less siliceous, as suggested by Emmons, Irving, and Loughlin (1927, p. 50). If this is true, the difference in texture may be a result of the more rapid cooling in the thinner sills. Likewise, it is possible that the Mount Zion porphyry of earlier reports represents merely a greatly silicified and highly altered facies of the Evans Gulch porphyry.

JOHNSON GULCH PORPHYRY

The term Johnson Gulch porphyry was proposed in Professional Paper 148 as a substitute for "Gray porphyry" as originally used by Emmons. The name was suggested by the type locality.

DISTRIBUTION

The Johnson Gulch porphyry commonly occurs in the form of sills, but dikes are numerous, especially in Iowa Gulch. Certain thick sills of Johnson Gulch porphyry occur in Evans and Little Evans Gulch and there are several thin sills at the head of Alps Gulch. A thick sill resembling the Lincoln porphyry crops out on the southern slope of Canterbury Hill and Prospect Mountain.

In Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, p. 48) it was suggested that much of the Gray porphyry in this area (now regarded as the Johnson Gulch porphyry), entered the region along a cylindrical conduit, leaving a chilled margin of the porphyry that now makes up a large part of Breece Hill. This hypothesis appears to be strongly supported by the finding of numerous dikes of Johnson Gulch porphyry on Printer Boy and Long and Derry Hills. Many such bodies follow the early north-south faults that are so conspicuous a structural feature.

Many bodies of rock generally resembling this porphyry differ strikingly in texture or seem to be variants in mineral composition. This statement applies especially to certain dikes in Iowa Gulch. In case of doubt the procedure has been followed of arbitrarily classing the rock concerned as the Johnson Gulch porphyry to avoid perhaps useless refinements of classification.

DESCRIPTION

Megascopically the typical unaltered rock (fig. 40) is medium gray— the darkest of the Gray porphyry group. This color is due chiefly to the groundmass, for despite a moderate quantity of biotite platelets and scattered hornblende needles, most of the phenocrysts are of light color. They include quartz crystals as much as 5 mm (about ⅕ in.) in diameter, slightly smaller and more numerous plagioclase crystals, and a few orthoclase phenocrysts as much as 2.5 cm (about 1 in.) in greatest dimension.

Under the microscope few orthoclase phenocrysts are visible (fig. 43). Indeed, they are so few that they are absent from many hand specimens. Under medium or high power they are seen to contain inclusions of plagioclase, quartz, biotite, and several accessory minerals. There are also cloudy aggregates of finely divided iron oxide. Chemical analysis shows that the potash feldspar contains a high percentage of soda and noteworthy amounts of lime (Emmons, 1886, p. 333).

The plagioclase phenocrysts make up about 30 percent of the rock, mostly as well-formed and characteristically zoned crystals, and as both albite and Carlsbad twins. In composition the plagioclase ranges from oligoclase to andesine, and is generally intermediate (about $Ab_{70}An_{30}$). Commonly it is highly altered to sericite or even further to a carbonate—probably calcite. Inclusions of quartz, apatite, zircon, and rutile are common.

Quartz phenocrysts form about 5 percent of the rock. They are partly euhedral, but many contain irregular inclusions and reentrants of the groundmass, which, as in other members of the Gray porphyry group, may well be the result of a reaction between phenocrysts and the "rest-magma". The average length is 2 to 3 mm (about 0.08 to 0.12 in.). Many are shattered, and recemented with sericite.

Biotite in pseudohexagonal platelets and in shreds as much as 1 mm in diameter makes up as much as 5 percent of the rock, but the quantity is varied and a great proportion of the mineral is in particles so small that it is virtually a part of the groundmass. Locally it is altered. It contains a few apatite and zircon inclusions.

In the Johnson Gulch porphyry from the Comstock mine, hornblende phenocrysts, though not numerous, are at least conspicuous, attaining sizes of as much as 3 by 5 mm (Emmons, Irving, and Loughlin, 1927, p. 49). In the Board of Trade Amphitheater a sill that in all other respects closely resembles typical Johnson Gulch porphyry contains 10 to 15 percent of conspicuous hornblende phenocrysts which are still fresh and under the microscope show brilliant green to greenish-brown pleochroism. Hornblende is, in general, a relatively minor constituent of the Johnson Gulch porphyry, though not uncommonly so greatly chloritized as to make its distinction from biotite difficult. The same stages of alteration may be recognized as were described for biotite.

The groundmass consists of quartz, with accessory quantities of sodic(?) plagioclase and orthoclase(?). The grains are so small that the composition of the plagioclase feldspar cannot be closely determined; Emmons, Irving, and Loughlin (1927, p. 49) identified alkalic feldspar (presumably orthoclase), as well as plagioclase. Typical accessory minerals are euhedral or subhedral magnetite, apatite, rutile, and zircon.

Typically, the Johnson Gulch porphyry is bleached where much altered. The feldspars are commonly changed to sericite and, where most altered, to calcite. Orthoclase usually is less altered than plagioclase. As in the other porphyries, the dark minerals are bleached, chloritized, and epidotized, and in extreme cases they are replaced by a carbonate, presumably calcite.

CLASSIFICATION

The chemical analyses published in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, p. 50) and the mineralogic composition described above, identify the Johnson Gulch porphyry with the granite or quartz monzonite groups. If some of the potash reported in analyses has been introduced subsequent to solidification of the rock (as indicated by the almost universal presence of sericite) the rock should be grouped with the quartz monzonite porphyries; that is the classification accepted in this report.

DISTINCTIVE FEATURES

Where not so bleached by alteration as to make the component minerals unrecognizable, the Johnson Gulch porphyry megascopically resembles the Lincoln and Sacramento porphyries of the Gray porphyry group. It differs from the Lincoln porphyry especially in the scarcity of large, well-formed orthoclase crystals; virtually every hand specimen of typical Lincoln porphyry contains four or five large orthoclase individuals whereas specimens of Johnson Gulch porphyry of similar size rarely contain more than a single crystal, and many specimens show no orthoclase phenocrysts. It is darker and lacks the relatively very large quartz crystals that are so conspicuous in the Lincoln porphyry; however, it does contain a few euhedral and "resorbed" quartz phenocrysts.

In contrast to the Johnson Gulch porphyry, the Sacramento porphyry contains even fewer orthoclase phenocrysts, and but very small quartz crystals. Its phenocrysts do not have the great range in size of those in the Johnson Gulch porphyry, whose composition and texture thus appear to be intermediate between those of the Lincoln and Sacramento porphyries.

The Evans Gulch and Iowa Gulch porphyries as a whole have a finer groundmass and smaller phenocrysts. Their textures are more granitoid than that of the conspicuously porphyritic Johnson Gulch porphyry.

Gray porphyry exposed on Printer Boy Hill was supposed (Emmons, Irving, and Loughlin, 1927, p. 46) to include rock of the Lincoln porphyry type although it is clear, despite a considerable degree of alteration, that the porphyry should be identified with the Johnson Gulch porphyry. Probably the error was due to the extensive alteration and to the presence of a few large well-formed crystals of orthoclase. The absence of characteristic Lincoln porphyry quartz bipyramids seemingly went unnoticed.

IOWA GULCH PORPHYRY

DESCRIPTION

The Iowa Gulch porphyry of the Gray porphyry group closely allied in composition to the Johnson Gulch porphyry, is exposed on Long and Derry Hill, near the place where the crest is crossed by the road from Iowa Gulch to Empire Gulch. Other outcrops are on West Sheridan Mountain, at several places on the south slope of Ball Mountain, and in some of the dikes in the Rex and Musk Ox mines. Two other dikes are believed to represent the Iowa Gulch porphyry. One lies about 6,000 ft east of the Hatch Ranch at an altitude of 10,982 ft; the other, on the 12,065-ft spur on the northwestern slope of Empire Hill, is more porphyritic and quartzose than the type rock and in those respects resembles the Johnson Gulch porphyry.

The Iowa Gulch porphyry is less quartzose than the Johnson Gulch porphyry. Its relatively unaltered condition and conspicuous flow lines, and the presence on the north side of Long and Derry Hill or a tufflike facies, suggest that the rock was intruded under conditions differing somewhat from those governing the intrusion of the other rocks of the Gray porphyry group. The low quartz content also places it among the aberrant facies of the Gray porphyry group, if not actually into a different group altogether. This porphyry is believed to be sufficiently distinctive to merit a new name, and it has therefore been designated by its type locality.

The dominant, nonclastic facies of the Iowa Gulch porphyry is a light-gray to light brownish-gray porphyry, with a dense, stony groundmass that locally shows banding and flow lines (figs. 37, 39). Dark phenocrysts of biotite and white, well-crystallized feldspars are common. In some varieties tiny quartz phenocrysts also are seen with the naked eye or the hand lens, but they are nowhere conspicuous. In places the rock includes fragments of the same composition, sharply bounded against the matrix (fig. 46); elsewhere it contains inclusions of the neighboring sedimentary rocks. This facies is best exposed on the northern slope of Long and Derry Hill, along the Iowa Gulch-Empire Gulch road, at an altitude of 11,000 ft. It is this facies of the porphyry that is interpreted as indicating intrusion under reduced pressure and practically explosive conditions, circumstances that not only caused disruption of the country rock, but also shattered the chilled walls and tore loose fragments of the still molten but viscous lava. This hypothesis is supported by the almost vitreous texture of some of the groundmass (fig. 39). Similar features have been described from the Uncompahgre district by Burbank under the term "clastic dikes" (Burbank, 1930, pp. 195–200; 1941, pp. 204, 205) and also from Leadville by Emmons, Irving, and Loughlin (1927, pp. 55–59) in the late (rhyolitic) intrusives. The rock here described, however, cannot be referred to the rhyolite intrusions recognized by Emmons and his associates, as the rock is distinctly less siliceous and much of it is so similar in mineral composition to the Johnson Gulch porphyry as to be virtually indistinguishable.

Under the microscope (fig. 47) the groundmass appears to have a typical felted and partly or almost completely glassy texture; it is studded with tiny feldspar needles in trachitic arrangement; this feldspar is oligoclase-albite, largely sericitized. About two-thirds of the groundmass consists of silicified or devitrified rock, now quartzose. The phenocrysts consist of plagioclase and biotite, plus a little quartz. In different hand specimens plagioclase phenocrysts averaging 0.6 mm in diameter and ranging from oligoclase-albite to calcic andesine make up about 20 percent of the rock.

Quartz phenocrysts are very irregularly distributed with none at all in some places and in excess of 5 percent of the volume in other areas. Characteristically they have a globular form, such as is common in tuffs and surface flows and an average diameter of approximately 0.2 mm (0.08 in.).

Phenocrysts of biotite are fairly abundant. Biotite is light olive-green to brown where fresh, but is largely altered. It forms books and shreds averaging about

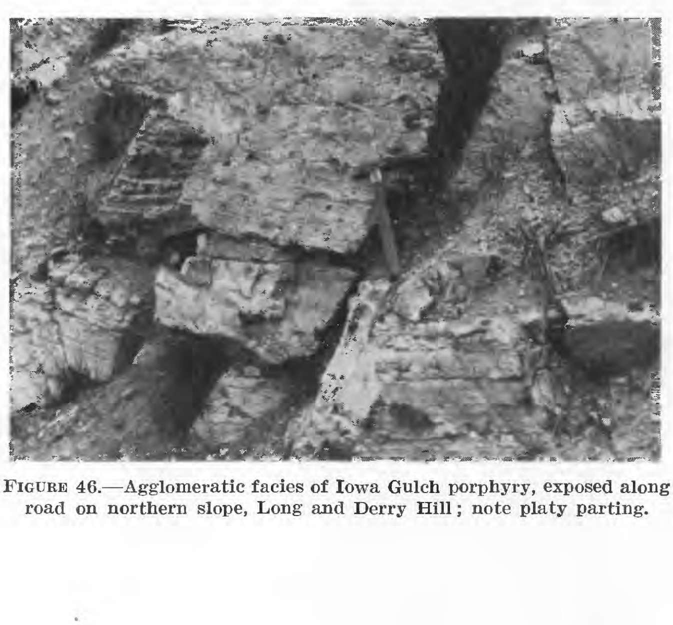

FIGURE 46.—Agglomeratic facies of Iowa Gulch porphyry, exposed along road on northern slope, Long and Derry Hill; note platy parting.

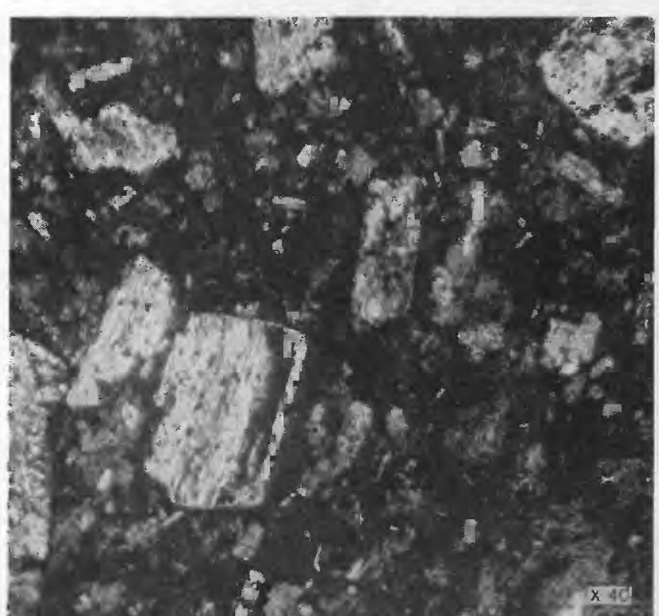

FIGURE 47.—Iowa Gulch porphyry, granular phase. Phenocrysts are oligoclase-albite, highly altered. Note small feldspar laths and cloudy groundmass. × 40; crossed nicols. Iowa Gulch, near Lillian mine.

0.7 mm (0.28 in.) in longest diameter and makes up 3 percent of the rock; inclusions of quartz, apatite, and zircon are characteristic. No phenocrysts of orthoclase could be identified.

Other accessory primary minerals are sphene, zircon, and apatite, all in relatively large euhedral crystals, magnetite (partly titaniferous), and specularite.

ALTERATION

The alteration products of the Iowa Gulch porphyry resemble those of the other Gray porphyries. The feldspar is sericitized and some of it is replaced by a highly sodic plagioclase (albite?) and quartz. Mica has been partly bleached, and partly converted first to chlorite and to epidote, and later to calcite. Some of the large crystals of all of the minerals have been shattered and recemented with calcite. Where highly altered the rock is dark greenish-gray and the numerous feldspar phenocrysts contrast sharply in color.

CLASSIFICATION

Despite its intense alteration and its megascopic resemblance to the Johnson Gulch porphyry, the differences in composition make the Iowa Gulch porphyry a distinct rock unit. The plagioclase feldspars are more calcic than those in the other Gray porphyries, orthoclase is rare or absent, and quartz phenocrysts are nowhere abundant, and generally rare. These features, together with the trachitoidal texture, favor classification of the rock as a quartz latite or perhaps dacite rather than a quartz monzonite.

DISTINGUISHING FEATURES

Megascopically the Iowa Gulch porphyry is the most varied of the rocks of the Gray porphyry group. With the exception of certain aberrant varieties, the Iowa Gulch porphyry differs from the more typical porphyries of the group, such as the Johnson Gulch and Lincoln types, in the lack of conspicuous quartz phenocrysts. From the Sacramento porphyry it differs in its much larger proportion of groundmass. It resembles the Evans Gulch and Mount Zion porphyries in its relatively fine texture and the small average size of its phenocrysts, but the Iowa Gulch porphyry is somewhat darker, its groundmass is more stony, and as a whole its texture is more distinctly porphyritic; indeed, a blue-gray facies of it that occurs in sills on West Sheridan Mountain presents an especially sharp contrast to the lighter-gray or flesh colors of the Evans Gulch porphyry.

QUARTZ DIORITE PORPHYRY

OCCURRENCE

Quartz diorite porphyry occurs as a dike on the southwestern slope of East Ball Mountain. It ranges in width from 5 to 15 ft and trends about N. 20° E. uphill from an altitude of 12,450 ft, along the western slope of the mountain. It dips 68° E. Offset in one place by a fault and in another without apparent faulting, it can be traced continuously northward about 5,000 ft.

DESCRIPTION

Megascopically the quartz diorite porphyry is a dark greenish-gray rock essentially of holocrystalline texture, resembling the Iowa Gulch porphyry but slightly darker. Only a few phenocrysts are visible to the naked eye; they are chiefly feldspar and scarce flakes of hornblende. The groundmass is finely crystalline to dense, the dense facies being more typical of the southern end of the dike.

Under the microscope the phenocrysts are seen to include andesine and a little altered hornblende, small euhedral crystals of apatite and octahedrons of magnetite. The groundmass is made up almost wholly of microlites of a plagioclase near oligoclase and of hornblende, small crystals of quartz (apparently secondary) and a mineral resembling highly altered biotite.

Like the other gray porphyries, this rock is considerably altered. The phenocrysts of feldspar have been changed to sericite and at their peripheries even to calcite. The feldspar microlites have been far less altered. The hornblende and mica(?) have been converted to chlorite, yellowish epidote, and calcite. Effects of silicification are not conspicuous.

CLASSIFICATION

The composition of the quartz diorite porphyry closely resembles the older units of the Gray porphyry group of the Alma district, designated by Singewald and Butler (1931, pp. 394–395) as monzonitic diorite porphyry and by Patton and his associates as hornblende diorite porphyrite (Patton, Hoskin, and Butler, 1912, pp. 85–89). Rocks of this group are less siliceous and darker than the other rocks here assigned to the Gray porphyry group. Only the Iowa Gulch porphyry, resembles them in color; indeed, these two rocks may represent different gradational facies of the same general rock type. On this basis and and on the general lack of orthoclase, the rock is best designated as a quartz diorite or dacite porphyry.

AGE RELATIONS OF UNITS OF THE GRAY PORPHYRY GROUP

As recently as 1927, the date of the publication of Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 51–52), nothing was known about the relative ages of the various units of the Gray porphyry group, though various analogies were drawn with adjacent districts, tending to show that the quartz-monzonites are younger than the more dioritic rocks. Subsequently Singewald (1932, pp. 62–63) confirmed this suggestion from observed field relations in the Alma district on the eastern side of the Mosquito Range. The different kinds of porphyry of the Gray porphyry group are more easily distinguishable in the outlying parts of the Leadville district than in the central Leadville district, and some field evidence as to their relative ages has been obtained. A discussion of these relations is presented in the following paragraphs, though this necessitates a brief anticipation of some of the structural features described in greater detail on later pages.

The Alma district is so near that evidence found there (Singewald, 1932, p. 26) may be used as a basis for the inference that the dioritic rocks in the area here considered are older than the more monzonitic porphyries. The dike of quartz diorite on East Ball Mountain would accordingly be the oldest unit of the Gray porphyry group. Sills of the Lincoln porphyry of Little Ellen Hill, the Evans Gulch porphyry, and the Sacramento porphyry are cut by the Mosquito fault or its branches, which, in Iowa Gulch and its vicinity, are related in origin to several other reverse faults. Along the planes of these reverse faults dikes of the Iowa Gulch and Johnson Gulch porphyries have been intruded in certain places. It may thus be reasoned that after the quartz diorite the next rocks in the igneous sequence were the Lincoln, Evans Gulch, and Sacramento porphyries, followed in time by dislocation along the Mosquito and related reverse faults. However, the relative ages of the Lincoln, Evans Gulch, and Sacramento porphyries are not determinable.

Next in age is the Iowa Gulch porphyry. The sill of this rock on the northern slope of West Sheridan Mountain is cut by a slightly transgressive sill of Johnson Gulch porphyry. It is accordingly the earlier of the two; however, it is intruded along reverse faults in lower Iowa Gulch much as is the Johnson Gulch porphyry. From these relations it would appear that these two members of the Gray porphyry group are younger than the steep reverse faults of the district. Furthermore, Crawford (1924, pp. 376–378) has shown that later intrusions in the Mosquito and Sawatch Ranges generally formed stocks, whereas the earlier ones commonly formed sills. The Mansfield plug, mentioned above, is composed of Johnson Gulch porphyry and is thus in agreement with this generalization; so also, by inference, is the Breece Hill stock, which, however, is too greatly altered to be classified with confidence on a purely petrographic basis (Emmons, Irving, and Loughlin, 1927, p. 54). The dikes of Johnson Gulch porphyry radiating from the Breece Hill plug support this inference.

In summary, the events related to intrusions of the Gray porphyry group are as follows:

Youngest: 5. Intrusion of Johnson Gulch porphyry.
4. Intrusion of Iowa Gulch porphyry.
3. Development of Mosquito and other reverse faults.
2. Intrusions of Evans Gulch and Sacramento porphyries and typical Lincoln porphyry.
Oldest: 1. Intrusion of quartz diorite porphyry East Ball Mountain.

It is noteworthy that the Johnson Gulch and Lincoln porphyries, which have in common the large orthoclase phenocrysts, are separated in time by a period of markedly differing intrusions.

NATURE AND SIGNIFICANCE OF ALTERATION

The gray porphyries of the Alma district, which are very similar to those of Leadville, were carefully studied by Singewald (1932, pp. 16–29) who gave special attention to their altered facies; similar observations have more recently been made on the rocks of the Gray porphyry group of Leadville. Singewald showed that the suggestion originally made by Patton (Patton, Hoskin, and Butler, 1912, p. 79) was in a sense correct, namely, that many of the constituents of the porphyries, though apparently primary, are really the products of end-phase alterations. This is especially true of orthoclase. The mineralogic and chemical changes producing this mineral were, however, almost negligible in the area here described, for they have prevailed chiefly in the larger pluglike intrusives, poorly represented in the marginal parts of the Leadville district, rather than in the more widespread dikes and sills. In the sills, albitization, epidotization, and sericitization, locally with extensive silicification, are the conspicuous and typical end-phase processes of alteration. At Leadville many of the highly quartzose varieties of the Evans Gulch porphyry, as well as the quartzose Mount Zion porphyry described in earlier publications (Emmons, 1886, p. 76; Emmons, Irving, and Loughlin, 1927, pp. 50–51), apparently owe much of their quartz content to a reaction between the rest-magma and the partly crystallized groundmass and phenocrysts. In view of this extensive reaction in certain members of the Gray porphyry group, it is significant that there is so little evidence of reaction rims surrounding the euhedral quartz and orthoclase phenocrysts of the Lincoln porphyry intruded under similar conditions; this suggests either that the composition of the rest-magma was close to that of the phenocrysts, or that at the time and place of crystallization the Lincoln porphyry contained but few constituents sufficiently volatile to permit reaction.

The striking fact that throughout the Gray porphyry group alteration is most extensive in the sills and least in the dikes seems to oppose the conclusion of Singewald (1932, p. 27) that the alteration was produced in large part by new "mineralizers" not originally present in the sills, but added by the deeper, as yet unconsolidated, magma body. If this were true the dikes, which clearly fed the sills in many places and were presumably the last to cool of the now visible igneous bodies, would have been the more intensely altered.

TERTIARY OR QUATERNARY(?) IGNEOUS ROCKS

LITTLE UNION QUARTZ LATITE

LOCATION AND STRUCTURAL RELATIONS

Emmons (1886, pp. 88, 352–353) found and mapped three bodies of an unusual rock which he designated quartziferous trachyte. As shown in greater detail on the geologic map of the present report, there are two such bodies, one near the head of Little Union Gulch, half a mile south of the ranch house on the Hatch Ranch, another in Union Gulch, 1¼ miles west of Empire Gulch. These two masses are essentially identical petrographically. Their outlines give the impression of plugs of irregular form. The western and smaller one is elliptical in plan, its longer axis trending northwest, and has an area of about 900,000 sq ft (about 20 acres). On the northeast it is bordered by a fault which raises pre-Cambrian rocks against it. Where it is flanked by Cambrian quartzite it appears to have risen in the center of a syncline bordered by the Cambrian. The eastern body is more irregular in plan, but is essentially triangular. It seems to have risen along the southern extension of the Union fault or more probably along the closely related Mike fault. It is bordered on the north by most of the Paleozoic sequence and elsewhere by pre-Cambrian granite.

DESCRIPTION

In contrast with most of the rocks of the Gray porphyry group and with the early White porphyry and later white porphyry, the Little Union quartz latite is distinctly brownish in color. Where fresh it is a light grayish-brown; it weathers to a darker color with rusty spots. Locally, especially near the margins, it contains angular inclusions of kaolinized and sericitized earlier igneous rocks and of arenaceous and schistose rocks, probably of pre-Cambrian age (fig. 38). It is speckled with flakes of brown mica and with white feldspar crystals that are poorly terminated. Flow lines are faintly visible and some surfaces are slightly vesicular.

Under the microscope (fig. 48) the rock is seen to consist mostly of a groundmass of brownish glass enclosing microlites of quartz, feldspar, and mica. This groundmass makes up about 60 percent of the total volume of the rock. The remainder is chiefly plagioclase feldspar (25 percent), quartz (5 percent), biotite (5 percent), and smaller and decreasing quantities of orthoclase (sanidine), magnetite, green hornblende, apatite, zircon, and sphene. An interesting feature is the presence of small lenses, mostly visible only with the aid of the microscope, composed mainly of fine grains of quartz and a sericitized mineral, probably plagioclase. Such lenses evidently represent inclusions of other rocks now very largely resorbed.

Phenocrysts of orthoclase are few but large. They are generally shattered and veined with quartz, al-

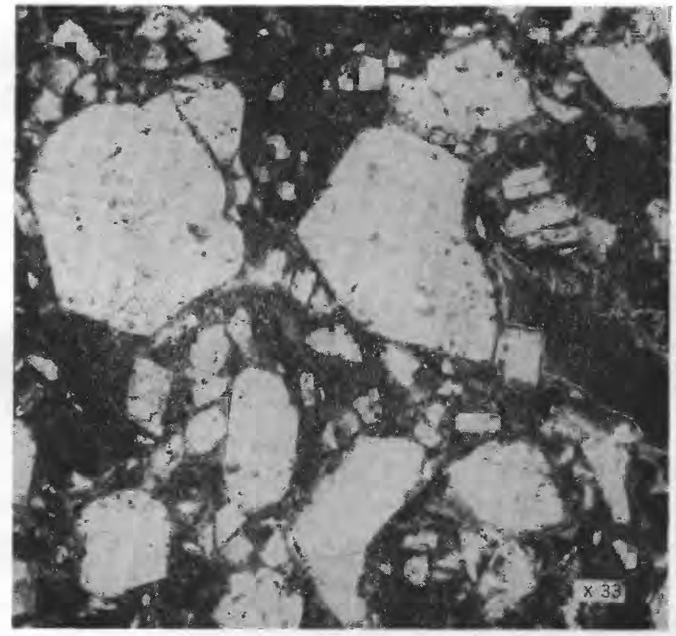

FIGURE 48.—Little Union quartz latite. Note flow structure and fragments of minerals (chiefly quartz, feldspar, and biotite). × 33; plain transmitted light. Head of Little Union Gulch.

bite(?) and sericite. Phenocrysts of plagioclase are zoned and commonly show well-defined multiple twinning; in composition they range from oligoclase to andesine.

CLASSIFICATION

The Little Union quartz latite was classed by Emmons as trachyte, but it is clearly too siliceous to come under that term as now applied. Moreover, the scarcity of orthoclase phenocrysts and the lack of evidence that the groundmass contains a sufficiently large percentage of potash would seem to distinguish it from the syenite-trachyte group of rocks. These facts, in addition to the intermediate composition of its plagioclase, warrant classing the rock as intermediate, that is, between rhyolite and diorite; it may best be called a quartz latite.

AGE

The two occurrences of Little Union quartz latite show no definite structural evidence bearing on the age of the rock. Some of the inclusions, though highly altered, appear to be of early White porphyry, which would thus antedate the quartz latite. Moreover, the occurrence of the rock along the probable trace of the Mike or of the Union faults suggests that its age is later than that of rocks of the Gray porphyry group and of the early White porphyry, which are elsewhere offset by these faults. Finally, the rock is far less altered than much of the early White porphyry and most of the rocks of the Gray porphyry group. For these reasons the Little Union quartz latite is believed to be younger than most of the intrusives of the Leadville district, and is tentatively assigned to the same general age as the rhyolite agglomerate, that is, Tertiary or perhaps very early Pleistocene (Emmons, Irving, and Loughlin, 1927, p. 59). Although the possibility is not excluded that it may be early Pleistocene, it is most probably Tertiary in age.

RHYOLITE AND RHYOLITE AGGLOMERATE

OCCURRENCE

Pipelike bodies and dikes of rhyolite or rhyolite agglomerate near Leadville closely resemble certain rock in the outlying area. Those in or near the district here described were first mentioned by Loughlin and his associates in 1927 (Emmons, Irving, and Loughlin, 1927, pp. 55–59). In the Leadville monograph no such rock had been described except for an area on the south side of Empire Gulch, which apparently coincides with what is here mapped as a sill of the Iowa Gulch porphyry lying below or within the Manitou dolomite (Emmons, 1886, pp. 351–352). In the outlying Leadville area no outcrops of unmistakable rhyolite were found at the surface. In the immediate vicinity of Leadville, as has been pointed out by Loughlin and his associates, the rhyolite until recently was found only in underground workings where it is easily mistaken for a fault breccia; however, obscure outcrops of a pipe that was discovered in the Resurrection mine in 1939 have been recognized around the small lakes to the northwest by R. T. Walker, geologist of the Resurrection Mining Co. (Personal communication).

An example can be seen in an old tunnel (prospect O–49, one of the Little Troubadour group) on the south side of Iowa Gulch about due south of the new Hellena shaft. The south heading of the east drift crosses a fault zone, cuts through beds of the Weber(?) formation, and finally enters a mass of rhyolite agglomerate. A similar occurrence was noted in a tunnel (prospect P–39, the easternmost of the three subparallel tunnels east of the shaft) located on the upper road, approximately 800 ft due northeast of the Lillian Mine on the south slope of Printer Boy Hill. The agglomerate here strongly resembles a breccia, for it seems to follow a vertical fissure.

PETROGRAPHY

Nowhere in the region here described has the writer observed a facies of the rhyolite that might be regarded as a true flow; instead, it is everywhere an agglomerate or breccia. Its appearance in the Little Troubadour tunnel mentioned above is typical. Megascopically it bears much resemblance to a fault breccia, for fragments of rock, generally angular, predominate. Close examination, however, shows the presence of flow lines, though these are largely concealed by the extreme bleaching and silicification that the rock has undergone. Some of the contained fragments are of micaceous "Weber(?) grits"; others are of the Gray porphyry group and white porphyries, and still others are of pre-Cambrian granite. In general, the early matrix appears more altered than the agglomerate described by Emmons, Irving, and Loughlin, but, as in the examples cited by them, kaolin is the chief alteration product.

Under the microscope (fig. 49) the glassy base of the rock is seen to contain conspicuous brownish flow lines, numerous oriented inclusions with a subparallel (trachitoid) arrangement, and drawn-out patches of devitrified glass. Many subangular fragments or phenocrysts of quartz and a few of plagioclase are seen. Most of the feldspar "phenocrysts" are shattered and their larger cracks are filled with quartz, small amounts of hydrothermal sericite, and large quantities of carbonates believed to be late hydrothermal or weathering products. Primary magnetite and a very few shreds of biotite were also noted. Some specimens contain secondary pyrite and sparse grains of topaz, suggesting the rhyolite reported from Chalk Mountain by Cross (in Emmons, 1886, pp. 347–348). The matrix is so greatly altered that it is impossible to recognize any primary minerals.

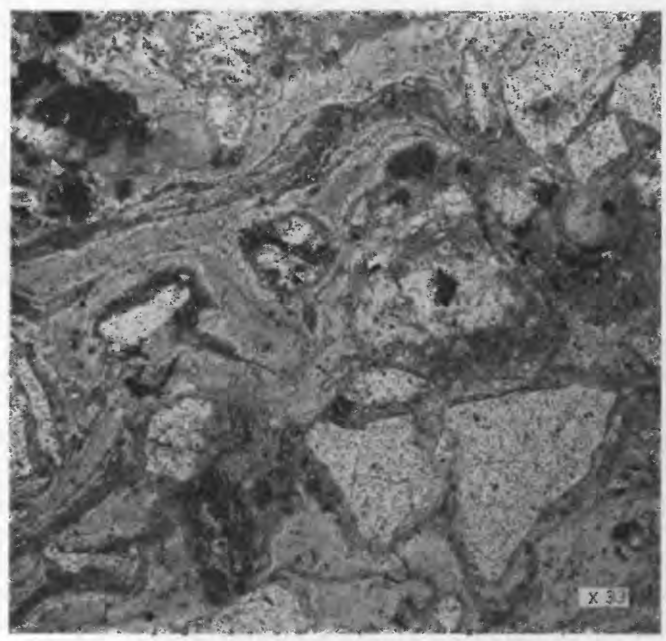

FIGURE 49.—Rhyolite agglomerate. Shows flow lines in light-brown glass and finely crystallized quartz, surrounding fragments of coarse quartz and altered feldspar crystals. × 33; plain transmitted light. From "dike" in prospect south of Hellena mine, Iowa Gulch.

AGE

The above description suffices to show the close resemblance between the rock here described as rhyolite from the workings of the Little Troubador group and elsewhere and that mentioned by Emmons, Irving, and Loughlin as occurring in the Josie, Ollie Reed, and Eureka pipes. The rock described by them appears chiefly in pipes, whereas that observed in the Iowa Gulch region has been found only in dikes; however, fingerlike dikes have also been described by Loughlin and his associates (Emmons, Irving, and Loughlin, 1927, pp. 56–57), extending outward from the pipes similarly to some of the "clastic dikes" described by Burbank (1941, pp. 204, 205) and to the dikes here mentioned. Structurally and lithologically, therefore, the breccia in dikes of the Little Troubador tunnel and of mines nearby closely resemble the agglomerate of the Josie pipe and others nearer Leadville, and may reasonably be referred to the same age—"Tertiary or perhaps the very early Pleistocene" (Emmons, Irving, and Loughlin, 1927, p. 59).

STRUCTURE

GENERAL SUMMARY

EARLIER GEOLOGIC WORK

In the early work of Hayden and his associates (1881) the broader lines of the structure of central Colorado were recognized and correctly drawn. The studies of Hayden served as the basis for the more detailed work of Emmons (1886) who gave a picture of the Leadville district on a larger and more accurate scale; in some of his work in the immediate vicinity of Leadville Emmons used so large a scale of mapping that the structural and areal geologic relations affecting mining could be very clearly expressed, but in other areas peripheral to the central area his maps did not permit as great detail, the scale being only 1:31,680. Emmons, Irving, and Loughlin (1927), while accepting with some revision the chief structural features outlined in these earlier studies, revised the maps prepared by Emmons mainly in the light of information furnished by the intervening four decades of underground exploration. They demonstrated that faulting had been a more important factor in the structural history than had been recognized in Emmons' earlier work, yet little detail was added to the structural picture of the area surrounding the immediate environs of Leadville for no new areal work was undertaken in the peripheral region. They realized the inadequacy of the information available as to the broader structure in the inner parts of the Leadville district and urged that a detailed study of the surrounding region be made.

The following discussion deals with structure in detail in the entire area mapped, with the exception of that part already mapped on a scale of 1:9,600 and published as plate 13 of Professional Paper 148. In addition, short discussions are included of structural observations made in newly opened parts of the Ibex group of mines on Breece Hill, the South Ibex or Venir properties on the southwestern slope of Breece Hill, and the Eureka and related properties on the northern slope of Ball Mountain. With the exception of these particular areas, however, it is assumed that plate 13 of Profesional Paper 148, the map of the immediate environs of Leadville, is essentially correct.

MAIN STRUCTURAL FEATURES

The main structural feature of the region is a large, eastward-dipping, faulted monocline composed of the Paleozoic formations and the sills intruded into them. This is essentially a part of the eastward-dipping limb of a major anticlinal structure of which the axis is roughly along the crest of the Sawatch Range, approximately 20 miles to the west. Although there has been some folding parallel and transverse to the regional northerly trend of the homocline, the folds so produced are commonly local and related to drag on faults; such folds, in fact, generally have axes parallel to the strike of the faults. Except for local drag effects, the dips of the sedimentary strata rarely exceed 25°, and even where there has been fault drag the abrupt changes in dip characteristic of local close folding are absent.

Upon this monocline, generally dipping eastward, is imposed a pattern of faults and folds which is simple in plan but complex in its effects. The simplicity in pattern of the faults is due to the general parallelism of their traces on the present surface. The complexity in effects is caused by the facts that the dips are varied and the throws differ markedly from fault to fault and even along the same fault. The net effect of the faulting, however, is steplike, for along almost all of the major faults the east side is relatively higher. They constitute what Cloos has designated an antithetic fault pattern (Cloos, 1928, p. 251; Balk, 1936, pp. 60–61); that is, they have net uplifts which have tended to compensate for the rise of the strata westward incidental to the formation of the major eastward-dipping homocline. Typical structures of the region are shown on plate 2.

POSSIBLE SOURCES OF ERROR

In contrast with Professional Paper 148, this report is based mainly on surface rather than underground data. Of the relatively small number of mines once operated in the marginal part of the Leadville district, only a few are still accessible, and even in these mines the workings are not generally extensive. Consequently the structural evidence is in many places incomplete. At higher altitudes the exposures are generally good, but the heavy glacial cover in the bottoms of Evans, South Evans, Iowa, and Empire Gulches adds further difficulties to an understanding of the structure.

The most serious difficulty, however, is the fact that in areas where the most doubt exists—as, for example, in Iowa Gulch near the Hellena mine—the underground data on which an interpretation hinges are usually found only in older reports by geologists and miners, whose observations not uncommonly seem to conflict with other first-hand evidence. Thus the personal factor has to be duly weighed.

For these reasons especially, some of the structural interpretations set forth below are subject to error. An attempt has been made to indicate on the map and on structure sections their degree of reliability by using solid lines for boundaries and other structural features based mainly on factual observations, and by using dashed lines for those which involve personal factors or a large degree of inference.

FOLDS

GENERAL CHARACTER

Across the major homocline that underlies the region strikes range from N. 5°–25° W. over most of the area; the eastward dips range from 7° to 25° and average about 18°. In the northern part of the area, however, from Canterbury Hill eastward to the Board of Trade mines, most of the strikes are westerly, and along the crest of the range to the south they are chiefly northeasterly. There are also numerous local deflections in strike and dip along cross folds or in zones affected by fault drag. Thus, on Empire Hill the dominant strikes are N. 60°–70° E. with southeasterly dips, but this departure from the normal direction of strike is in part assignable to drag along the Mosquito fault. On the southwestern slope of Little Ellen Hill there is an area where the beds strike due east and dip 20° N., but this deflection, again, appears to be local. It will be recalled that on most of the major faults the western side is lowered. Associated with many major dislocations is an effect suggestive of drag whereby the beds along the western wall, for example, dip steeply westward for distances rarely exceeding a hundred yards before they flatten, as though in the trough of a syncline, and then resume their normal eastward dip. These features, whatever their cause, give the impression of folding (pl. 2). Actually such structures are gently pitching troughs with axes parallel to the faults that truncate their eastern limbs. Each has a corresponding anticline on its western limb. As these downfolds west of the major faults are conspicuous, the more striking examples are described individually.

Most of the folds seem to have a northward pitch, because the regional monocline has a strike that trends more west from north than does the range crest itself. For example, the contact between the Cambrian and pre-Cambrian, exposed at the southern end of the area at an altitiude of 13,550 ft on Horseshoe Mountain, falls to an altitude of 12,100 ft at a position 5 miles almost due north of this, on the Mosquito Pass road along the northern slope of Evans Amphitheater. The contact between the same two units, as exposed farther west drops from 12,025 ft at Rocky Point to 11,600 ft 1½ miles nearly due north. The northward components of dip for the two examples cited are respectively 240 and 280 ft per mile. (Sections F–F′, G–G′, and H–H′, pl. 2.) The similarity of these two figures, though taken from widely separated areas and in slightly different directions, indicates the constancy of the northward component of dip and favors its interpretation as of regional rather than local origin.

It may be noted here that Emmons (1886) tended to assign most irregularities in outcrop to folding, as opposed to faulting. Subsequent studies, chiefly underground and in the excellent exposures near the crest of the range, east of the area studied in detail by Emmons, have demonstrated the importance of faulting and reduced to a minor role many of the folds that Emmons indicated; indeed, it is now clear that folds on axes transverse to the major faults and independent of fault drag are almost negligible.

The outcrop pattern shown on the areal map, plate 1, gives the illusion of folds in localities where the beds are actually nearly horizontal. Circular or ovoid outcrop patterns (as on Upper Long and Derry Hill and West Dyer Mountain) merely reflect the influence of knoblike hills on the outcrops of uniformly eastward dipping formations. There are also numerous small, gentle rolls or local changes in strike, but they are of little structural significance.

UNION SYNCLINE

A strong synclinal fold, designated the Union syncline, extends southward from near the Mitchell Ranch in sec. 5, T. 10 S., R. 79 W. through the center of sec. 8. Its axis strikes due south. Although this syncline is not clearly exposed near Mitchell Ranch, its trough or axis is well indicated a mile farther south by a sill of early White porphyry preserved between bordering outcrops of the underlying, synclinally folded Leadville dolomite. The natural exposures here are not good but there are numerous prospect pits, which reveal bedrock, and the distribution of these pits affords convincing evidence of the fold. On both the east and west limbs of the syncline, the Dyer dolomite and Parting quartzite members of the Chaffee formation are visible, and still farther from the axis there are outcrops of a sill of Iowa Gulch porphyry, which here lies within the Manitou dolomite. From the center of sec. 8 southward to Little Union Gulch, the eastern limb is cut off sharply by a fault, discussed below, which brings pre-Cambrian rocks on the east against Leadville dolomite on the west. Southward the syncline ends against a large mass of Little Union quartz latite. The syncline is distinctly asymmetrical, as shown by the greater width of each formation exposed on the western limb of the fold; apparently the dip steepens on the eastern limb against the fault.

From Mitchell Ranch northward there is only a suggestion of the fold where the axis (as located in sec. 8), if projected northward, would cross the Blow Ditch. Still farther north the east limb is cut off by the Mike fault, but features suggestive of the northward continuation of the Union syncline appear between the Mike and Pilot faults in the vicinity of the Yak tunnel, as shown by a cross section published in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pl. 15, sec. E–E′).

EMPIRE HILL SYNCLINE

The summit of Empire Hill, in the eastern half of section 9 and the western part of sec. 10, T. 10 S., R. 79 W., is on the axis of a fold here designated the Empire Hill syncline. The axis of this structure trends approximately south. The eastern limb of the syncline dips steeply westward, apparently because of drag along the Mosquito-Weston fault (described below) which brings pre-Cambrian rocks on the east up against Paleozoic rocks on the west. The effect of faulting upon the eastern limb was to drag the beds locally to an overturn with dips of as much as 75° E., as shown on the saddle east of Empire Hill. The western limb of the fold, on the other hand, has dips as low as 18° (secs. C–C′ and D–D′, pl. 2).

On the summit of Empire Hill the strike of the Weber(?) formation is N. 60°–70° E. and its dip is 15°–20° S. Evidently the fold pitches southward at a fairly steep angle, for dips of 40°–45° S. are recorded a short distance east and southeast of the 12,320-ft summit of Empire Hill.

SHERIDAN TRANSVERSE SYNCLINE

On Mount Sheridan and the adjacent West Sheridan Mountain the beds are deflected from their normal regional strike and dip by a transverse synclinal fold of northeasterly trend and plunge (secs. C–C′ and G–G′, pl. 2). Southwest of the southerly of the two West Sheridan peaks the strikes are slightly west of north and the dips are gently northeastward, and these directions persist southward along the range crest to Peerless Mountain; on the northern slope of Mount Sheridan, the strikes are east of north and the dips are southeast. These facts serve to outline the axis of a fold transverse to the typical northerly strike and easterly dip of the regional structure. This fold is strongest along a north-south section, such as section H–H′, plate 2. Because of the easterly dip of the regional homocline, this transverse fold plunges eastward.

MONOCLINE OF UPPER LONG AND DERRY HILL

Viewed from Iowa Gulch, the beds of Cambrian quartzite on the north slope of Upper Long and Derry Hill are seen to dip steeply westward, contrary to the regional structure, in a conspicuous monocline, here designated the Long and Derry monocline. The base of the Sawatch quartzite crops out at an altitude of about 11,750 ft on the slope due north of the hill's crest but declines westward in ½ mile to 11,250 ft at a point due south of the Hellena mine. This sharp reversal of the regional dip is one of the most striking of the entire district.

Probably, the Long and Derry monocline was produced by the westward thrusting and drag along the Weston fault complex to the west. The other major faults of the region show similar drag effects and this one is typical. It is noteworthy only because it is greater than most others. Southward the monoclinal fold is lost in the fault complex on the southern slope of Upper Long and Derry Hill; northward it is cut off by the Iowa fault.

DYER MONOCLINE

The Dyer monocline is well exposed on the western slope of Dyer Mountain, where the interfingering masses of Weber(?) formation and porphyries are seen to dip steeply to the north. The beds dip as much as 45° northward and strike nearly due east. This monocline is graphically illustrated in section H–H′, plate 2, and recorded on the map by a decline in the contact between the lowest Weber(?) strata and the underlying White porphyry from an altitude of 13,000 ft due west of the crest of Dyer Mountain to one of 12,750 ft ½ mile north, at the col between the Evans and Dyer Amphitheaters. Still farther north this transverse monocline swings into the usual northwest-striking and northeast-dipping monocline characteristic of the region as a whole.

Very probably this monocline is accentuated by the relatively abrupt thickening in the great sill of early White porphyry resting on the Leadville dolomite (sec. H–H′, pl. 2). This sill thickens from 60 ft on the west slope of Mount Evans to 600 ft on the southwest slope of Dyer Mountain, only 1½ miles to the south. Upbowing of the sedimentary beds *beneath* the sill proves, however, that the steep northerly dip is due in part to tectonic movements.

LITTLE ELLEN SYNCLINE

On the southeast slope of Little Ellen Hill, the Weber(?) strata and the sills of Evans Gulch and Lincoln porphyries are turned steeply upward toward the east, as though dragged by movement on the Mosquito fault. There is thus outlined a structure here designated the Little Ellen syncline, of northward plunge, whose axis can be traced N. 10° E. across the crest of Little Ellen Hill and onward toward the head of Birdseye Gulch (sec. A–A′, pl. 2). The syncline is asymmetrical, with the steeper dips on the eastern side, adjacent to the Mosquito fault.

Good exposures of the westward dipping rocks of the eastern limb of the syncline are not common. They are usually found close to the fault trace only, but in some localities—for example on the eastern slope of Little Ellen Hill—they are not uncommon.

BIRDSEYE GULCH SYNCLINE

For about 2,000 ft east of the col between the head of Birdseye Gulch and the northern branch of Evans Amphitheatre, the Weber(?) strata and associated sills dip westward in sharp contrast with the eastward dipping rocks to the west. These westward-dipping beds form the east limb of the Birdseye Gulch syncline, almost on the northward strike continuation of the Little Ellen syncline described above and, like the latter, bounded on the east by the Mosquito fault. The resemblance between these two folds suggests that perhaps they should be regarded as virtually one syncline, and both attributed to the drag that accompanied movement along the great Mosquito fault.

FAULTS AND FISSURES

GENERAL ASPECTS

The following discussion deals with faults and fissures, fissure veins, fractures, and joints, but because the faults are more conspicuous and offer the clue to the structures, they are dealt with in most detail. Like those in the region adjacent to Leadville, the faults of the area here described fall into three general classes—premineral reverse, premineral normal, and postmineral normal. Some faults, however, appear to have been the sites of two successive movements, one reverse and the other normal. Along such faults, only the net effect of the several movements is recorded in the displacement now visible, and of course the records of successive stages are lost. At least three faults having possible multiple and opposite movements are reported by Emmons, Irving, and Loughlin (1927, pp. 77–78 and p. 80). Such effects are not surprising because later deforming forces could most easily be relieved by movement along fractures made during an earlier time of deformation although the nature or direction of the deforming force may have been different.

The dominant trend of the faults is northerly and, as their dips are steep, even the rugged topography does not cause their outcrops to depart greatly from northerly courses. A few faults of small displacement strike more nearly east and west; for example, on the southern slope of Canterbury Hill some faults of considerable throw, apparently allied to the Pendery fault, strike N. 45°–50° E. In the southern head of the Evans Amphitheater one normal fault of small displacement but almost a mile in length strikes N. 55° W. In the Iowa Amphitheater some normal faults strike N. 55°–90° W. On the east wall of the Empire Amphitheater some minor faults strike N. 45°–70° E., and between Empire Hill to the east and the heads of Empire and Union Gulches to the west there are several faults, the strikes and courses of which are virtually due east. The only faults of large throw that strike in a direction markedly different from due north, however, are the Iowa (Iowa Gulch) fault near the Hellena mine, and the South Dyer reverse fault in Dyer and Iowa Amphitheaters; the former has a strike generally due east and the latter has an average strike of about N. 50° W.

Most of the normal faults are nearly vertical and even the reverse faults have uncommonly steep dips. Noteworthy exceptions are the South Dyer and a few minor reverse faults on the west flanks of Mounts Sherman and Sheridan. These faults have dips sufficiently low to be regarded as low-angle thrusts, but in these examples the small horizontal displacement hardly justifies the term thrust.

Almost without exception the east sides of the major faults are upthrown. This observation had already been made by Emmons, Irving, and Loughlin (1927, pl. 39, opp. p. 64; also p. 97), where it was shown that movement along the major faults was mainly uplift, that the northern part of the Weston fault was the only major fault whose east side was downthrown, and that even this fault conforms with the general rule in places. In some localities of subparallel minor faulting, alternate small fault blocks have been moved up or down, as illustrated by the offset of Cambrian key horizons on the northern slope of Upper Long and Derry Hill and by the faults cutting across the Union syncline near the heads of Union and Empire Gulches. Elsewhere, the movement has been steplike, as illustrated in the series of offsets of the Parting quartzite member of the Chaffee formation on the southern slope of Printer Boy Hill. There the upthrow is uniformly on the eastern side, much as in the larger movements.

Many of the larger faults divide into branches along their strike and each thereafter takes up a part only of the displacement of the major fault and finally dies out. Illustrations of this type of distributive faulting or "virgation," called by the miners "sprangling out," "horse-tailing," or "forking," are furnished by the Union, Weston, East Ball Mountain, and Liddia faults, as described below. Other major fault planes split into two parts, each of which takes up a part of the displacement elsewhere represented entirely along the main fault; farther on the two branches may reunite. Examples of this type of branching are conspicuous along the South Dyer, Ball Mountain, Weston, and Mosquito faults.

Bedding-plane faults, similar to those already discussed in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 64–65) were formed near the terminations of many of the lower-angle thrust faults, the movements of which were distributed along the bedding and generally near the crest or trough of an intersected fold. Several examples of this type of distributive faulting are described below.

A common phenomenon accompanying later deformation was the renewal of movement along an old fracture. Several places where this probably occurred were noted by Emmons, Irving, and Loughlin (1927, pp. 78, 80)—for example, along the Weston, Mike, and Mosquito faults. One significant example, proved by interesting evidence, is a small subsidiary fault parallel to the main Hellena fault on the fifth level of the Hellena mine and east of it. The drift is in early White porphyry, presumably a sill, as grits of the Weber (?) formation lie above and below the porphyry east of the fault on the first and third levels. A steep fault both walls of which consist of early White porphyry, is indicated by steeply dipping bands of black shale of the Weber(?) formation, enclosing alined fragments of the porphyry (fig. 50). The shale and the included fragments probably represent gouge torn from shale of the Weber(?) formation and porphyry at a time when one wall of the fault at this level was shale faulted down against the early White porphyry; subsequently a reversal of movement brought porphyry once more opposite porphyry on this level. A similar process may account for blocks of pre-Cambrian granite found between walls of the Weber (?) formation of the main Hellena fault on the upper levels. An alternative explanation is that the shale was rendered sufficiently plastic during faulting to flow up or down along the fault plane, carrying with it fragments of the more brittle porphyry.

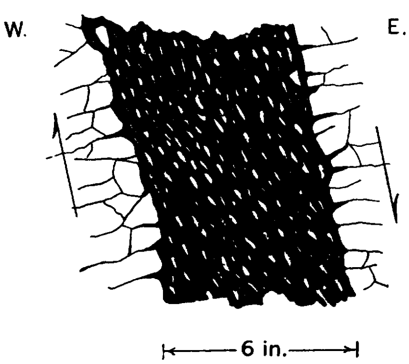

FIGURE 50.—Shale "dike" fragments of the White porphyry. Note oblique arrangement of elongate porphyry particles suggesting movement indicated by arrows. Hellena mine, 5th level, east.

PLAN OF DESCRIPTION

Neither the exact nature nor the age of several of the faults described below is fully known, hence they are described in a geographic order. For this purpose the area here mapped in detail and surrounding the central Leadville district has been divided into three sections—northern, eastern, and southern. The northern section lies north of latitude 39°15′45″ and extends from the western edge of the area mapped eastward to longitude 106°13′00″ W.—that is, to an imaginary line extending southward from the western edge of the cirque containing the Board of Trade mine toward the Diamond shaft. The eastern section extends from longitude 106°13′00″ W. to the east margin of the area mapped. The southern section embraces the remainder of the mapped area south of latitude 39°13′45″. The central Leadville district, whose southern and eastern boundaries respectively are formed by the sections just outlined, and whose northern boundary overlaps slightly the northern section as defined above, has already been described in Professional Paper 148 and only a few slight changes from the account given there will be mentioned in the sections that follow.

In each of these sections the faults are described from west to east and from north to south. Each major fault is treated in detail, and under the same heading mention is made of the allied or closely associated minor faults, fissures, and fissure veins.

FAULTS OF THE NORTHERN SECTION

HYPOTHETICAL NORTHWEST-TRENDING FAULT AND RELATED STRUCTURES

In Monograph 12, the area northwest of the town of Leadville between Capitol Hill and the cemetery was figured as one of fairly normal structural relations in which the only complication was the presence of a tongue of white porphyry interpreted as separating locally the Blue from the White limestone; some irregularities in the contact between the pre-Cambrian and the higher formations were also recognized (Emmons, 1886, Atlas Sheet 14). In Professional Paper 148, the existence of a hypothetical fault was indicated on plates 11 and 13 and on the corresponding structure sections. The fault was believed to dip west and thus to be a normal fault, bringing a small mass of pre-Cambrian rocks, northwest of Capitol Hill and west of the area shown on plate 17 of Professional Paper 148, against a larger mass of White limestone (Manitou dolomite) which lay still farther west and for whose occurrence in the area near the Leadville cemetery Irving had adduced some evidence.

In the course of the work here reported, opportunity was afforded to study the area adjacent to the mouth of Evans Gulch and upstream along the East Fork of the Arkansas River to a point due north of the Canterbury Hill tunnel. The exposures of bedrock in this area are few, and the cover of alluvium and glacial outwash in the valley of the two streams mentioned is heavy; nevertheless, fairly convincing evidence can be found for the presence of at least four faults. Detailed mapping was not carried northwest into this area.

The easternmost of the four faults would seem to correspond to the "hypothetical fault" shown south of the East Fork of the Arkansas River on the maps of Professional Paper 148. Its extension north of the East Fork is indicated by a fairly abrupt widening in the outcrop of Leadville dolomite. The effect of this fault is apparently to raise the west side, though south from the southern edge of the area the relative movement is reversed. The unusual hingelike effect of this movement is really due to differences in the direction of dip of the beds on opposite sides of the fault.

The other three faults are exposed on the slopes north of the East Fork of the Arkansas River. The first fault has a northeasterly strike and brings Leadville dolomite against Manitou dolomite. The general strike of the beds of Leadville dolomite on the north bank of the East Fork, averages N. 30° W. and the dip is 10° to 15° SW. About 1,000 ft west of the point where these observations were made, the dolomite is strongly shattered as though by faulting, and about 500 ft farther due west shattered Manitou dolomite crops out, striking N. 25° E. and dipping 60° to 70° SE. This steepening of the dip is suggestive of a fault having the southeast side downthrown. An alternative explanation is that the eastern side moved southwestward along the fault plane. The movement might thus have been either chiefly vertical or chiefly horizontal.

Farther west, pre-Cambrian gneissic granite appears on the line of strike of the Manitou dolomite and shale of the Peerless formation. This indicates the presence of the second fault, whose movement may have been like that of the first, the east side having been downthrown.

Still farther west in the valley of the East Fork, about 1,200 ft west of the place where the highway crosses the stream, the third fault, to judge by the drag of the beds, cuts Cambrian quartzite, dipping 45° E. and striking northnortheast. The east side is downthrown, much like the two similar faults to the east.

PENDERY GROUP OF FAULTS

The Pendery fault was mapped by Emmons and Irving in their study of the Downtown area (Emmons and Irving, 1907, pp. 27–28) and is shown without revision in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 87–88 and pl. 13). It is the largest of a rather closely spaced group of faults, mapped in part in the Canterbury Hill tunnel, in part in the new Leadville drainage tunnel. The northern extension, west and north of Fryer Hill, could be only roughly suggested in earlier work, and the new drainage tunnel, driven in 1945, cut it about 1,000 ft west of its indicated position, the trend of the fault at the level of this tunnel being N. 34° E. and its dip 67° NW. Its aggregate throw in the Downtown area ranges from 1,000 to 2,000 ft; at the new drainage tunnel it is 1,500 ft or more. The trend and amount of throw indicate that the main Pendery fault should have been cut by the Canterbury Hill tunnel, but no fault that could be definitely correlated with it was found there (pl. 1), though the fact that a thick sheet of gray Johnson Gulch porphyry lies on both sides of the expected position of the fault would make the finding of the fault difficult.

In the Downtown area it was demonstrated that certain faults east of the Pendery fault are members of the Pendery group, having similar strikes and dips and supplementary movement. North of Fryer Hill also the irregular pattern of the sedimentary rocks, as exposed in outcrops and mine workings, points to the presence of a similar group of subordinate faults. Locally, as at the eastern shaft of Prospect A–94 and in the pits of Prospect A–82 (pl. 1), wide breccia zones and considerable crumpling indicate the presence of such faults. They have northeasterly trends and appear to be roughly parallel with the Pendery fault. They cannot be traced far south of the Chicago Boy mine, as they enter a thick sill of Johnson Gulch porphyry where surface exposures and underground data are lacking. It is believed that these minor faults cut the northwest extension of the Mikado fault. None of these faults of the Pendery group has a large displacement; surface observations indicate that only two have a stratigraphic offset exceeding 100 ft (sec. A–A′, pl. 2).

IRON FAULT AND ITS BRANCHES

The Iron fault, according to Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pl. 12 and p. 89), extends from the west side of Iron Hill northeastward to Little Evans Gulch, but its termination at the northern end is not known. A northeastward-trending fault in line with it 2,800 ft due west of Lake Isabelle offsets one of the sills of Evans Gulch porphyry, which here cuts the Weber(?) formation. Because of its seeming continuity with the previously recognized trace of the Iron fault east of the Pawnolos shaft, this fault is regarded as the eastern and somewhat more conspicuous branch of the Iron fault.

About 3,500 ft east of the Chicago Boy mine, an outcrop of silicified Leadville dolomite, locally much shattered (as at Prospect A–98 and the Uncle Sam shaft) is indicative of an upthrown block, possibly bounded by two western branches of the Iron fault, or by related parallel faults. Farther northeast, in line with the western of these two branches, sills of Evans Gulch porphyry in the Weber(?) strata are offset, as shown on plate 1. These two faults are mapped tentatively as western branches of the Iron fault, but their connection with the main part is not definitely traceable.

For a brief description of the southern end of the Iron fault, see page 71.

NORTHERN END OF THE WESTON FAULT

At the northernmost place on the Weston fault where measurements can be made, the fault dips steeply eastward and drops the eastern side 60 ft (Emmons, Irving, and Loughlin, 1927, p. 79). The northward extension of the Weston fault is probably slightly offset where it is intersected by the later Iron fault, in accordance with the probable dips and known displacements of the two faults. The Weston fault thus projected may be the cause of the peculiar offset of the Evans Gulch porphyry sill north of the Iron fault shown on the map, plate 1. There is no conclusive evidence, however, for correlating this offset with that due to the Weston fault south of the Iron fault, despite the similarities in amount and direction.

FAULTS OF LAKE ISABELLE AMPHITHEATER

Two small faults, apparently unmineralized, offset limestone lenses in the Weber(?) formation northeast of Lake Isabelle; each trends northeastward and the southern side of each is raised 20 ft. Two others are inferred west of Lake Isabelle to explain abruptly angular changes in the outline of the Evans Gulch porphyry sill that underlies most of the floor of the Lake Isabelle Amphitheater. None of these four faults shows signs of mineralization.

FAULTS OF THE EASTERN SECTION

NORTHERN PART OF MOSQUITO FAULT

The longest and most conspicuous fault in this region is the Mosquito fault. If, with the Weston fault, it is regarded as making up a complex that begins at the southern edge of the area mapped, it can be traced for 6½ miles within this area alone. It has been mapped in considerable detail much farther north, through Climax, 10 miles north of Leadville, to Tenmile Creek, 20 miles north of Leadville (Emmons, 1896, pp. 3–4; Butler and Vanderwilt, 1931, pp. 332–333) and also southward to Weston Pass, 10 miles south of Leadville (Behre, 1932, pp. 61–63). Thus, the length through which it is well known is 33 miles. Reconnaissance work indicates that it is traceable for not less than 50 miles, as a similar and probably identical fault has been mapped far northward from Tenmile Creek, and also into South Park, 18 miles south of Weston Pass (U. S. Geol. Survey, Geological Map of Colorado, 1935; Stark, Johnson, Behre, and others, 1949, pl. 1). The Mosquito fault may therefore be regarded as one of the major faults of the Rocky Mountains in Colorado.

Northward from the point near Empire Reservoir, where it is concealed under alluvial cover but presumably separates from the Weston fault, the Mosquito fault is of uniform character. The exposures from the reservoir northward as far as the crest of Upper Long and Derry Hill are too sporadic to give a clear picture of the fault itself. On the crest and northern slope of Upper Long and Derry Hill, and the south slope of East Ball Mountain the exposures are poor and only the presence at the same altitude of rocks of strongly dissimilar character and ages reveals the approximate location of the fault plane on the surface. The first direct evidence for the exact location of the fault is at a caved tunnel on the south slope of East Ball Mountain (Prospect N–128, pl. 1), where dump materials reveal considerable breccia of "Blue" (Leadville?) dolomite, whereas pre-Cambrian granite crops out a few hundred feet to the east. The fault can be followed across the northwest shoulder of East Ball Mountain by tracing the pre-Cambrian granite on the east of the presumptive fault line and clastics of the Weber(?) formation on the west. The Mosquito fault also crosses the head of the north branch of South Evans Gulch as indicated by exposures of the Leadville dolomite and the Dyer dolomite member of the Chaffee in a block lying between the main fracture and a northwestward-trending branch. In the saddle between Little Ellen Hill and East Ball Mountain a small body of an early White porphyry sill underlying the Dyer dolomite indicates the point where the two faults reunite. The displacement everywhere along the Mosquito fault is down on the west side with, commonly, an upward dragging of the beds.

On the southern slope of Little Ellen Hill beds of the Weber(?) formation, constituting the west wall of the fault, have been steepened by drag for a hundred yards from the fault plane and locally dip as much as 90° E., though normally not exceeding 20°. Still farther north, in the floor of the Evans Amphitheater, a series of openings, notably those of the Best Friend claim, have been made along the Mosquito fault revealing a sliver like that found in South Evans Gulch, bounded on the east by the main Mosquito fault and on the west by a local branch, that reunites with the main fault about a mile farther north. East of the main fault the pre-Cambrian granite is at the surface; west of it in the sliver is Leadville dolomite, and west of the branch fault is the Weber(?) formation. Exposures are so poor, however, that the dips and strikes of the fault planes can not be measured.

At the northern edge of the area mapped, approximately 2,500 ft west of the range crest, the Mosquito fault crosses the spur connecting the main range with Prospect Mountain. The fault trace is covered by rubble, but soft shaly sandstones of the Weber(?) formation on the west have been dragged upward abruptly and dip steeply west near the fault (sec. A–A′, pl. 2). Springs issue along the approximate line of the fault.

The net down-dip displacement on the Mosquito fault is not less than 600 ft in the vicinity of East Ball Mountain and increases northward to Birdseye Gulch; in the floor of Evans Amphitheater the throw is at least 5100 ft. Both in this large displacement and in the upward drag along its west wall, the fault closely resembles the combined Mosquito-Weston fault at the southern edge of the area mapped. The direction of dip of the Mosquito fault is known with certainty in only one place in the area mapped, but its straight trace in this rugged topography indicates that the angle of dip must be steep. On the southern slope of Empire Hill—the south edge of the Leadville area here described—the Mosquito-Weston fault dips 75° to 80° E., and the walls are mineralized. The Mosquito fault was regarded as a postmineral normal fault by Emmons, Irving, and Loughlin (1927, p. 95) but the mineralization observed in Prospect N–128 southwest of East Ball Mountain and in Prospects C–80, C–88, and C–103, and especially the rich ore reported from the Best Friend and other mines nearby in the floor of Evans Amphitheater[2] prove that the Mosquito fault

[2] John Harvey of Leadville, Colo., reports that in prospects south of the Best Friend, Doyle recovered about $100,000, chiefly in gold and silver and that a small amount of ore bearing 100 to 200 ounces of silver and 6.40 ounces of gold was recovered from veins parallel to the Mosquito fault in Prospect No. C–80.

was present before mineralization began in these places. The reversals in direction of dip from place to place along its course favor the interpretation that the Mosquito is a steep fault. Further, the mineralization and intense compression to which the beds west of the fault were subjected at Weston Pass, Empire Hill, East Ball Mountain, Little Ellen Hill, Birdseye Gulch, and Climax, suggest that it is one of the premineral faults of compressional origin; indeed, it is one of the largest of this class so far mapped in the Mosquito Range.

FAULTS ON FLOOR OF EVANS AMPHITHEATER

Although they may not be branches of the Mosquito fault, the plexus of faults trending about N. 30° E. and traceable across the pre-Cambrian floor of the Evans Amphitheater appears to be a part of the Mosquito fault system. Three large faults can be traced from the northern slope of West Dyer Mountain to the northeastern wall of the Evans Amphitheater. Their displacements, like that of the Mosquito fault itself, increase northward; measured at the boundary between the Cambrian and pre-Cambrian formations, the vertical displacements on individual faults range from 50 to 250 ft (sec. A–A, pl. 2). In addition, both the northern slope of West Dyer Mountain and the northeastern walls of the Evans Amphitheater are cut by smaller faults, approximately parallel to the others; some of them raise the eastern, others the western wall, the vertical displacements along each amounting to about 50 ft.

The hooked form of the seemingly vertical dike of later white porphyry that is cut and offset by the easternmost of the three large faults, suggests that the chief movement along them was horizontal; moreover, the fact that this dike itself is broken indicates that at least some of the movement on the fault took place after intrusion of the dike. It seems reasonable to assume that this faulting after intrusion represents renewal of movement on an existing fracture plane.

Finally, if the Mosquito fault and the associated minor faults are premineral but were reactivated after intrusion of the later white porphyry (itself probably later than mineralization), the mineralization must have followed soon after the first movement of the fracture planes, after which came intrusion of the porphyry and renewed movement along the northeastward-striking set of faults in Evans Amphitheater. The writer favors this interpretation not only for faults subsidiary to the Mosquito fault in the region here discussed, but also for the Mosquito fault itself farther north at Climax.

One of the comparatively few northwestward-striking faults cuts across the one just described. The walls of this cross fault are highly iron-stained and much brecciated near Prospect C–89, where the fault displaces the later white porphyry dike referred to above. To the southeast it is hidden by the great rock stream that descends from the main range to the east. This fault plane appears to be vertical, with a throw of about 60 ft; the northeast side of the fault moved up. The vertical movement on this fault and the almost vertical dip of the northeasterly trending fault must account for the failure of either fault to offset the other where they intersect. Apparently, the horizontal displacement along the north-trending fault increases northward, being nothing at its intersection with the northwestward-trending fault, about 200 ft where it cuts the dike of later white porphyry, and more than 1,000 ft where it crosses the contact between the Cambrian and pre-Cambrian to the north.

FAULTS ON MOUNT EVANS

Several small faults that are nearly parallel to the Mosquito fault were mapped on Mount Evans. The only important one crosses the crest of the range about 1,200 ft south of the summit of Mount Evans. It strikes N. 30° E. and lifts the eastern side about 40 ft.

FAULTS ON DYER MOUNTAIN

A broad shattered zone striking N. 70° E. crosses the northern knob of Dyer Mountain. Along it conspicuous bleaching and kaolinization of the rocks has taken place. On its northern edge this zone is intersected by several less conspicuous jointlike fractures, deeply weathered, and yielding sharp columns at the range crest; these fractures strike N. 40° to 50° E. and dip 80° E. About 600 ft west of the summit of Dyer Mountain is a small fault trending parallel to the faults just described and apparently part of the same system.

FAULT COMPLEX ON EAST BALL MOUNTAIN

Several subparallel northerly and north-northeasterly faults appear to branch from a fault seen at an altitude of 11,750 ft on the southern slope of East Ball Mountain. They are similar to the faults in Evans Amphitheater and parallel in strike to the Mosquito fault. They are most striking where they offset the contact between pre-Cambrian and Cambrian rocks or cross the sills of early White porphyry in the Cambrian rocks.

Of nine such faults, all of which can be seen to dip steeply westward, all except one raise the east side, and all have throws not exceeding 50 ft; their aggregate movement is about 350 ft up to the east. The longest of them cuts the South Dyer fault, a relatively low-angle reverse fault, failing to displace it markedly only because the South Dyer fault itself here turns sharply to a dip much steeper than its common one. None of the faults on East Ball Mountain is known to be mineralized, but small parallel fissures in the pre-Cambrian granite farther south contain gold.

SOUTH DYER FAULT

The South Dyer fault is the nearest approach to a low-angle thrust of any in the area mapped, for where it is exposed it dips 40° to 65° NE.; it strikes transversely to the general trend of faults in the area. Its north side is upthrown, bringing pre-Cambrian rocks on the north against Cambrian, Ordovician, and intrusive rocks on the south (secs. B–B′ and G–G′, pl. 2, and fig. 51). At its southeastern end, beyond the Liddia subjacent sill of heavily sheeted early White porphyry. A second lens of Manitou dolomite adjoins the first one farther east along the fault trace. These detaiis are too small to be shown on the map of the district, but are indicated on figure 53.

About 50 ft higher and 60 ft east of the eastern end of the lenses of Manitou dolomite a branch reverse fault unites with the major fault to the southeast. It is probable that similar distributive movements along

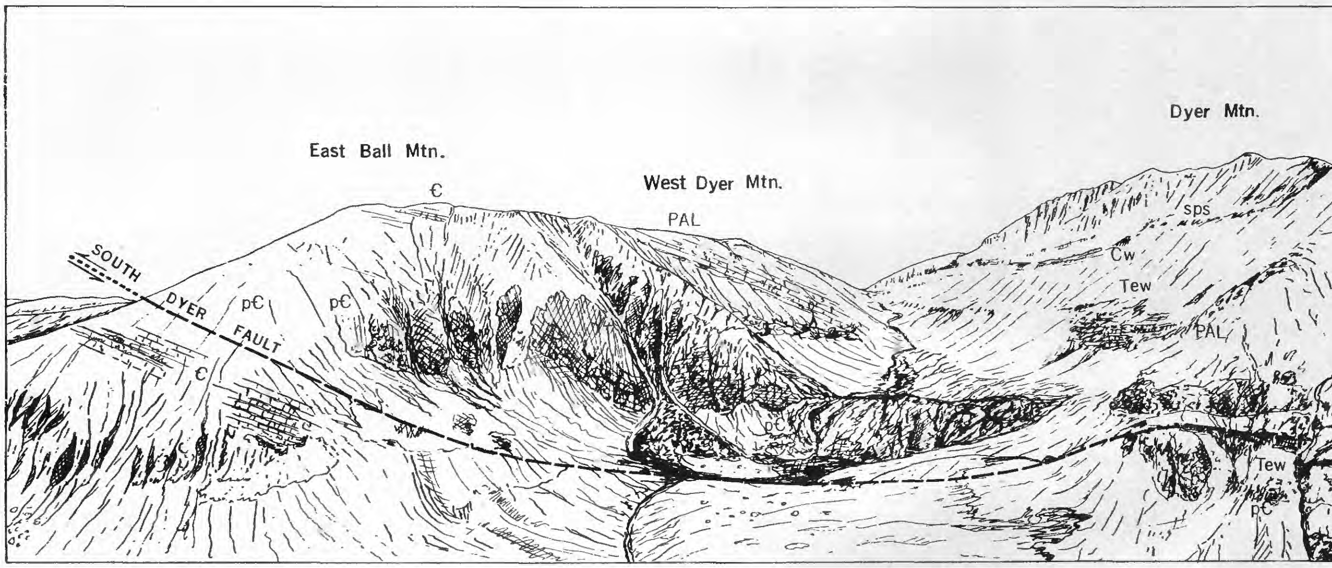

FIGURE 51.—East Ball Mountain, Dyer Mountain, and Dyer Amphitheater from West Sheridan Mountain. Diagram showing chief geologic features. Explanation: pre-Cambrian (*p*Ꞓ), Cambrian (Ꞓ), pre-Weber(?) Paleozoic sediments (*PAL*), Weber(?) formation (*Cw*), sill of Sacramento porphyry (*sps*), White porphyry (*Tew*). The location of the South Dyer fault may be clearly seen on East Ball Mountain and approximately on Dyer Mountain, but is only inferred in Dyer Amphitheater.

fault, it frays out in the bluffs west of Hill Top Pass (fig. 52), where its trace is marked by steep upturning of beds in the footwall, considerable shattering, and a splitting up into several minor faults, some of which pass into bedding-plane faults. Westward it is cut off by the Mosquito fault, but it may correspond to a fault having a similar east-southeast trace and a throw of 200 ft, which is seen in the block between the Ball Mountain and Mosquito faults. This segment is recognizable on the map by its curved trace, which passes through a point 1,200 ft southwest of U. S. Land Monument Alpha. It could be interpreted as the eastward continuation of the Iowa (Iowa Gulch) fault because of its parallel trend, but its northerly dip and its upthrown northern side favor its interpretation as a segment of the South Dyer fault.

Outcrop indications of the South Dyer fault are various. A wide breccia zone lies along a part of its course on the southern slope of East Ball Mountain. The fault trace is well exposed on the southwest spur of Dyer Mountain; here it splits, and a small lens of Manitou dolomite, too small to be shown on plate 1, appears beneath the main fault plane and an accessory fault which acts as its southwestern boundary against the bedding planes would be recognizable elsewhere along the South Dyer fault if the surface were adequately exposed. The facts noted illustrate well the irregular virgation, or splitting and reuniting, commonly observed in low-angle thrust faults. It is significant that, despite shattering, silicification, and some iron-staining,

FIGURE 52.—Southwestern slope of Mount Sherman adjacent to branches of South Dyer fault to left (north) of northern branch of fault; Cambrian (Ꞓ), irregularly intruded by sills of White porphyry; thick White porphyry sill (*WP*); Manitou dolomite (*Om*); and Devonian and Mississippian rocks (*D–M*).

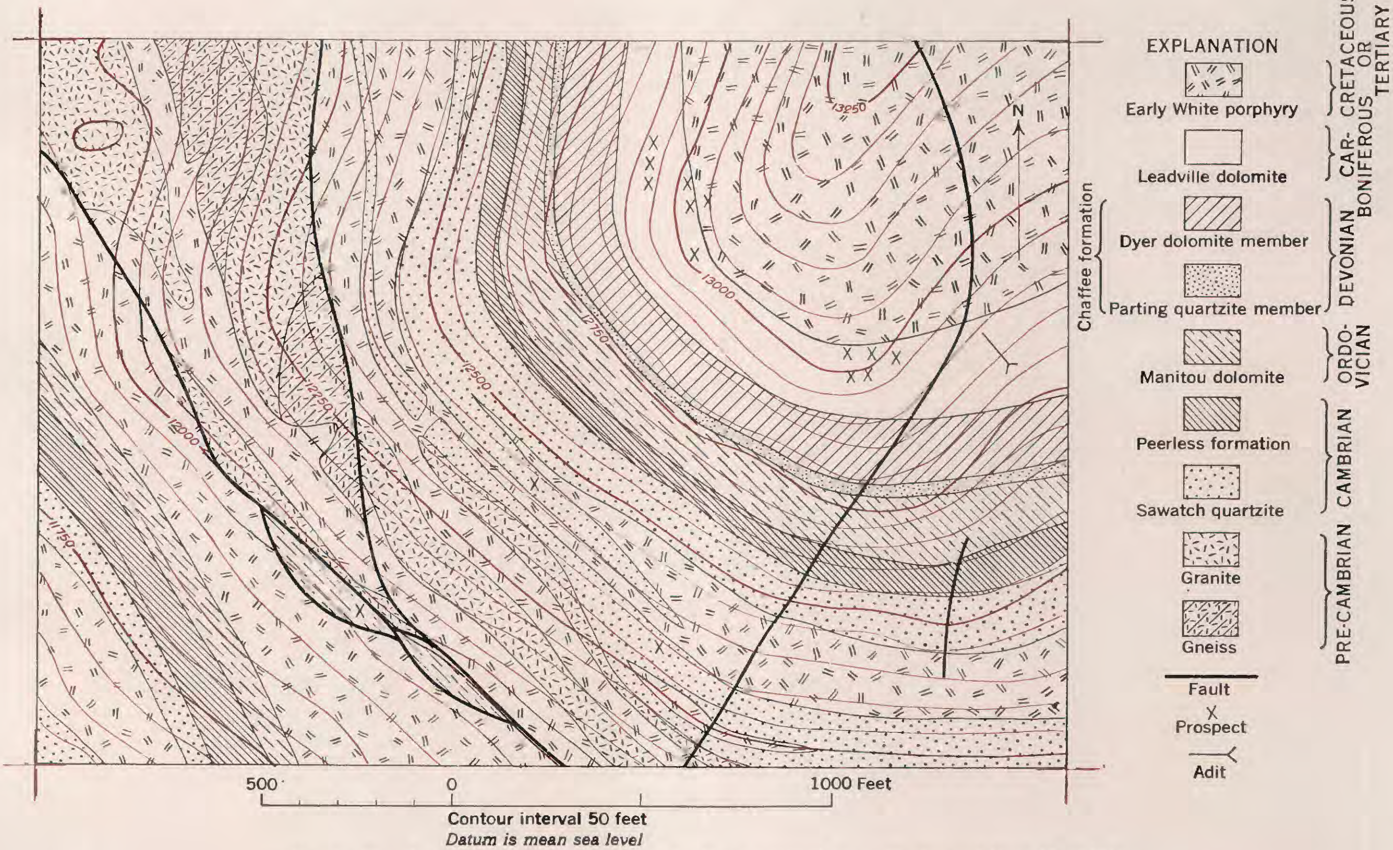

FIGURE 53.—Detailed map of South Dyer fault, as exposed on south slope of Dyer Mountain.

there is no evidence of any economically valuable minerals along the outcrop of the fault.

Farther east the western branch of the Liddia fault crosses and raises the South Dyer fault on the east about 100 ft vertically, displacing its horizontal trace about 700 ft. Still farther east the South Dyer fault breaks into several branches which disappear on the southwestern slope of Mount Sherman.

LIDDIA FAULT

The relatively straight Liddia fault dips steeply west and strikes generally N. 25° E. It is exposed on the southern slope of Dyer Mountain near the Liddia mine (fig. 54) and in the workings of that mine, north of which it separates into two faults, both with upthrow to the east (secs. B–B′, H–H′, pl. 2). Though not readily traced across Iowa Amphitheater, the fault appears to split near its southern end and some of the resulting fault planes are visible on the west spur of Mount Sheridan, one fault crossing the divide into Empire Amphitheater. All of these southern branches have the upthrow to the east. They all are vertical or dip westward—at the Liddia mine about 75° at the surface and 65° underground. The vertical displacement is 530 ft at the Liddia mine and increases southward. About 300 ft north of the Liddia mine, where the fault splits, the western branch has a throw of 300 ft, the eastern branch a throw of only 35 ft. The western branch merges obliquely with a normal fault approximately parallel in strike with the bedding of the Dyer fault. The eastern branch is lost in a thick sill of early White porphyry.

On the sheer cliffs that form the southern wall of the Iowa Amphitheater the four branches of the Liddia

FIGURE 54.—Trace of mineralized Liddia fault system near the head of the Iowa Amphitheater, showing offset of the potentially productive Leadville dolomite (*Cl*). A thick sill of White porphyry (*Tew*) can be seen near the head of the amphitheater. The Liddia Mine (near *A*) and the Continental Chief Mine (near *B*) are both located in the Leadville dolomite.

fault have the effect of raising the successive contacts to the east in steplike fashion with a combined vertical movement of about 750 ft, most of which is along the easternmost branch.

It is noteworthy that in the Liddia mine the main Liddia fault is supplemented by minor ones (well displayed in the workings) which differ from the main fault in their steep southeastward dips but resemble it by dropping the west side, in this case 17 ft. In the description of the Liddia and adjoining properties, reasons are given for regarding the Liddia fault as a postmineral fault which has displaced a once continuous ore body (p. 130–131).

FAULTS AT NORTH HEAD OF IOWA AMPHITHEATER

At the north head of the Iowa Amphitheater most of the faults are roughly parallel with the Liddia fault. They strike N. 25°–40° E., dip west or are vertical, and raise the east side; the throw of any single fault nowhere exceeds 30 ft. These faults tend to be shattered and open, indicating a tensional origin.

The one northwestward-trending fault in this region, designated the Dyer fault in Monograph 12, is indicated in the floor of Iowa Amphitheater by repetition of the Manitou dolomite, and the Parting quartzite and Dyer dolomite members of the Chaffee formation. This fault dips southwest and has a maximum upthrow of about 50 ft to the north.

None of these faults offers any evidence of premineral movement and, by analogy with the strikingly similar Liddia fault, all are probably postmineral.

NORMAL FAULTS ON MOUNT SHERMAN

On the western slope of Mount Sherman a complex of faults has visibly offset the sedimentary formations and the intruded thin sills. In general these faults dip steeply, and all are normal. There is no uniformity in strike; some of the faults, such as the Liddia fault and those at the head of Iowa Amphitheater, trend northeast, but a few trend west or northwest. Careful study of relations between these two sets of faults suggests that they were essentially contemporaneous in origin; in one locality, 3,000 ft south of the Continental Chief mine, an east-west fault cuts a northeasterly one, whereas 1,500 ft to the southwest the northeasterly fault displaces two of northwesterly strike.

Ore has been mined near these faults but there is no obvious evidence of ore; the mine workings are no longer accessible for study, so whether any of the faults are of premineral age cannot be determined.

THRUSTS ON MOUNT SHERMAN

Four low-angle thrust faults of small displacement and extent are recognizable on the west slope of Mount Sherman. Three of them lie near the McGuire properties (Prospect N–106, pl. 1); the fourth is approximately 3,500 ft to the south. All are closely similar in strike, ranging from N. 5° W. to N. 25° E., and dip 35° to 60° E.; on all of them the east side is upthrown a maximum of 50 ft. They are characteristically accompanied by breccia and by drag of the beds on both sides of the fault plane (fig. 55, and sec. B–B′, pl. 2).

The evidence is inconclusive but these faults are believed to be premineral in age, partly because there are similar faults in mineralized zones at the Continental Chief mine and partly because of the generally close but inconspicuous association of ore minerals. It has been shown that thrust faults of this general type throughout the Leadville district are generally related to ore deposition (Emmons, Irving, and Loughlin, 1927, pl. 39, pp. 65–77, 96), and probably the Sherman thrust faults are typical.

FAULTS ON WEST SHERIDAN MOUNTAIN

The numerous minor faults that complicate the outcrop pattern of formations on the two peaks of West Sheridan Mountain are of little structural significance. Those just west of the crest of the northern peak are unusual in that their downthrow is generally on the east instead of on the west; faults below and west of the 12,500-ft contour, however, have the normal pattern, with the eastern side raised.

A normal fault fissure in the saddle between the southern West Sheridan Mountain and Mount Sheridan is of interest because it is occupied by a dike of later white porphyry. This fault strikes N. 15° E. and dips about 80° W. It supports the generalization that certain of the northeast-trending faults provided channels for the later white porphyry intrusions.

FAULTS ON MOUNT SHERIDAN

Three kinds of faults may be seen on Mount Sheridan. Several faults with steep dips strike N. 35°–65° E. and, with one exception, have their northwestern sides dropped. In no fault of this group does the throw exceed 40 ft.

A second group of faults is obviously related to the branches of the Liddia fault, for its members trend northward and dip steeply west; their western sides are downthrown. Examples of this group are the

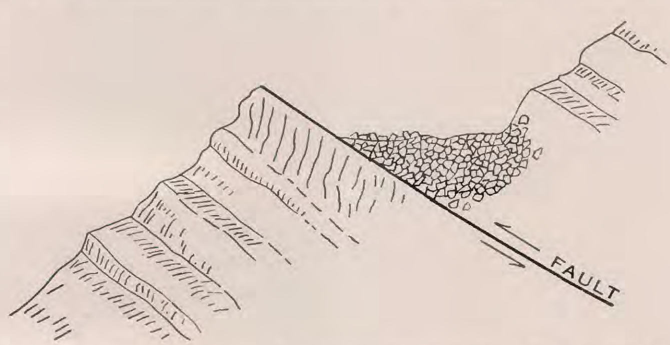

FIGURE 55.—Sketch of one of Sherman thrust faults. It dips 30° E., whereas beds dip 35° E. Note heavy jointing below fault and talus above.

faults crossing the ridge between the peak of Mount Sheridan and the lowest part of the ridge connecting it with West Sheridan Mountain (sec. C–C′, pl. 2). These faults are commonly indicated by some brecciation and by heavy iron-staining.

Of a third kind is the fault of sinuous trace which extends from the southern head of Iowa Amphitheater southward across the west slope of Mount Sheridan to the sag between Peerless and Horseshoe Mountains. At this sag it splits and both faults pass over the crest of the range. This fault is remarkable in that the western instead of the eastern wall is raised. It is a low-angle fault with steep eastward dip at a few places. The fault plane is characterized by conspicuous silicification and a breccia zone in much of which silicified fragments of the bordering limestone are cemented by highly ferruginous siliceous cement. Its plane is virtually but in many places not wholly parallel to the bedding and therefore it cannot be regarded as a bedding-plane fault. This fault is itself cut and displaced by a small fault of the later northeast-trending group.

FAULTS BETWEEN PEERLESS AND HORSESHOE MOUNTAINS

In addition to the fault described in the preceding paragraph, the ridge crest from Peerless Mountain southward contains two kinds of faults. Three shear zones of slight displacement, striking N. 35° W. and dipping about 45° NE. cross the ridge, 1,200 ft north of Horseshoe Mountain. These faults are revealed only by the shattering and iron-staining of the Leadville limestone on the ridge crest; they appear to die out down both slopes. All three are normal faults, each with its northeast side dropped about 15 ft.

On the eastern flank of Horseshoe Mountain, a low-angle reverse fault virtually follows the contact between Manitou dolomite and Parting quartzite member of the Chaffee formation.

FAULTS AND SHEAR ZONES ON FINNBACK KNOB

The pre-Cambrian rocks of Finnback Knob and of the slopes connecting the knob with Horseshoe Mountain and Empire Hill are of such uniform lithologic composition that the displacement along fault planes cannot be measured. There are, however, numerous shattered zones that represent either joints along which there has been some slight shearing, or actual faulting. With only one exception they have trends ranging from N. 35° E. to N. 30° W. The dips are steep—generally almost vertical.

Shear zones of the type described are greatly varied. Some consist of highly shattered and closely jointed granite, in one place 40 ft in width; kaolinization, iron-staining, and quartz-filling are not uncommon. A few are occupied or closely paralleled by dikes of later white porphyry and trend east-northeast. One such dike, 1,500 ft due west of Finnback Knob, gives the impression, by its relation to two parallel shear zones, that it represents a fault that offsets the zones in question.

The strikes and dips of these shear zones strongly suggest that they correspond to the small, discontinuous northeast-trending faults on the slope between Mount Sheridan and Peerless Mountain. As they are situated stratigraphically at greater depth in the relatively homogeneous pre-Cambrian rocks, they are more persistent than in the less competent sedimentary rocks. The later white porphyry, which emerges here in several dikes and also in a pluglike mass in Empire Amphitheater, may have been guided by these shear zones.

Evidence concerning the age of the shear zones is not clear but, if they correspond to the small faults between Mount Sheridan and Peerless Mountain, they are some of the more recent faults of the region.

FAULTS NEAR HILLTOP MINE

The area around the Hilltop mine east of Mount Sheridan has been mapped in detail (fig. 56). Structural details are discussed and evidence for interpretation of the structure appears in the description of the mine, but a brief summary is given here. The faulting is superimposed on a moderate eastward dip, typical of the regional homocline. Only three faults are clearly exposed at the surface; others are covered by talus. Underground, the Hilltop fault strikes N. 21° E. and dips 70° NW.; it may be interpreted either as a hinge fault, or as a strike-slip fault along which the eastern side moved northward horizontally. This fault is premineral, as it contained a large ore shoot. Two smaller faults striking N. 35° W. and apparently dipping about 70° SW. are indicated on the surface by ill-defined breccia zones. The Hilltop fault ends against them. The three faults approach intersection near the buildings of the Hilltop mine. To the northeast is the curvilinear Fulton fault, which strikes approximately N. 45° W. but is not exposed at the surface. The intersection of the Fulton with the other faults mentioned is 500 ft north of the Hilltop No. 2 shaft (fig. 56).

A small fault in the southwestern part of the Hilltop area has a course of N. 5° W. and is probably a strike-slip fault along which the east side moved southward relatively.

FAULTS OF THE SOUTHERN SECTION

IRON AND DOME FAULTS

Only the positions of the Iron and Dome faults south of Rock Hill (about 39°13′45″ N. latitude) can be determined from examination of the scattered prospect holes which reach bedrock through the high terrace gravel cover (pl. 1). The northern end of the Iron fault was discussed on page 65.

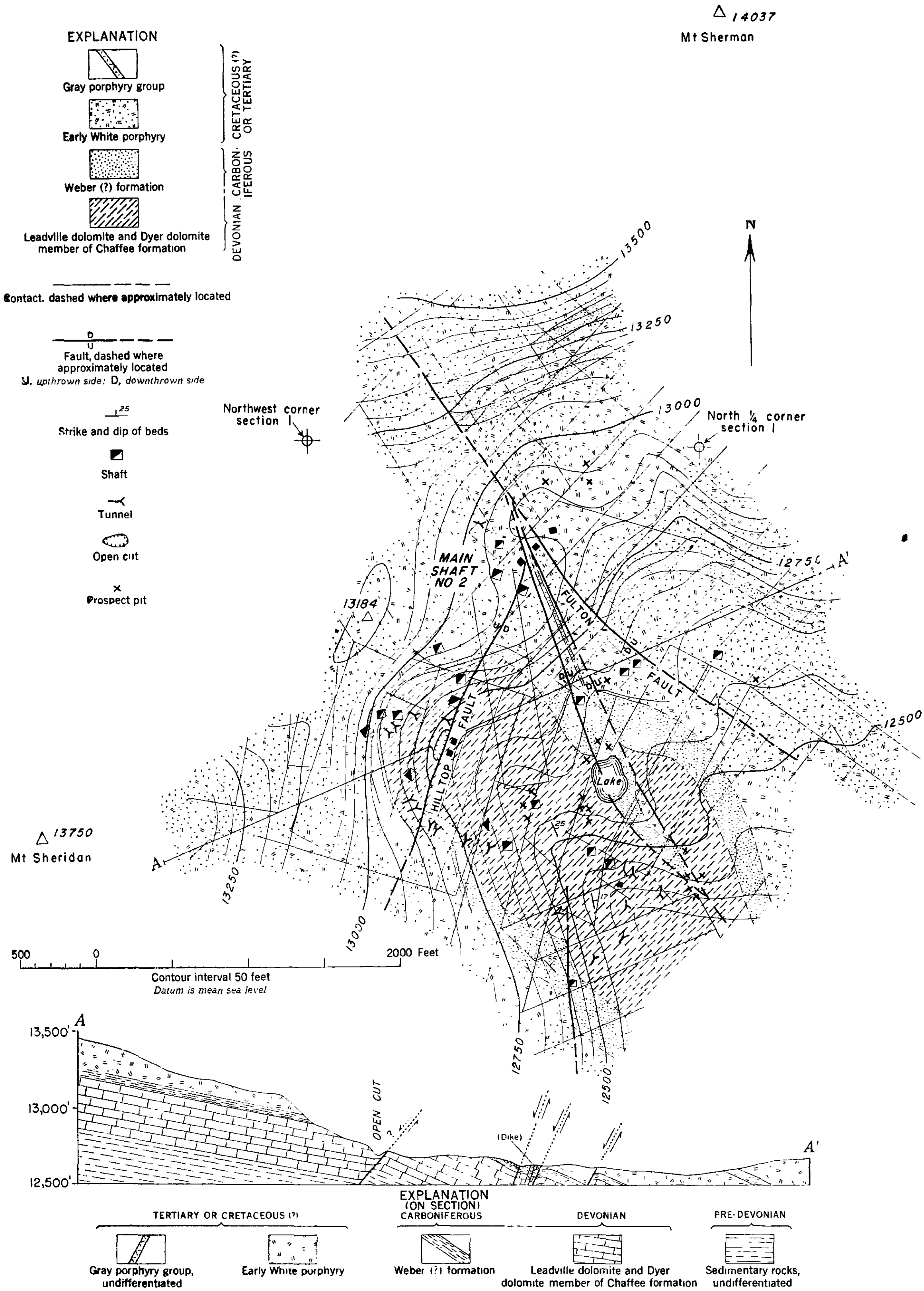

FIGURE 56.—Geologic map of Hilltop area.

MIKE AND PILOT FAULTS

The Mike and Pilot faults converge in the area where Printer Boy Hill drops off to Rock Hill and extend as a single large fault, designated the Mike fault on the geologic map, taking up the movement represented by both farther to the north. The Mike fault is largely reverse and the Pilot fault wholly normal, but north of the junction their combined displacements are additive as the eastern side of both is upthrown. The relations between these two faults were fully discussed by Emmons, Irving, and Loughlin (1927) who showed that from Iowa Gulch northward most of the displacement of the combined faults south of Printer Boy Hill was taken up by the Pilot fault (sec. B–B′, pl. 2).

Along the course of the Mike fault southward from Printer Boy Hill, workings are not extensive and details of displacement cannot well be traced. The position of the Mike or combined Mike-Pilot faults, however, is exposed at the surface in two areas—the southern slope of Long and Derry Hill and the area north of their junction with the Union fault, about a mile southeast of the Mitchell Ranch.

On the southern slope of Long and Derry Hill, where the road into Empire Gulch crosses the fault, the west wall is composed of early White porphyry, whereas the east wall, as shown by prospects nearby, is of a light-gray dolomitic limestone, inferred to be Manitou. The throw here is at least 500 ft (sec. C–C′, pl. 2). The fault is concealed beneath Empire Gulch and southward, but the displacement presumably decreases as is seen at the exposure on the 11,250 ft knob about 4,400 ft southeast of Mitchell Ranch. Here the fault passes between an outcrop of heavily shattered and iron-stained Cambrian quartzite, striking northwest and dipping 20° NE., and dumps of several caved prospects showing Parting quartzite and Manitou dolomite. The stratigraphic throw of the fault here is only about 150 or 200 ft and opposite to that farther north. For a distance of 1,500 ft from here southward essentially the same relations hold, but the fault trace curves to the southwest and finally joins or is cut off by the Union fault (sec. D–D′, pl. 2). It is possible that the Mike fault reappears from beneath the Union fault farther south, bending westward across the head of Little Union Gulch; this relation is inferred from the outcrop pattern of the Devonian, Ordovician, and Cambrian rocks on the eastern limb of a syncline that is here cut by the Union fault (pl. 1). The Mike fault is believed to be cut by and to end at a large plug of Little Union quartz latite, but it must be admitted that evidence regarding its possible extent farther south is uncertain as exposures are poor and the rock here is all granite and yields no conclusive evidence.

Whether the fault south of the junction of the Mike and Pilot faults is reverse or normal is not clear from field evidence. It is assumed to be reverse and relatively flat in the southerly part as it has a sinuous trace and is associated with folding but the fact that it is not confined to a single anticlinal limb greatly weakens this argument. South of the junction its dip has not been observed, and its trace on the topography, described by Emmons, Irving, and Loughlin (1927, p. 79) is not a dependable criterion according to the latest mapping; hence the present designation, Mike fault, south of the junction is entirely arbitrary. Although effects of sulfide mineralization are not recognizable along the fault itself, silicification and iron-staining of the walls indicate, though they do not prove, an origin antedating ore deposition.

FAULTS NEAR MITCHELL RANCH

An area of two kinds of faults with small displacements lies between Mitchell Ranch and Little Union Gulch, north of the large plug of Little Union quartz latite, and west of the Mike fault.

Most of the faults trend almost east-west and blocks alternately raised and depressed, together with the local synclinal structure, give a complex pattern to the surface geology. Indeed, it is mainly this outcrop pattern that has been used for locating the faults, as they are not well exposed. Locally the walls of these faults are somewhat mineralized.

Of a second kind are the reverse faults that meet the bedding at very small angles or actually follow it for short distances. Along such faults, exposed about 5,000 ft due south of Mitchell Ranch, sulfide mineralization is fairly extensive. The Leadville dolomite adjacent to these faults is silicified. For further details see the description of Prospects T–209, T–272, T–273 on pages 159–160.

PARALLEL FAULTS ON PRINTER BOY AND LOWER LONG AND DERRY HILLS

The fault patterns on Printer Boy and on Lower Long and Derry Hills are closely similar, for the faults trend virtually north-south and some extend across both of these hills and the intervening valley. The fault fissures of this group seem to belong to the same system and to possess essentially the same characteristic features. Of 18 such faults mapped between the Mike and Weston faults, all except two have the downthrow on the west. Though the faults seen on the surface could be studied underground in only a few places, their courses across Iowa Gulch, together with mechanical considerations, lead to the inference that they are mainly normal and dip west—probably steeply. Observations underground in the Ontario, Altoona, and Brian Boru mines confirm this inference except that the Sangamon (one of the faults in the Lower Altoona tunnel) and two minor faults in the Brian Boru tunnel dip 60° to 70° E.

Records of the productive mines, such as the Lillian and Printer Boy, and several smaller workings, show that fissures having dips and strikes similar to the faults of this area are of premineral age. Therefore, these are probably premineral faults, as are parts of the bounding Mike and Weston faults. Furthermore, six of the fault fissures mapped are occupied by dikes of Johnson Gulch porphyry, the kind of intrusive rock with which much ore is associated.

A fault of unusual trend extends southwestward from the Doris workings in Iowa Gulch. It is known from exposures southwest of the Doris mine, and also from descriptions of observations made by operators in the Doris workings which are no longer accessible. This fault has a trend similar to that of the Iowa fault (pp. 77), but a contrary displacement, bringing Leadville dolomite on the northwest against the normally overlying sill of early White porphyry on the southeast; the upthrow is thus on the northwest. Southwestward this fault seems to be offset by one of the northward-trending faults characteristic of the northern slope of Long and Derry Hill; still farther on it seems to end against another such fault. It can be traced no farther northeastward than the thick sill of the early White porphyry east of the Doris mine, but it may well pass between the lenses of Leadville dolomite lying just west of the Weston fault and the slender, curved outcrop of the same rock believed to extend through the Julia-Fisk workings. In attempting to correlate these dolomite lenses on opposite sides of the fault allowance must be made for their probably irregular positions in the thick sill of enclosing White porphyry. Moreover, the large amount of inference should be recognized in this region where a heavy cover of talus, alluvium, and glacial material combines with the inaccessibility of old mine workings to obscure the geology.

UNION FAULT

In earlier work the course of the supposedly normal Union fault was believed to be quite different from that shown on the maps accompanying this report. Emmons (1883, Atlas sheets 7, 13) believed that the structure at its south end showed that the Union fault cut off the Mike-Pilot fault, but that to the northeast it crossed Long and Derry Hill and entered Iowa Gulch, where it terminated against the Weston fault. This interpretation was accepted later by Emmons, Irving, and Loughlin (1927, pl. 11). Recent field work and study of age relations strongly indicate that, as the Union fault is the later one, it probably displaced the Weston. Moreover, for the Union fault to extend to Iowa Gulch before uniting with the Weston fault would necessitate a considerable change in strike and trend from those dependably inferred for it on the northwestern slope of Empire Hill; projection of their trends northward from Empire Hill, where they are definitely recognized, would bring them together on the southern rather than the northern slope of Upper Long and Derry Hill. Finally, there is no field evidence that the Union fault crosses the crest of Long and Derry Hill west of the Weston fault, whereas the numerous minor faults shown on the northern slope of Upper Long and Derry Hill east of the Weston fault can be satisfactorily explained as splits of the Union fault—that is, as the tailing out of the fault after it has crossed and offset the Weston fault.

As interpreted above, the throw of the Union fault is about 200 ft just north of the large plug of Little Union quartz latite; it increases to as much as 1,200 ft where it crosses the bottom of Empire Gulch (secs. D–D′ and C–C′, pl. 2). Northward it decreases again, so that its two major branches on the southern slope of Upper Long and Derry Hill have throws of 100 and 150 ft respectively where they cut the Weston fault.

The Union fault is believed to dip westward, but evidence is not conclusive. Its trace cuts across the Mike fault, indicating that it is later than at least one of the reverse faults. It is not known to be mineralized, though smaller faults parallel to it and possibly representing branches, are said to have been mineralized in the Ready Cash or Two Mile High workings on the northern slope of Upper Long and Derry Hill. The data as to mineralization along the Union fault are thus contradictory, but the fact that the Union fault is younger than the Mike fault is consistent with its being a normal fault of postmineral origin.

WESTON FAULT NORTH OF EMPIRE HILL

Of the fault complexes studied in the course of this work, by far the most difficult to understand is that surrounding the Weston fault, from the northern slope of Empire Hill to the southern slope of Printer Boy Hill. There the Union, Mosquito, Weston, Hellena, Iowa, and Ball Mountain faults, all of which are major features to the north and south, intersect within an area 2 miles across. At such a junction many minor breaks occur, and these minor breaks may be confused with branches of the major faults. Glacial, alluvial, and plant cover and talus slides combine to conceal relationships on the slopes of Long and Derry Hill and in the adjacent valleys. The workings, numerous enough and elsewhere frequently helpful, are here mostly old and inaccessible; the few accounts of geologic details which are available concerning former underground exposures, are in large part conflicting or vague. Uncertainties are added by the fact that much of the rock that crops out is early White porphyry. It belongs to one of five bodies exposed on or near the crest of Long and Derry Hill—four sills or tongues of sills in the Weber(?) formation and Leadville dolomite exposed just west of the fault complex and another at the base of the Cambrian quartzite as seen just east of the fault complex. As these sills are lithologically similar, the correlation of a given exposure is commonly uncertain. The stratigraphically higher ones bear relations to inclusions or partings of Leadville dolomite and grits of the Weber(?) formation that are in themselves not clear, as shown on the map (pl. 1) in Iowa Gulch 1,800 ft due west and a like distance southwest of the Hellena shaft. Finally, the junctions of so many major faults, each with the possibilities of curvatures in strike and in dip and several with multiple movements, add features that are almost insuperably baffling.

Facing all these difficulties, it must be frankly admitted that the data at hand are not adequate to permit a positive and final solution, free from assumptions. The best that can be done is to make certain that such assumptions as are used (1) are not contrary to what is known about the faults concerned as studied farther north or south and (2) are not inconsistent with the usual relations seen in similar fault complexes elsewhere. Several alternative explanations are given in some detail below; not all the aspects of each have been discussed, as this would require a volume. The reasons for rejection are briefly given. Finally, what seems to be the most acceptable explanation is offered. This procedure should make clear to the critical reader the tentative nature of any explanation and should enable him to fit any new facts that may become available into one of the hypotheses outlined below or to modify the interpretation.

Plate 5 presents two alternative interpretations. According to one the trace of the Weston fault south of the Iowa fault is inferred to be marked by the line where pre-Cambrian and Cambrian rocks and their associated sill of early White porphyry on the northeast come against beds of the Weber(?) formation or the Leadville dolomite or Dyer dolomite member of the Chaffee formation or their sills of the early White porphyry on the west. This hypothesis assumes that the Union fault breaks into a group of distributaries of which the westernmost is the Hellena fault, and that each of them, generally dropping the northwestern side, offsets the Weston fault; of the distributaries only the Hellena fault is thought to raise the Weston fault to the northwest and thus displace it northward. In its northwestward extension the Weston fault is broken into two parts which, extending farther northwest across Iowa Gulch, reunite to form the Weston fault as known farther north.

This hypothesis is acceptable in making the mineralized Weston fault older than the nonmineralized Union fault and in correlating the eastward dipping Weston fault south of Long and Derry Hill with the generally eastward dipping Weston fault from Printer Boy Hill north. But it is highly improbable that the Hellena fault, known to be a mineralized reverse fault, is the northward extension of the apparently unmineralized normal Union fault. More probably the Hellena (a reverse fault) is a branch of the similarly mineralized Weston fault which is a reverse fault south of Long and Derry Hill.

Plate 5 also presents a second alternative: the main Union fault, which trended northeast south of Empire Gulch, makes an abrupt turn to the north-northwest and nowhere intersects the Weston fault, though the latter is cut and offset by several lesser distributaries of the Union fault. Under this hypothesis the Hellena fault is the sole northward extension of the Weston fault as developed south of Long and Derry Hill. This hypothesis is attractive in offering an explanation of the westward dip attributed (on uncertain evidence) to the "Union" fault as generally designated on Printer Boy Hill and in correlating the Hellena fault with the similar reverse mineralized Weston fault south of Empire Gulch. But it calls for a radical change in strike for the Union fault in Empire Gulch. Further, the northward extension of the normal, westward-dipping, seemingly nonmineralized Union fault south of Empire Gulch would be continuous with a generally reverse, eastward-dipping mineralized fault north of Iowa Gulch. Moreover, this hypothesis gives to the eastern branch of the "Union" fault south of the Iowa fault in Iowa Gulch the same general kind of offset (pre-Cambrian against White porphyry and Leadville dolomite) as is shown by the Weston fault south of Long and Derry Hill. For these reasons this hypothesis, likewise, is not acceptable.

On the basis of maps alone two other explanations have been offered. It has been suggested that the main parts of the two faults did intersect—but only above the present surface. Under this hypothesis the sliver between the two western branches of the Weston fault north of Long and Derry Hill is the hanging (west) wall of the Weston fault as well as the hanging (east) wall of the Union fault; the Hellena fault would then be a branch of the Weston fault. This hypothesis ascribes to the fault west of the sliver only a small part of the total displacement typical of the Union fault south of Long and Derry Hill, requires of the Union fault a very sharp turn in Empire Gulch, and does not account for the structure between the crest of Long and Derry Hill and Empire Gulch.

It has also been suggested that the Weston fault lies between the crescentic mass of early White porphyry crowning Long and Derry Hill at an altitude of about 11,700 ft and the Cambrian rocks exposed to the east. Northward the fault is thought to extend in two sections, becoming three where the Hellena fault, with a more northerly strike, splits off to the northeast. The Union fault intersects the Weston fault, under this hypothesis, offsetting it, much as already suggesed in the first two hypotheses. In short, this concept differs from that offered below only by setting the main Weston fault in a different location on the crest of Long and Derry Hill, an improbable location on the evidence of the generally good exposures of the intrusive contact between the Sawatch quartzite and the sill of White porphyry at an altitude of about 11,730 ft.

Plate 1 shows the interpretation here accepted, under which the Union fault cuts the Weston fault on the southern slope of Long and Derry Hill. The Union fault ends on Long and Derry Hill in many distributaries, which abruptly dissipate the large throw marking this fault south of Empire Gulch. These distributaries can be recognized, though with greatly diminished throw, locally even reversed, on the cliffs that form the northern edge of Long and Derry Hill. Thus, all three of the faults that extend northward across Iowa Gulch are interpreted as branches of the Weston fault, as indicated by their dip, displacement, mineralization and trend, which are all consistent with those of the Weston fault as exposed on Empire Hill. There is, it is true, a change in trend in the case of the Hellena fault but no more violent one than if that fault were assumed to be a branch of the Union fault. The middle one of the three branches of the Weston fault is the major fault in displacement up to the point where its northeastern upthrow (pre-Cambrian against Leadville dolomite and sill of the White porphyry) is largely neutralized by the northeastern downthrow of the Iowa fault. The exact points at which the two westerly splits of the Weston fault come off from the Union fault are masked, as indicated by dashed lines.

This hypothesis has the advantage of being consistent with the known movements and with the local and regional pattern. The writer holds it tentatively, subject to such revision as new facts developed by further exploration may necessitate.

North of Iowa Gulch the Weston fault is a premineral fault but it was modified by later opposite movement along the Iowa fault and became a normal fault, the east side being relatively downthrown (p. 78) as previously indicated by Emmons, Irving, and Loughlin (1927, pp. 78, 95–96).

PARALLEL FAULTS ON UPPER LONG AND DERRY HILL

In addition to several minor displacements that represent distributive movements along the northern branches of the Union fault, the north slope of Upper Long and Derry Hill shows many small faults in the block between the Ball Mountain fault and Hellena-Weston complex. In a general way these faults are parallel to the master faults, trending either due north or north-northeast. They fall into two classes.

Numerous faults of north-northeasterly trend on the northern brow of Upper Long and Derry Hill are especially well exposed at the contact between Cambrian and pre-Cambrian. They generally have a downthrow to the east and are vertical or dip steeply eastward. Chiefly they strike similarly to the Union fault but are opposite in direction of downthrow and generally in direction of dip. These faults could not well be classed as distributive faults of the Union fault. They may, however, be antithetic faults in the hanging wall of the Union fault (p. 74). They may also represent minor adjustments on the monocline of Upper Long and Derry Hill, along which the Cambrian beds dip steeply westward. Faults of this type are so numerous and their displacements so slight (1 to 20 ft) that not all of them could be represented on the map.

Within a 1,000-ft zone west of the Ball Mountain fault, there are two step faults large enough to be mapped, and several other parallel faults having a very small throw. The eastern side of each fault is downthrown, so that from west to east the top of the pre-Cambrian descends to valley level. These faults are mentioned again in the discussion of the Ball Mountain fault (p. 78).

HELLENA FAULT

The Hellena fault presents several problems similar to those of the Weston fault north of Empire Gulch. In the lowest tunnel of the Ella Beeler group (Prospect O–47, described in greater detail on p. 148), the Hellena fault was still accessible to study in 1932 (fig. 96). At this place its hanging wall dips 65° E. and its footwall 80° E. The fault zone between walls is 27 ft wide, filled with gouge and breccia, and has an average strike of N. 15° E. Though the fault zone itself is not mineralized, small parallel fissures in the hanging wall contain ore; moreover, higher workings of the Ella Beeler group, no longer accessible, are said to have contained rich ore in the fault fissure.

South of the Ella Beeler tunnel, talus, soil and vegetation conceal the outcrop of the Hellena fault, but it probably contributes to the shattered, silicified, and darkly iron-stained zone that crosses the crest of Upper Long and Derry Hill at an altitude of about 11,700 ft. Still farther south the course shown on the map is purely hypothetical.

Northward from the Ella Beeler workings also the thick glacial and alluvial fill in Iowa Gulch conceals the fault at the surface, but it is well exposed on all levels of the Hellena mine and is known to have been found in the American Continental workings, 600 ft north of the Hellena shaft. In the Hellena shaft the fault dips eastward at angles ranging between 65° and 85°. As in the Ella Beeler tunnel, it is largely open, and locally blocks of granite 30 ft across lie between walls of Weber (?) formation and porphyry, suggesting either up and down movements with drag and the introduction into the fault plane, by "trailing out," of rock actually present at lower levels, or transportation of it by plastic gouge. The size of some of the blocks makes the latter explanation very unlikely. The fault is irregular in strike, but averages about due north; on the first and third levels of the Hellena mine it is N. 2°–3° E., but on the lower levels it is N. 3°–4° W. On the first and third levels, where it is best exposed and its walls most sharply marked, the fault is distinctly curvilinear with several gradual changes in strike. Similarly, as shown in figure 88 (p. 141), the dip changes from level to level, being steep (68°), on the highest levels, flattening on the 290-ft level, and steepening again to 65°–75° at still greater depths.

The vertical displacement along the Hellena fault is varied. South of the western part of the Iowa fault, pre-Cambrian and Weber (?) rocks form opposite walls, though the exact stratigraphic positions of the rocks seen is in doubt; the minimum dip slip or vertical displacement is thus at least 510 ft, and probably much more considering the unknown thickness of intruded porphyry sills. North of the Iowa Gulch fault the displacement is less conspicuous, Weber (?) strata being against Weber (?) strata or against sills or dikes, as contrasted with pre-Cambrian farther south (sec. B–B′, pl. 2).

In general, therefore, the Hellena fault is a reverse fault, its strike approximating due north and its dip 70°–75° E.; its vertical displacement averages 600 ft up on the east. The fault or its branches or auxiliary fissures are mineralized, so it is clearly a premineral fault.

The possible northward extent of the Hellena fault fissure has long been discussed by mining men. Figure 57 offers the available pertinent data and suggests that the Hellena fault may be the same as the Sunday vein; as indicated, however, the Sunday vein may also be continuous with either of two minor fractures west of the Hellena fault. Certainly the Sunday and Hellena veins are alike in mineralization and displacement, though their dips are opposite—a condition not highly surprising even if the two were parts of the same fault. The northward projection of the Hellena vein, if given the dip and strike observed in the Hellena workings, would lie a little east of the Sunday vein; therefore the two cannot be correlated with certainty, and on the geologic map of the district the Hellena fault is therefore discontinued a short distance north of the Continental workings.

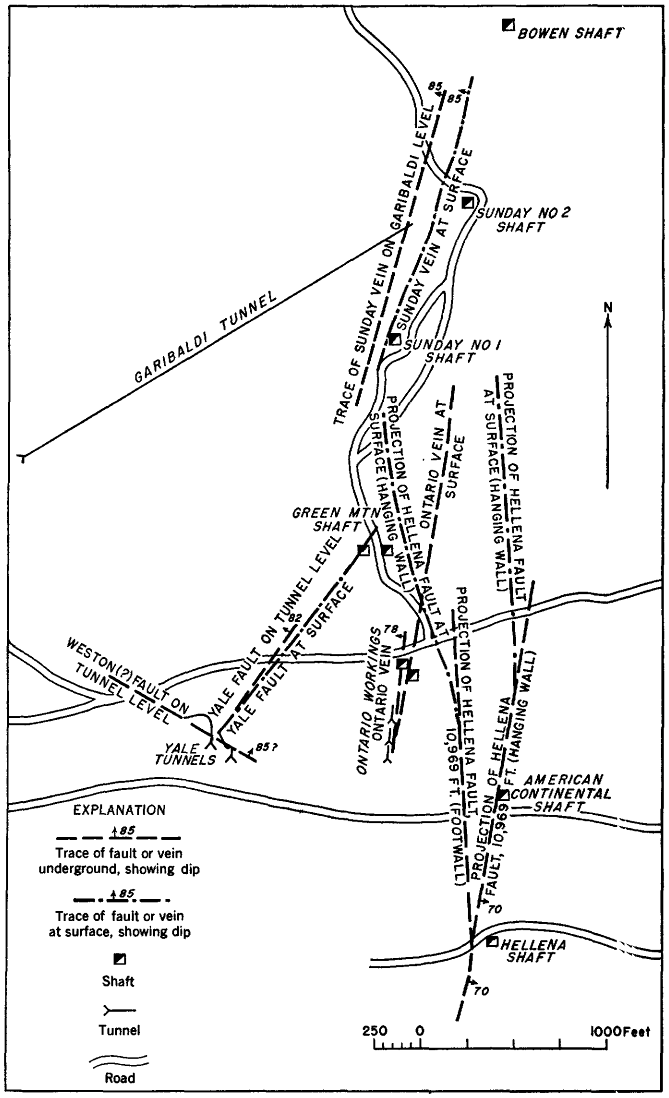

FIGURE 57.—Map showing possible southward extension of the Sunday vein, in relation to Yale fault-fissure, Ontario vein, and Hellena fault.

IOWA FAULT

The Iowa fault was inferred by Emmons as long ago as 1880. This fault has been designated the Iowa Gulch by miners. In the vicinity of Upper Long and Derry Hill the Weber (?) formation and associated sills are exposed at the surface in Iowa Gulch, and the pre-Cambrian is overlain by Cambrian rocks on the slope to the south. This discordance implies the presence of an east-west fault, along which the southern side is greatly lifted. The east-west trend of the postulated fault contrasts with most other faults, which have a northerly strike and are recognized on the slopes bordering Iowa Gulch between the Weston and Ball Mountain faults. There is no fault, gouge, breccia, or other evidence of the fault itself at the surface, however, nor in any of the workings now accessible, and therefore its exact course can only be inferred somewhat vaguely by a study of the dumps of older workings and by rare, thinly scattered outcrops. The fault trace appears to curve southeastward east of the Weston fault and to be offset along the Hellena fault, east of which it trends northeastward before resuming its normal easterly course. The curvature east of the Hellena fault was perhaps induced by an earlier horizontal movement along that fault, or it may have resulted from drag upon the Iowa fault plane as the eastern side of the Hellena fault went down. Though in Iowa Gulch its effect is still recognizable in the block of ground between the western branch of the Ball Mountain fault and the main Ball Mountain fault, there is no evidence of the Iowa fault east of the main Ball Mountain fault.

At its western end the Iowa fault probably unites with the Weston fault. Because the Iowa fault has as much downthrow on its northern side as the Weston fault has on its western side, both faulting the Weber(?) formation against pre-Cambrian granite, the union of the two results in a virtual neutralization of displacement along the Weston fault north of the junction and undoubtedly accounts for the apparent reversal of displacement along the Weston fault from Long and Derry Hill across Iowa Gulch to Printer Boy Hill, as pointed out by Emmons, Irving, and Loughlin (1927, pp. 95–96).

Therefore, it seems that the Iowa fault does not extend east of the Ball Mountain fault. This termination of the Iowa fault at the Ball Mountain fault and the lack of any adjustment between the great displacement on the Iowa fault near the Weston fault to the west on the one hand, and east of the Ball Mountain fault, on the other, are still not adequately explained. Most probably the Iowa fault marks the south end of a large downfaulted block whose western and eastern limits are the Weston and Ball Mountain faults.

FAULTS NORTH OF IOWA GULCH BETWEEN HELLENA AND BALL MOUNTAIN FAULTS

Three north-trending faults are traceable north of Iowa Gulch, in part by breccia and in part by outcrop pattern. They are parallel to the Hellena and Ball Mountain faults. Dikes of Johnson Gulch porphyry lie parallel to these faults as though intruded along related fissures on which little displacement took place. Some prospecting has been done along these faults, but no noteworthy ore bodies have been found; however, the fact that the dikes of Johnson Gulch porphyry occur along the fissures parallel to them implies that they are of premineral age.

BALL MOUNTAIN AND RELATED FAULTS

The Ball Mountain fault as described by Emmons (1886, p. 85) has a curved course across Ball Mountain; north of Ball Mountain it splits into several branches not distinguished from the southern part of the Silent Friend fault. From the Modoc fault southward the total dip slip of the Ball Mountain fault increases from 1,000 to 2,000 ft. Emmons (1886, Atlas sheet 13) mapped the fault as extending southward across Iowa Gulch to intersect the Mosquito fault on the summit of Long and Derry Hill. No new evidence has been found which would greatly modify his mapping of this fault.

The Ball Mountain fault was not mapped north of Ball Mountain in the present study. In the Nevada tunnel two faults intersect, and from their position might be interpreted as branches of the Ball Mountain fault, but their displacements are so slight that they are believed instead to represent branches of the Silent Friend fault (p. 80 and fig. 58). The Ball Mountain fault is inferred to lie southwest of the workings of the Nevada tunnel.

Southeast of the summit of Ball Mountain the geology along the supposed trace of the Ball Mountain fault is complicated. The main Ball Mountain fault extends south-southeast toward Iowa Gulch. East of it are two subparallel faults which can be traced southeastward to their intersection with a transverse fault which trends west-northwest and seems to end westward against the Ball Mountain fault. In the interpretation here adopted the two faults east of the Ball Mountain fault are considered to be subsidiary faults, similar to others that accompany major faults in this region; the fault trending west-northwest is regarded as the South Dyer fault, faulted down west of the Mosquito fault. None of these faults could be studied underground, and none of them is sufficiently well exposed at the surface to permit a close determination of strike and dip. The total dip slip of the Ball Mountain fault is between 900 and 1,250 ft at a point halfway between the crest of Ball Mountain and Iowa Gulch.

A striking feature of the Ball Mountain fault is an intensely altered and silicified breccia formed along a zone in the Johnson Gulch porphyry west of the fault, and extending from the summit of Ball Mountain southward almost to Iowa Gulch. The writer believes the silicification accompanied ore deposition and indicates that the Ball Mountain fault is of premineral age. The fault cuts large bodies of Johnson Gulch porphyry, believed to have closely antedated mineralization, but elsewhere the intrusion of dikes of the porphyry and mineralization closely followed the faulting. For example, on the northern slope of Upper Long and Derry Hill, the main Ball Mountain fault and also two minor accessary faults east of it are occupied by dikes of Johnson Gulch porphyry.

About 1,800 ft north of the stream in Iowa Gulch, a branch of the Ball Mountain fault swings to the southwest and then turns south, parallel to the main fault, with which it reunites on the crest of Upper Long and Derry Hill (sec. B–B′, pl. 2). This branch acts as a step fault, taking up a part of the displacement of the Ball Mountain fault. The branch fault can be recognized on the crest of Upper Long and Derry Hill, where its net dip slip is about 125 ft, whereas that of the main Ball Mountain fault is only about 50 ft and decreases southward.

South of the crest of Long and Derry Hill exposures are few, and accessible openings are absent. It is inferred that here the main Ball Mountain fault and the branch fault meet and farther south join the Mosquito fault.

MOSQUITO-WESTON FAULT COMPLEX SOUTH OF EMPIRE GULCH

From the Empire Reservoir southward the combined Weston and Mosquito faults bring pre-Cambrian granite on the east against shales and grits of the Weber(?) formation on the west, producing a total vertical displacement of at least 1,200 ft. Of this displacement at least 525 ft, and very probably much more, is contributed by the movement along the Weston fault, whereas the

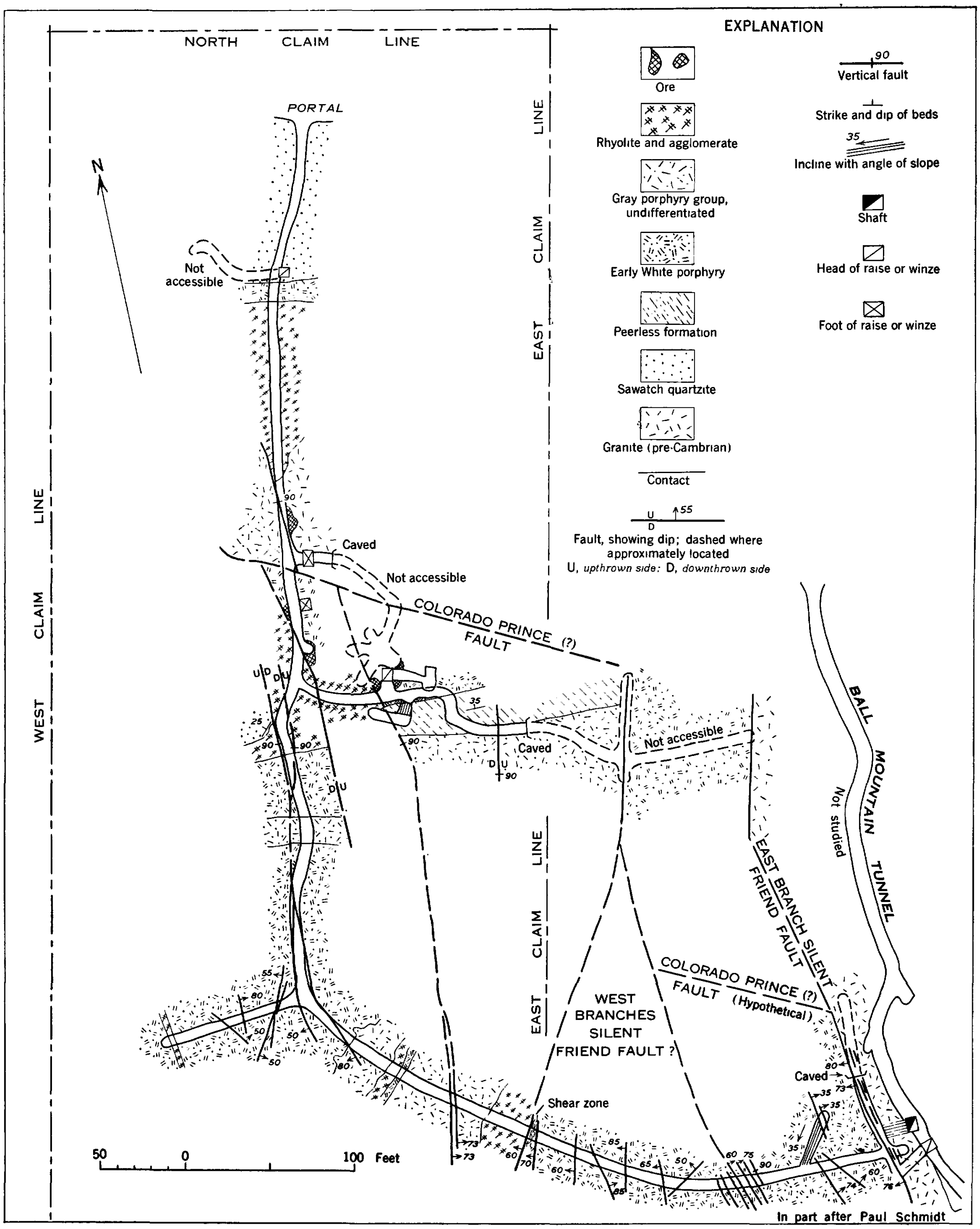

FIGURE 58.—Geologic map of Nevada tunnel (in part after Paul Schmidt).

net vertical displacement along the Mosquito fault can amount to little more than 400 ft and is probably less. It appears therefore that the Weston fault is here the more important of the two major faults.

This faulting locally produced faults accessory and parallel to the main fault. Its effect is shown on the ridge between Finnback Knob and Empire Hill by a quartz-cemented fault in the pre-Cambrian granite 400 ft east of the Mosquito-Weston fault. Another accessory fault brings a wedge of Leadville dolomite between shale of the Weber(?) formation on Empire Hill and the pre-Cambrian granite to the east; locally as much as 20 ft of gouge and breccia fill this fault zone. The beds lying just west of the main fault zone were apparently dragged up strongly so that locally they dip steeply westward (sec. D–D[1], pl. 2).

The Mosquito fault is mineralized farther north (p. 66). On the southern face of Empire Hill copper carbonate stains along the main fault and quartz deposited along the accessory fault in the adjacent pre-Cambrian granite suggest a premineral age for the southern part of the Mosquito fault.

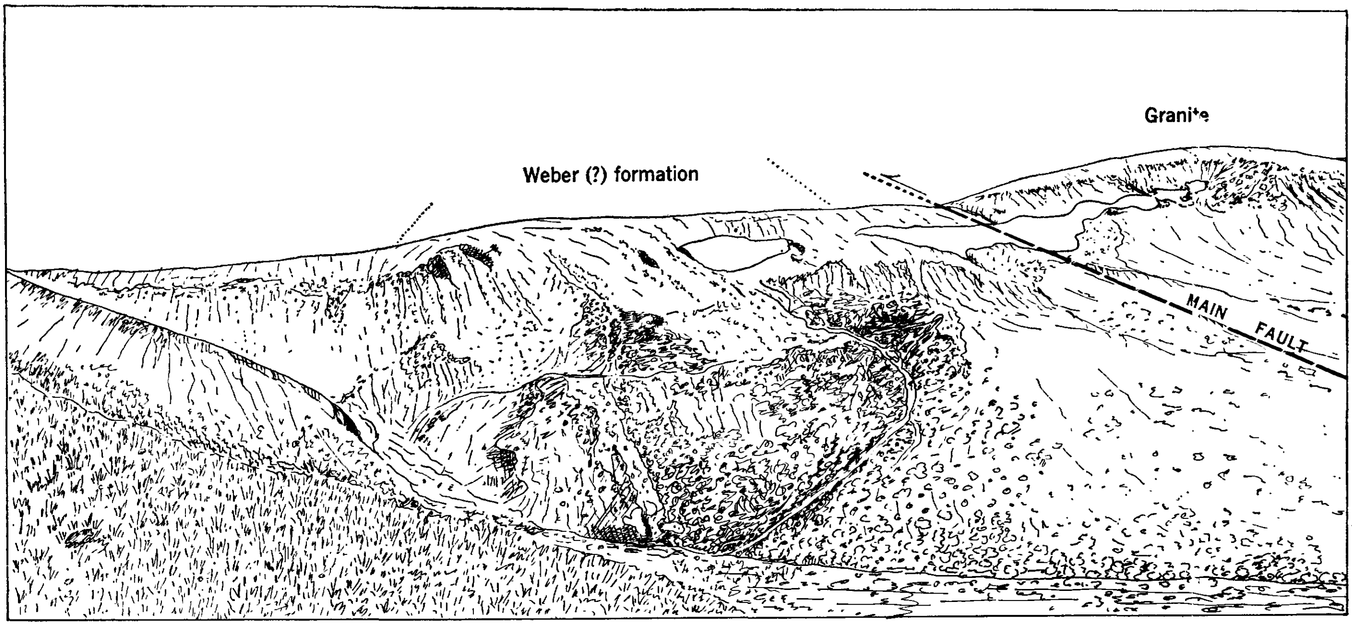

FIGURE 59.—Diagram of chief geologic features, southern face, Empire Hill. Shale beds of the Weber(?) formation show distinctly, dipping first westward (left), then vertically, and (farther east) steeply eastward; part of apparent dip change is due to perspective. Main fault passes through largest snowbank, to east of which massive pre-Cambrian granite may be seen.

FAULTS ON WESTERN SLOPE OF EMPIRE HILL

On the western slope of Empire Hill, at an altitude of 11,750 ft and higher, several minor normal faults trend approximately east-west and offset the Paleozoic beds. The maximum displacement on them is 150 ft; generally it is far less. Their strikes and the fact that no ore has yet been found along them indicate that these are postmineral faults.

FAULTS IN THE CENTRAL PART OF THE LEADVILLE DISTRICT

Certain faults in the Ibex mine and in the Nevada Tunnel in the central part of the Leadville district were studied because of their bearing upon the general structure of the region. A detailed consideration of these faults is given in the descriptions of the two mines.

FAULTS IN THE NEVADA TUNNEL

The Nevada Tunnel is on the south side of South Evans Gulch at an altitude of 11,300 ft, near the south prong of the Ollie Reed pipe of rhyolite agglomerate (pl. 1 and fig. 58). Operators believed that the tunnel intersected the Silent Friend and Colorado Prince faults and perhaps also the Ball Mountain fault. Two branches of the Silent Friend fault have been found in the tunnel workings, and the western of them splits southward into a third branch (fig. 58). In addition, a fault identified as the Colorado Prince fault has been intersected in the Nevada workings. The Ball Mountain fault, however, is inferred to cross the Nevada claim some distance south of where it is shown on plate 13 of Professional Paper 148. Two faults, not named on the map (fig. 58), striking essentially due north and mineralized, were discovered in the western part of this mine. They may be branches of the Ball Mountain fault, which has proved to be of premineral age. Relative age evidence alone is not conclusive, however, and the writer does not consider these faults to be part of the Ball Mountain system, especially as the strikes are more westerly and their displacements too slight.

BOWDEN AND RELATED FAULTS IN THE IBEX MINE

A thrust fault, designated the Bowden thrust after W. E. Bowden, who carried on the development work by which it was discovered, was found on the lowest (12th) level from the No. 2 shaft of the Ibex mine. Pre-Cambrian granite has been raised on the northeast against a sill of early White porphyry that engulfs shale of the Peerless formation. On higher levels the same sill of early White porphyry, here on the northeast, lies against Manitou dolomite. The strike of the fault plane is irregular but averages about N. 50°–55° W. and the dip ranges from 47° to 13° NE. The Bowden fault is offset by normal faults. Subparallel minor thrusts, observed on the 12th, Bott, and 10th levels, strike N. 40°–45° W., and dip 45°–50° NE. (pls. 6–8. and fig. 60).

Like the Tucson-Maid fault, the Bowden thrust apparently passes upward into the bedding plane that separates the Parting quartzite member of the Chaffee from the Manitou dolomite just below the 7th level; up its dip, the fault follows along the southwest limb of the syncline marked in these two units on the 7th level (compare fig. 60). This type of faulting has already been discussed at some length by Emmons,

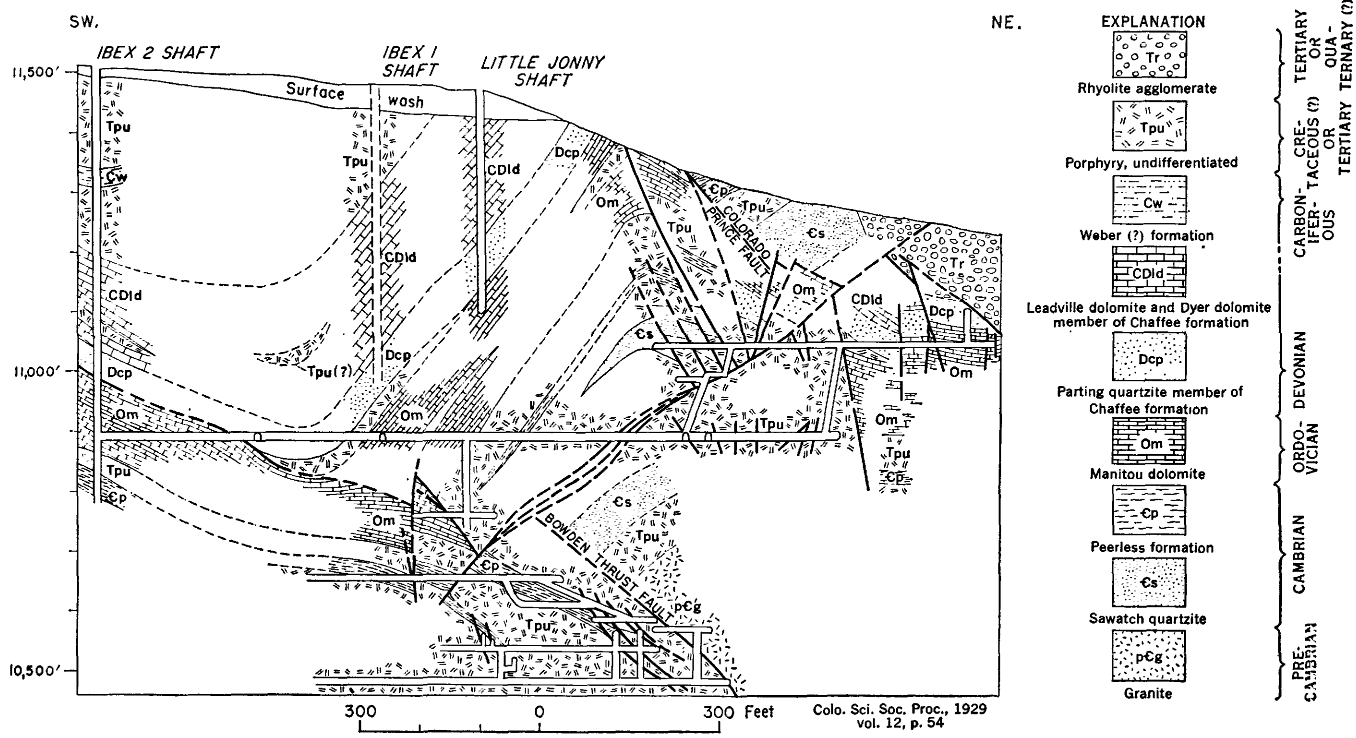

FIGURE 60.—Vertical section N. 25° E. through Ibex No. 2 shaft, showing Bowden thrust fault.

Irving, and Loughlin (1927, pp. 64–65), who cited several examples. Illustrations from other mining districts also are well known (Behre, 1937, pp. 512–529). Such deflections of faults along bedding surfaces are most common at contacts between units markedly dissimilar in rigidity: here the deflection is in the shaly lower layers of the Parting quartzite member of the Chaffee formation and the underlying more rigid beds of Manitou dolomite.

The subsidiary faults associated with the main Bowden thrust are nearly parallel in strike and dip, much like those associated with the Tucson-Maid and South Dyer thrust faults and the steeply dipping Mosquito, Ball Mountain and Liddia faults. As is generally the case, the accessory faults of the Bowden thrust repeat the pattern of the major fault, that is, they have the northeastern side raised in relation to the southwestern one.

CLASSES AND AGES OF FAULTS

Emmons, Irving, and Loughlin (1927, p. 63) recognized four classes of faults:

1. Fissures and local faults caused by the intrusion of sills of the Gray porphyry group.
2. Reverse faults and auxiliary faults and fissures accompanying regional folding, including a few of the main faults of the region, in part affected by earlier reverse and by later normal faults.
3. Normal faults and fissures formed after folding but before ore deposition.
4. Normal faults formed after ore deposition.

The foregoing descriptions of the faults in the Leadville district adduce no evidence that requires changes in this general classification. Some of the faults hitherto regarded as premineral are now known to be postmineral in age and vice versa, but the accuracy with which the ages of faults have been determined in previous studies demonstrates the carefulness of earlier geologists. It need only be added that the first class enumerated above should be extended to include faults produced by the intrusion of early White porphyry. The intrusion of such great masses as the main sill of early White porphyry, which is at least 1,000 ft thick on Mount Sherman, must have been accompanied by considerable movement, doubtless including much faulting. A fault of this type is clearly seen on the southwestern slope of Mount Sherman, where three units of Cambrian quartzite are offset, with a corresponding change in thickness and position of the intruding sill. In this case no continuous fault plane is recognizable, and only that part of the Cambrian beds lying between the two branches of the sill has evidently been broken and displaced; the sill flowed around the ruptured ends so as to form a continuous intrusive body.

The major faults in the region mapped are classified below. Those marked with asterisks (*) are faults of doubtful age or along which movement appears to have taken place during at least two periods, and commonly in such a way that the net displacement is oppositely directed at different points along the fault trace. Faults of the first class, as listed above, are so few and so unimportant economically that no effort has been made to list or describe them.

Premineral reverse faults

Ball Mountain*
Bowden
Colorado Prince
Hellena
Horseshoe Mountain thrusts
Mike*
Mosquito*
Sherman thrusts
Silent Friend
South Dyer
Sunday
Tucson-Maid
Weston*

Premineral normal faults

Big Four
Cord
East Ball Mountain faults*
Fulton
Garbutt
Hill Top
Ibex No. 4
Iowa (Iowa Gulch)*
Long and Derry Hill north-south faults
Mitchell Ranch faults
Modoc
Mount Sherman
Peerless
Printer Boy Hill north-south faults
Resurrection faults
St. Louis
Winnie-Luema

Postmineral normal faults

Adelaide
Cloud City
Dome
Dyer
Empire Hill, west slope, faults
Iron
Liddia
Mikado
Moyer
Pendery
Pilot
Toledo
Union

Many of these faults have been discussed above, and for the remainder the observations and interpretations of Professional Paper 148 remain unchanged. Therefore, a further justification of this classification is unnecessary.

Certain special features are involved in dating movements along the faults. In some cases, such as the Ball Mountain and Peerless faults, the mineralization along the fault consisted only of silicification, a process not clearly identical in nature with ore deposition; this creates doubt as to the dating of the fault with respect to ore deposition. In other examples the date of faulting is obscured by contradictory evidence. A dike of later white porphyry occupies one of the fault fissures crossing East Ball Mountain, but this porphyry is offset by a fault parallel to the dike fissure. But for this evidence, the parallel faults might have been considered contemporaneous, although actually postmineral faulting and dike intrusions of later white porphyry alternated.

It is commonly believed that most of the faulting occurred during the Laramide revolution (that is, in very late Cretaceous or in early Tertiary time) when most of the folding also took place. This agrees with the conclusions concerning regional mineralization in central Colorado (Burbank, 1933, pp. 277–301) that closely related intrusion, folding, premineral faulting, and ore deposition took place as was well established for the Leadville area in Professional Paper 148. Studies on the western slope of the Mosquito Range, have revealed several incidents of intrusion and deformation. Discussion of the position of ore deposition in this sequence is presented only briefly here, being reserved in part for later sections (pp. 108, 109).

As represented on Little Ellen Hill, the intrusion of Lincoln porphyry, apparently contemporaneous with some folding that favored the separation of beds along the bedding planes and thus aided in the formation of extensive sills, was followed by the formation of the Mosquito and subparallel faults at the southeastern end of Little Ellen Hill. Such steep reverse and normal faults are locally the sites of intrusions of Johnson Gulch porphyry (fig. 61), which is thus evidently later than Lincoln porphyry. In places the Johnson Gulch porphyry itself is faulted, as in a small exposure in Iowa Gulch about 2,500 ft west of the Hellena mine.

The faulting near the Hellena mine still further illustrates the complexity in the sequence of events: the Iowa fault is offset by the ore-bearing Hellena fault, although the Hellena fault complex is, as already explained, a branch of the Weston-Mosquito fault complex which follows and breaks across the eastern limb of the Empire syncline.

Finally, on the walls of Iowa Gulch near the Lillian and Doris mines, steep premineral faults, later than

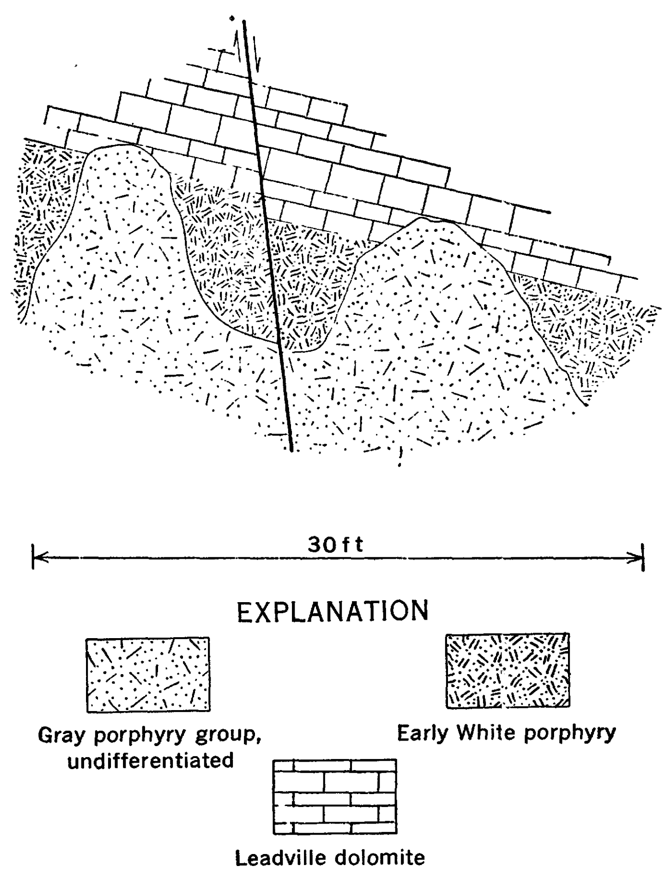

FIGURE 61.—Member of early Gray porphyry group similar to Johnson Gulch porphyry cutting sill of White porphyry and Leadville dolomite; all rocks are cut by a later fault.

the Iowa and probably also later than the Hellena fault, are occupied by dikes of Johnson Gulch porphyry, which thus appears to be the youngest of the porphyries. When all such evidence is pieced together, the following sequence of events on the west slope of the Mosquito Range during the Laramide orogeny is determined:

1. Gentle folding with small-scale faulting.
2. Intrusion of early White porphyry, chiefly as sills with some feeding dikes along fissures developed by (1).
3. Intrusion of older rocks of the Gray porphyry group: Lincoln porphyry, Sacramento porphyry, etc.
4. Thrusting, chiefly from the east or northeast.
5. High-angle reverse faulting (for example, Hellena) offsetting faults of (4) and sills of (2) and (3).
6. Normal faulting with results as in (5) and which may have occurred simultaneously with (5).
7. Intrusion of main Breece Hill plug and perhaps of other poorly defined plugs, and also dikes and small sills of Johnson Gulch porphyry, in part along faults of (6).
8. Contact metamorphism near Breece Hill, bordering accessory plugs and dikes.
9. Ore deposition in veins and "blankets."

As the Laramide revolution in this part of Colorado occurred in two stages (Blackwelder, 1914, p. 647; Stark, Johnson, Behre, and others, 1936, p. 107; 1949, pp. 135–138), events 1 to 4 above probably occurred in the earlier stage and events 5 to 9 in the later one. The only astonishing feature is the close petrographic similarity between the Lincoln and Evans Gulch porphyries of the earlier stage and the Johnson Gulch porphyry of the later one—a resemblance that points to consanguinity.

A postmineral stage of deformation, not included in the table above, occurred in later Tertiary time after a period of quiescence. It was characterized by (1) the development of additional faults, wholly normal and generally with downthrow toward the west; (2) intrusions of late white porphyry and rhyolite, essentially contemporaneous with (1), which gave rise to dikes and to pipes of the rhyolitic agglomerate. Both the intrusions and the faults cut ore bodies. They probably took place in the late Miocene or early Pliocene but field evidence demonstrates only that they occurred after the Laramide revolution and before Pleistocene glaciation.

FUNDAMENTAL CAUSES OF STRUCTURAL FEATURES

In recent years many facts have been added to those upon which Lee (1923, pp. 285–300) based his generalizations regarding the origin of the southern Rocky Mountains. Conspicuous among them are the many thrust and reverse faults discovered by numerous workers in the course of detailed studies in Colorado. A picture of this faulting is furnished by the geologic map of Colorado published in 1935 (Burbank, Lovering, Goddard, and Eckel); a discussion of the structural features shown on the map has been presented by Burbank and Lovering (1933, pp. 277–301). Much that follows is based upon their summary. The ideas earlier expressed by Chamberlin (1919, pp. 145–164, 225–251) and Flint (1924, pp. 410–431) though lacking details also were in general agreement with the facts now available, at least insofar as they apply to the purely tectonic, as distinguished from the physiographic features. These features in generalized form are outlined on plate 9, which is derived chiefly from the geologic map of Colorado.

A study of the faults shown in plate 9 strongly favors the concept of tangential compression in the outer shell of the earth's crust, forming downward-tapering wedge-shaped blocks elongate parallel to the ranges. This interpretation is not opposed by asymmetry in the compression, nor by the possible effect of a geosynclinal subsidence in early Tertiary time east of the present Front Range. Before actual fracturing, compression appears to have caused a bulging expressed in the anticlinoria of the Sawatch and Front Ranges. Continued stress caused fracturing and great thrust faults that bordered the individual structural blocks on the east and west. The faults bounding the eastern escarpment along the Front Range may be regarded as very steep reverse faults, as, in fact, several of them have been previously interpreted. Examples are the faults of the "mineral belt" (Lovering and Goddard, 1938, pp. 38–39), the Ute Pass fault (Finlay, 1916, pp. 11–12 and maps) near Colorado Springs, and the steep reverse faults mapped by Ziegler (1917, pp. 728–731) near Boulder and Golden, where all the accompanying features, such as eastward overturning, wide fracture zones, and wedging of formations in thin bands along the faults (Johnson, 1934, p. 22), are those characteristic of both low-angle and high-angle thrusting. The belt of faulting along the eastern edge of the Colorado Rocky Mountains, however, bears far fewer characteristics of low-angle thrusting than the belt along the western edge of the major ranges of central Colorado. Along the western edge are conspicuous reverse faults, several having gentle dips—the Williams Range fault (Lovering, 1935, p. 47) on the western flank of the Williams River Range, the Elkhorn thrust (Washburn, 1910, p. 307 and pl. 16; Behre, Schwade, and Dreyer, 1935, p. 65) on the western edge of the Front Range in South Park, and the Mosquito fault as here described. There are also numerous other reverse faults, including some low-angle thrusts, described from the region of Aspen, from the Sawatch Range, and from the Elk Mountains (Stark, 1934, pp. 1004–1007; Vanderwilt, 1935, p. 231; Goddard, 1936, pp. 562–564). Others were mapped, though not described in detail, west of Taylor Park and near the southerly end of the Sawatch Range. All of the more noteworthy thrusts in the western ranges, with two exceptions in the Sawatch Range

(Stark, 1934, pp. 1007–1012), raise the east side. The structure of the Sangre de Cristo Range (Burbank and Goddard, 1937, pp. 949–976) is reversed in this respect but may be omitted from consideration here.

Thus, the structure of central Colorado may be pictured as having a vertical section like a wedge, bounded on the east by the steeply westward-dipping reverse or normal faults of the Front Range, on the west by eastward-dipping reverse faults, some steep but others gently dipping or nearly horizontal. Where folds are preserved in the sedimentary rocks the axial planes in general dip in the same directions and at much the same angles as the associated reverse faults. Such major structures were probably caused by tangential compression with the force coming from the east; this might result in fracturing and uplift of the wedge and its "slivers." Uplift would be greater near the central parts than at the edges, but, because of the heterogeneity of the surface rocks, movements would be so irregular within the block that no very regular pattern would result. Folds, under this hypothesis, would be caused (1) partly by the bowing up of the beds in the major geanticline before actual fracturing began, (2) partly, on a smaller scale, as the result of crumpling, and (3) partly, on a still smaller scale, as a consequence of the drag along the reverse faults.

Perhaps intrusive magma would be squeezed up from deeper zones along the reverse faults or associated fractures, invading zones of fracture rather than individual planes of reverse faulting. In its upward movement, the invading magma would find parting planes between beds, such as the shale-limestone contact at the top of the Leadville dolomite, which slippage had rendered especially susceptible to penetration. This would originate the characteristic sills of Leadville, which would also tend to lift the superincumbent beds, yielding such laccolithic masses as the great sills of early White porphyry and Sacramento porphyry of Mount Sherman and Dyer Mountain (fig. 62).

There is one aspect of this orogeny that is not covered in the preceding description. The London fault in the Alma district bears some evidence of horizontal movement, the direction of movement being approximately parallel to the strike of the fault plane. This type of horizontal movement is also indicated along the Mosquito-Weston fault. Evidences of horizontal movement on a still smaller scale are conspicuous along most of the faults of the Continental Chief mine (fig. 83). Possibly much of the movement in the Mosquito Range is of such a sort that its chief component on the northeastern or eastern side of major reverse faults—that is, those trending about N. 20° W. to N. 20° E.—is northwestward or northward. These features suggest tearing rather than simple thrusting. However, the dis-

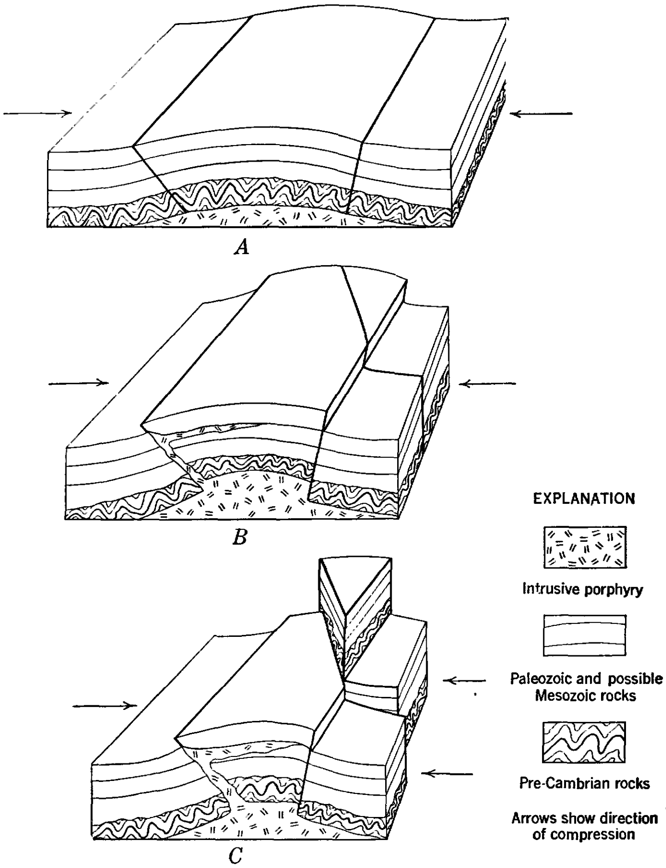

FIGURE 62.—Generalized diagram showing sequence of major tectonic events; view northward: *A.* Typical Laramide upfold; Paleozoic and possible Mesozoic sediments (*Pa–1*) above, pre-Cambrian (*pC*) below; *B,* movement along fractures with flatter thrusts of Mosquito or Sawatch ranges to left (west) and steeper reverse(?) faults of Front Range to right; after lifting, porphyritic magma (*pphy*) is intruded as batholith, dike, and sill; *C,* continued later pressure, greatest in northeastern area, where it yields faulting oblique in strike to other regionally dominant faults.

placements along faults parallel to some of the greater faults, such as the Mosquito fault in Evans Amphitheater, do not seem to accord with this hypothesis in that their eastern side has in places moved southward if the movement is chiefly horizontal; evidence on this point is contradictory and inconclusive, however, as may be seen from a study of the faults east of the Mosquito fault at the north edge of the Evans Amphitheater.

After the compressional movements, all faulting seems to have been normal. Some of the normal faults may represent no more than the reversal of dip toward the surface in faults that at depth were genetically compressional, but whose dip steepened upward, increasing with decreased overburden, as suggested but not clearly urged some time ago by Chamberlin and Miller (1918, pp. 23, 27). Most of the later normal faults that occurred during the Laramide revolution, however, were probably the result of subsidence, which is inferred to have followed intense compression. This explanation may also be best applied to the still later postmineral faults.

LATE CRETACEOUS OR EARLY TERTIARY INTRUSIONS AND THE STRUCTURE OF CENTRAL COLORADO

Attention has been directed to the localization of tectonic lines in central Colorado. Various features have been emphasized by different authors. Crawford (1924, pp. 365–388) assumed a large underlying batholith of early Tertiary quartz monzonite or granodiorite. He sought to show that early Tertiary mineralization was largely confined to regions where cupolas from this batholith approached or reached the present surface. Burbank and Lovering (1933, pp. 289–293) pointed out that these intrusive porphyries are distributed in a belt extending south-southwestward to the Mount Princeton batholith and beyond; mineralization follows the same general trend. This trend (pl. 10) is strong despite the fact that many fractures, including the major thrusts and high-angle reverse faults, trend northwest, and that the major folds and many other faults trend due north. The late Cretaceous or early Tertiary intrusives (for convenience here designated "Laramide") on the western slope of the Mosquito Range near Leadville are no exceptions. The position of the deformed zone of central Colorado and the adjoining region has been attributed by Butler (1929, pp. 33–34) to their peripheral location with respect to the Colorado Plateau; yet this relation should give the intrusive bodies, like the other structural features, a northwesterly rather than a northeasterly trend in central Colorado. Moreover, Butler's hypothesis of simple isostatic sinking does not account for the compression implied by the thrust faults, which are so dominant a structural feature of the region.

The northeastward trend of the belt of Tertiary intrusives seems to be attributable to one or both of two causes. The tectonic map of central Colorado suggests that the intrusives are confined to intersections of great north-south fractures with some moderately conspicuous northeast-trending ones, or to places where the north-trending set of fractures is sharply bent (Burbank and Lovering, 1933, pp. 290, 293). There is more fracturing at such places than elsewhere; if release of pressure is the cause of local melting with the formation and consequent rise of deep interior lavas, the porphyritic intrusives here discussed would appear at the surface in just such areas. If, on the other hand, the cause for the local appearance near or at the present surface is the availability of trunk channels, these also would be best developed where fracturing is extensive. In either case the intersections of northward or northeastward with northwestward fractures would be places favorable for the localization of porphyritic stocks and other intrusive forms.

A second factor that may have localized the "Laramide" intrusives in the northeast-trending belt is crossfolding (Burbank and Lovering, 1933, pp. 290, 293). As is typical for such structures, the great folds of central Colorado plunge at their ends; their highest points structurally are approximately midway along their axes, and these are the places where a potentially molten substratum should stand highest and approach the partly eroded surface most closely. Examples in point are the Twin Lakes and Mount Princeton batholiths, located near the geographic center of the Sawatch uplift. A still more striking example is the localization of the "Laramide" intrusives in the structurally high area separating the North Park and South Park synclines. Further evidence of stresses transverse to the northwest axes and faults are the numerous mineralized northeastward fissures at Leadville.

The northeast-trending belt of the "Laramide" intrusives may, of course, be the result of relative upbowing of the crust by magmatic pressure from below. It must be remembered, however, that a layer of liquid magma is not likely to exert a directional pressure on its own account; more probably it would transmit in the direction of least compression and easiest relief any pressure exerted upon it from the sides, and the direction of easiest relief would be upward and nonlinear in ground plan. In short, the northwest-southeast direction of compression suggested by the northeasterly trend of the porphyry belt is real and is in full accord with the horizontal displacement within and parallel to the planes of the northeast-trending faults, to which attention has already been directed.

SUMMARY OF GEOLOGIC HISTORY

Details presented above regarding the geologic history of the western slope of the Mosquito Range deal separately with the descriptions of its rocks and the more conspicuous structural features. The sequence of these events is summarized below.

The principal geologic events of the pre-Cambrian are but poorly registered in this immediate area. The record apparently begins with the deposition of sediments that were chiefly clastic but in small part calcareous, for limestone beds of pre-Cambrian age are found a few miles northwest of Leadville, on Homestake Mountain. A few flows of basaltic lava alternated with the deposition of sediments. The age of the sediments and associated rocks is believed to be Lower and Middle Huronian. Deposition of these rocks was probably followed or accompanied by intrusion and some deformation.

Deformation was followed by the intrusion of the Pikes Peak (?) granite, in the early part of the Algoman revolution and by the later intrusion of the Silver Plume (?) granite in the late part of the Algoman revolution. These intrusions doubtless caused further metamorphism of the older rocks, including the soaking of schists and gneisses with liquid phases of the two granites which resulted in extensive migmatization (Lovering and Goddard, 1938; pp. 7–17; Stark and

Barnes, 1935, pp. 470–474; Singewald and Butler, 1933, pp. 92–93).

At the close of the pre-Cambrian further deformation, chiefly along northwesterly lines, was followed by a long period of erosion, which resulted essentially in a peneplain. The Late Cambrian sea invaded this ancient land surface and deposited first sandstone and later shaly beds concurrently with progressive reduction in the relief of the surrounding country; these sediments were later compacted into the present Sawatch quartzite below, the Peerless formation above; probably deposition of the Peerless formation continued into earliest Ordovician time. Later, still during early Ordovician time, calcareous sediments were deposited and were eventually dolomitized, forming the Manitou dolomite; the age of this dolomitization is not clear but is believed to have been mainly contemporaneous with deposition. Deposition of the Manitou was succeeded in Black River or Trenton (Middle Ordovician) time by that of clastics yielding the Harding sandstone, which is found at Weston Pass, 10 miles south of Leadville, and farther south (Johnson, 1934, pp. 22–23). The absence at Leadville of the Middle Ordovician Harding sandstone and the Middle and Upper Ordovician Fremont limestone (Johnson, 1934, p. 23), and also the total absence of Silurian rocks points to a local uplift and a prolonged period of erosion extending through Silurian and into Devonian time.

The record of Devonian time begins with the deposition of the Parting quartzite member of the Chaffee formation of Late Devonian age. The Devonian seas were presumably shallow and were bordered at first by low-lying lands (as indicated by the shaly basal facies of the Parting quartzite) and then by uplifted margins. The depth of the sea and the nearness of the shore to the basin in which the Parting quartzite was formed varied greatly from place to place. Then came deepening and clearing of the sea, with the deposition of the Dyer dolomite member of the Chaffee, which, like the Manitou, was dolomitized during or shortly after deposition.

Sedimentation was interrupted by a gentle and uniform uplift in early Mississippian time, for the overlying Leadville is separated from the Dyer by discontinuous beds of sandstone and occasional limestone breccia. In this sea sediments forming the Leadville limestone accumulated either contemporaneously or later altered to dolomite. Conditions changed slightly from time to time during the period of calcareous deposition. Toward the close of this marine invasion the incoming streams deposited much silica, resulting in the conspicuous chert beds.

After Mississippian sedimentation, the sea withdraw while newly uplifted mountains appeared toward the east of the Mosquito Range. The top of the Leadville dolomite was locally eroded by stream channels, with the not uncommon development of sink holes, well exposed in the mines at Gilman, Colo. Later the sea once more rose in the Leadville region and dark shales and a few coal beds were deposited in estuarine environments, indicating swampy terrestrial conditions. After deposition of this fine-grained sediment, the water became shallower near Leadville or the adjacent land rose again; this change resulted in coarser sediments and the deposition of the sandstones and poorly sorted grits in the upper part of the Weber(?) formation. These sediments may very well have been deltaic, as the beds are characterized by channels, plant remains, irregular lenses, and abrupt changes in lithologic character; hence quartzites, grits, shales, and marine dolomitic limestones succeed one another irregularly. Some of the clastic beds were evidently derived from pre-Cambrian outcrops.

Similar sediments, but displaying features indicating aridity (such as red color and gypsum beds), overlie the Weber(?) strata described above. They are designated the Maroon and Lykins formations. They are not present in the immediate Leadville area, though they are found along the valley of the Eagle River 25 miles to the north, and in places at similar distances to the east and west.

Following Permian time, the sea withdrew from the Leadville region, and deposition was succeeded by erosion of unknown degree; Permian sediments were stripped from the Mosquito Range if they ever existed there. Sediments were deposited in early Mesozoic time in South Park and west of the Sawatch Range, but are not known in the Mosquito Range. In Late Cretaceous time, also, sediments were deposited in bordering regions. Whether Cretaceous rocks ever covered the Leadville region is not known, but they are present east of Leadville in South Park, northeast at Dillon and Breckenridge, and to the west of the Sawatch Range near Aspen and Snowmass.

At the close of the Cretaceous period the entire Rocky Mountain region was affected by a series of uplifts, collectively referred to as the Laramide revolution. Two distinct stages of this revolution are recognizable east of the Leadville area in South Park. Probably the first stage is represented at Leadville by several events: folding, intrusion of the early White porphyry and the earlier members of the Gray porphyry group, and, lastly, reverse faulting. This stage was followed by the second stage of deformation, characterized by steeply dipping reverse and normal faulting and intrusion of the Johnson Gulch porphyry (mainly in the form of dikes and plugs), followed perhaps by more normal faulting. Immediately thereafter came ore deposition. All of these events took place in very late Cretaceous and early Tertiary time.

There is no known record of great geologic activity immediately after mineralization; it was a period of widespread erosion whose traces today indicate a peneplain surface having some relief but averaging about 12,000 ft in altitude. Probably it is Middle Tertiary in age and can be correlated with the Rocky Mountain peneplain of some authors. A later uplift, characterized chiefly by vertical faulting, is recorded by the numerous postmineral faults. Contemporaneous with this faulting were the intrusions of later white porphyry dikes, rhyolite plugs and dikes, and (probably) plugs of Little Union quartz latite.

This uplift also caused drainage changes or early glaciation. A series of silt and gravel beds was deposited as the result of ponding by the earliest glaciers, of alluviation at the foot of recently uplifted mountains, or through the filling of fault basins. These benchlike deposits of late Tertiary or early Pleistocene beds are represented by the "lake beds" of Emmons, which began with fine sediments and became coarser upward. Today they constitute terraces composed of moderately well consolidated sediments that in places are as much as 500 ft thick.

The deposition of this material was followed by a climatic change or an uplift. Alluviation gave way to erosion. Two or more distinct periods of mountain glaciation ensued, evidences of which are visible along the minor streams near Leadville and in the Arkansas Valley. The times of glaciation are believed to correspond with the Illinoian stage and early and late Wisconsin stage of the Pleistocene. These glacial conditions resulted in the typical erosional features of mountain glaciation—U-shaped valleys, hanging valleys, cirques, and the like. At the end of Wisconsin glaciation the country had essentially its present appearance. Since the early Tertiary the ores have been oxidized and eroded and gold-placer gravels were deposited.

ORE DEPOSITS

MINERALOGY OF THE ORES

LIMITS OF STUDY

The present report deals primarily with the mineralogy of the ores of the outlying region, beyond the central Leadville district treated in Professional Paper 148. The mineralogy of the central district was very fully discussed in that report. In the marginal region, only a few mines were accessible and little mineral collecting could be accomplished. The following discussion is probably not complete but will afford a basis for comparison with the central part of the district and with similar deposits elsewhere.

BASIS FOR CLASSIFICATION

A classification has been followed that is essentially economic and chemical, and hence most useful to the miner. All minerals that yield the same metal in common metallurgical processes are grouped together, and in the detailed description of the minerals the lead minerals are discussed first, then the zinc minerals, and so on. A classification more in favor among mining geologists is that based on genesis; this is given below in brief tabulated form. According to this classification, based largely on the work of Lindgren (1933, pp. 207–212) and subsequently followed by most mining geologists here and abroad, the formation of minerals in ore deposits is determined largely by the temperatures during deposition; variations in depth and in distance from a magmatic source especially affect the temperatures of the depositing solutions and the pressures under which they lose their mineral content. Certain minerals may be regarded as geologic thermometers, and their temperature of formation may be roughly estimated; their pressure of formation, however, is not so readily subjected to quantitative interpretation. Deposits are classed as contact-metamorphic (pyrometasomatic); deposits formed at high temperature (about 300°–500° C.) and pressure (hypothermal); deposits formed at moderate temperature (about 200°–300° C.) and pressure (mesothermal); and deposits formed at low temperature (50°–200° C.) and pressure (epithermal). In recent years there has been a tendency to subdivide the epithermal deposits still further, recognizing a very shallow origin for some, to which the name telethermal has been applied (Graton, 1933, pp. 193–195). Although it is not possible in all cases to distinguish telethermal from epithermal ores in the marginal region at Leadville an attempt is made in the following pages to apply this distinction. In the table (p. 88) the ore minerals are classified in this way.

CLASSIFICATION BY GENESIS AND DEPTH ZONES

The list on page 88 includes only those minerals that have been observed by the writer or described by others as coming from the marginal part of the Leadville district. Gangue minerals are listed only if they were introduced by the mineralizing solutions; minerals that are a part of the country rock and fortuitously present as inclusions in veins or replacement bodies are not discussed.

PARAGENESIS AND ZONAL ARRANGEMENT OF MINERALS

The paragenesis of the ore and gangue minerals in the marginal parts of the Leadville district is in general closely similar to that of the central Leadville district (Emmons, Irving, and Loughlin, 1927, pp. 211–217). Mineral paragenesis and zoning have been briefly summarized by Loughlin and Behre (1934, p. 223). Figure 63, somewhat modified from Loughlin and Behre, shows the general relations between the various minerals and the different zones. It is more comprehensive than the following discussion, as this concerns only the ores of the marginal districts around Leadville. The dia-

Minerals of peripheral deposits classified as to genesis, alphabetically arranged

	Ore minerals	Gangue minerals
1. Supergene (oxidized zone)	Anglesite Aurichalcite Azurite Calamine Cerargyrite Cerussite Chalcanthite Chrysocolla Goethite Gold (native) Hetaerolite Hydrozincite Jarosite Limonite Malachite Melanterite Molybdite Psilomelane Pyrolusite Sauconite Silver (native) Smithsonite Turgite Wad	Aragonite Calcite Chalcedony Gypsum Kaolinite Quartz
2. Zone of sulphide enrichment	Argentite Chalcocite Covellite Silver (native) (?)	
3. Lowest temperature veins and replacements (telethermal)	Galena Pyrite Sphalerite	Calcite Dolomite Jasperoid Quartz
4. Low temperature veins and replacements (epithermal)	Argentite Chalcopyrite Galena Gold (native) Pyiite Silver (native) Sphalerite	Ankerite Barite Calcite Dolomite Fluorite Quartz Siderite
5. Moderate temperature veins and replacements (mesothermal)	Argentite Arsenopyrite Bismuthinite Chalcopyrite Enargite Galena Gold (native) Hematite Lillianite Proustite Pyrite Silver (native) Sphalerite Tennantite Tetrahedrite	Albite Ankerite Barite Calcite Chalcedony Dolomite Manganosiderite Muscovite (or sericite) Quartz Rhodochrosite Serpentine Siderite Talc

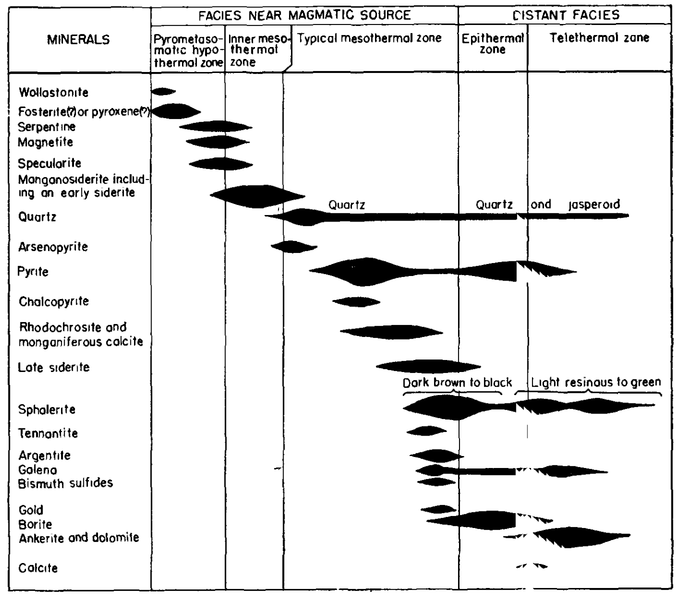

FIGURE 63.—Paragenesis of ores in Leadville district; horizontal lengths of figures show extent of deposition of minerals; closeness of vertical position indicates nearness of period of deposition.

gram shows which minerals appear in each zone, but actually the zones are not as sharply bounded as the diagram suggests, because of complicating structural factors; for example, mineral deposits formed along faults have linear or elongate-elliptical outlines in contrast to those of circular outline formed around a center from which the mineralizing solutions radiated. Besides, mineralization was largely confined to limestones and was virtually lacking in pre-Cambrian rocks; these two types of rocks represent opposite extremes in susceptibility to mineralization. Faulting and erosion have produced very irregular patterns for the limestones and pre-Cambrian rocks, so the ideal symmetry of zoning may be greatly modified or even obliterated by the presence of barren or poorly mineralized pre-Cambrian rocks in the midst of an otherwise normally zoned area. Finally, an outlying magma cupola at depth was apparently a source of the ore for a local and isolated center of a mineralization discordant with zoning as worked out for the central part of the Leadville district.

The chief departures from a simple zonal plan are in the most productive part of the Leadville district (Loughlin and Behre, 1934, pp. 241–242). Thus, along the Tucson fault, about 1¼ miles west of the Breece Hill stock, which overlies the presumptive center of mineralization, the largest bodies of high-temperature manganosiderite are located. An isolated center of mineralization has been found near the Mansfield, Lillian, and First National mines, and the mesothermal ores of this center have the effect of overlapping upon those of the Breece Hill stock to the north and of making an unexpected southward bulge in the mesothermal zone south of the Rex, Mansfield, Brian Boru, and neighboring workings.

Megascopic and microscopic examinations of the ores reveal few exceptions to the sequence indicated in figure 63. The chief exceptions are in the sequence and paragenesis of the sulfides. In the central part of the district sphalerite commonly occurs in masses on which chalcopyrite is deposited, but in the marginal parts of the area (as, for example, in the Hellena mine) the relatively rare chalcopyrite forms inclusions in the sphalerite. In mesothermal ores some galena is coated with crusts of crystalline pyrite or is crossed by minute veinlets of it, reversing the normal order; indeed in prospects in the floor of Evans Gulch, pyrite and galena seem to form a late facies of ore, as compared with an earlier generation of pyrite, from which they are separated in sequence by sphalerite.

Commonly sphalerite is deposited later than galena as veinlets of dark sphalerite, or as crustified veinlets whose central part is also sphalerite. Examples of this inverted sequence are seen in ore from the Lower Ontario tunnel and the First National mine. Some specimens from the First National mine showed two generations of galena, the earlier having almost the texture of steel galena, whereas the latter is coarsely crystalline and well terminated.

Such reversal or inversion of the normal order is assignable to "resurgence" (Spurr, 1923, pp. 288–291). This term is applied where, after the deposition of a series of minerals, a new influx of solutions like the original one repeats a part or all of the sequence. Resurgence may be induced simply by renewed supply of the mineralizing solutions, or by the opening of fresh and wider channelways through which solutions of a given temperature can approach nearer the surface than hitherto because of rapidity of flow; this process is to be especially anticipated at Leadville where, as has been shown, several movements probably took place along a given fault during the period of mineralization. In a region that is barely reached by solutions, because of its remoteness from the mineralizing center, minerals that represent cool, distant facies are deposited first; then, as the magma that furnished the mineralizers approaches nearer the surface and the temperature in this region rises, other minerals typical of higher temperatures may be deposited upon those first formed and the normal sequence is thus reversed. Or, finally, the deposits from several centers may overlap in time so that those of a high temperature but more distant center cut or follow deposits from a nearer but cooler source.

COMPARISON WITH DEPOSITS IN CENTRAL LEADVILLE DISTRICT AND ELSEWHERE

In a general way the Leadville district illustrates the principle of zoning, as developed by Spurr (1923, pp. 253–291), Emmons (1924, pp. 964–997), and Loughlin and Behre (1934, pp. 221–224). In the central part of the district near the Breece Hill plug, the ores were formed by the replacement of limestone. There the ores consist of magnetite and specularite, and small amounts of pyrite, chalcopyrite, galena, and sphalerite; the gangue minerals are serpentine, siderite or manganosiderite, and quartz. Small amounts of wollastonite, epidote, sericite, and quartz also occur here. Emmons, Irving and Loughlin (1927, pp. 147–148) interpreted this assemblage as representing two generations: (1) a group of pyrometasomatic minerals including wollastonite and olivine or an unidentifiable pyroxene, now altered to serpentine; (2) a group of high-temperature (hypothermal) minerals, deposited largely by replacement of earlier minerals of higher temperature and also by metasomatic replacement of the limestone. Small amounts of serpentine in the Altoona workings and near the Mansfield shaft and numerous dikes of Johnson Gulch porphyry in this area suggest that a plug similar to that of Breece Hill, but smaller, may lie not far beneath the surface. The inferred plug is indicated in dashed lines just west of the Mike fault on the map, but heavy cover and extensive hydrothermal alteration of the porphyry that is the surface rock here makes the form and even the existence of the plug uncertain. Its small size would account for the scant distribution of the pyrometasomatic minerals in this area and the meager evidence of hypothermal mineralization.

With the exception of this center of higher temperature and the local occurrence of actinolite in limestone lenses of Weber(?) formation near Lake Isabelle, the ore deposits found in the peripheral parts of the Leadville district are of mesothermal to epithermal aspect. The highly productive manganosiderite–pyrite–sphalerite–galena ores of the central part of the district and the barite–galena–sphalerite ores of the marginal parts, represented in the Hilltop and Continental Chief mines, may be regarded as hot and cool mesothermal facies respectively (Loughlin and Behre, 1934), or as mesothermal and epithermal facies respectively, as now believed by the writer. The following general facts favor the interpretation that the central Leadville mineralization is mainly mesothermal and the marginal mineralization epithermal.

1. A comparison of diagnostic minerals, as listed by Emmons (1942, pp. 51, 63, 71), shows more minerals listed in zone 5 (table, p. 88) that are typical of deposits formed at moderate temperature than at high temperature. When due allowance is made for complications of structural control, the outer (zone 4) of the table on page 88 is evidently epithermal, as it surrounds a mesothermal zone from which it is separated by a relatively barren zone of one half mile or more.

2. Certain minerals in the mesothermal zone (zone 5) are especially characteristic of that or of cooler zones, rather than of hypothermal zones. Outstanding examples are the silver and copper sulfo-salts of antimony and arsenic, proustite, enargite(?), tennantite, and tetrahedrite, and also bismuthinite and barite. Argentite is also present but may be secondary and hence is of doubtful significance.

3. Certain other minerals listed from zone 5 are more typical of epithermal than of mesothermal veins; examples are barite (where present it occurs as the dominant gangue), argentite and native silver. However, because of the scarcity of diagnostic minerals, some of which may even be secondary, this evidence is not conclusive.

4. Chalcopyrite, a mineral characteristic of mesothermal ores, is absent from zone 4. Its absence is conspicuous because its presence elsewhere in the district demonstrates the presence of copper in the mineralizing solutions nearer the source.

5. In the deposits of the outer zone (5) extensive blankets are conspicuously absent, which is suggestive of the effects of solutions weakened by loss of reactive agents and lowering of temperature.

Despite the above contention, there are areas distant from the central Leadville district in which typical mesothermal ores are conspicuous. One such place is the floor of Evans Gulch, near and north of the Best Friend mine, where pyrite is more abundant in the ore than is usual in typical epithermal deposits, such as those of the Continental Chief and Hilltop mines. Another and larger area extends from the Hellena mine and prospects near it, north to Printer Boy Hill, south to the crest of Long and Derry Hill, and westward at least as far as the Rex mine in Iowa Gulch. This distribution of minerals characteristic of higher temperatures, even though they do not represent hypothermal or the more intense mesothermal conditions, lends further support to the inference that a pluglike mass of intrusive rock lies close to the surface near the Mansfield shaft.

The mineral assemblage characterizing the more distant facies of the Leadville district, such as the deposits of the Continental Chief and Hilltop mines, is especially striking. Typical ore of this kind is found in dolomitic limestone and consists of barite in long bladed crystals that have extensively replaced the limestone, and of crystals of galena and sphalerite deposited on the barite in open cavities commonly present. The sphalerite is dark chocolate-brown ("marmatite") to light olive-green or even a honey-yellow; the olive-green variety is most common in this facies. Such ore is said to contain as much as 4 ounces of silver to the ton, but in what form has not been determined. Pyrite and quartz in small amounts may be present. This mineral assemblage, the tabular ore bodies and similar replacement veins (see descriptions of the Continental Chief and Hilltop mines, pp. 135 and 136), the well-crystallized bladed habit of the barite, its position in the mineral sequence before the sulfides, and the exceptionally light color of the sphalerite are sufficiently characteristic to merit the use of a type name for such ores. A convenient term derived from this region is the Sherman type of ore, after Sherman Mountain on or near which several such deposits are located.

Another areal relationship is evident in the marginal part of the Leadville district. Wherever rocks and structures were favorable, ore-forming solutions that traveled still farther from the source apparently formed deposits showing an even simpler mineral assemblage than that of the Sherman type. This is well shown in prospects about a mile south of Mitchell Ranch and better still at the Ruby mine in the Weston Pass mining district, about 10 miles south of Leadville and near the crest of the Mosquito Range. At the Ruby mine the primary ore minerals are disseminated galena, light-colored or dark-brown sphalerite, and small quantities of pyrite; the gangue consists of dolomite, calcite, and crystalline quartz, and white to light bluish-gray jasperoid (Behre, 1932, pp. 56–75). Such ores are generally lean in silver and do not contain barite; indeed, it might be contended that all the gangue minerals are such as might be derived from the country rock by mere solution and redeposition—a process resembling lateral secretion and in which the solutions that brought in the ores served only as transporting media. It is probably significant that deposits conforming to this type are located on or adjacent to bedding planes or to faults essentially parallel to the bedding; such channelways would involve the maximum distances of travel for the mineralizing solutions and a very large amount of cooling, and hence would afford the most favorable opportunity for dissolving and reprecipitating gangue materials from the country rock.

Published descriptions of the deposits of the central part of the Alma district, on the eastern slope of the Mosquito Range about 11 miles east-northeast of Leadville (Singewald and Butler, 1930, pp. 295–308; 1931, pp. 289–406; 1933, pp. 89–131) and of Leadville (Loughlin and others, 1936, pp. 410–441) reveal virtually identical mineral zones at corresponding distances from the apparent mineralizing source if due allowance is made for differences in structural conditions in the two districts. As at Leadville, the Sherman type is definitely recognizable at Alma, and also those types characteristic of the higher-temperature zones.

The individual zones at Leadville as discussed here, and at Alma as described by Singewald and Butler, are recognized in many other districts and further comparisons are not necessary to the purpose of this report. One striking analogy, however, may well be pointed out—the general resemblance in mineralogy between the telethermal deposits at Leadville and the much-debated Mississippi Valley lead and zinc deposits. Even the structural features of the two regions, if attention is concentrated on the immediate neighborhood of the ore deposits, are not highly dissimilar, especially when it is recalled that ore deposition in the Mississippi Valley districts is in many instances strongly controlled by bedding planes as accessory channels and sites of deposition (Fowler and Lyden, 1932, pp. 232–233), whatever the course of the hypothetical trunk channels.

DESCRIPTION OF MINERALS

LEAD MINERALS

Anglesite.—The sulfate of lead ($PbSO_4$) is normally an oxidized product of galena and is common throughout the district though not present in large quantities. Its formation is generally attributed to direct oxidation of galena in place, but an alternate explanation has been offered (Butler, 1913, p. 10). Almost all galena collected from near the surface showed the characteristic gray coating, less than 1/16 in. in thickness, that indicates the oxidation of galena to anglesite in advance of the reaction with CO_2 to form the carbonate; on such material the anglesite is not in visibly crystalline form. Cerussite, the carbonate, usually forms a thicker white border, or successive and banded layers having an aggregate thickness greater than the shell of anglesite, and it is generally chalky or of a translucent milky white hue.

Cerussite.—The carbonate of lead ($PbCO_3$) is an alteration product from the reaction between carbon dioxide (CO_2) of the atmosphere, or that dissolved in the ground waters, and galena or anglesite. Many believed it is formed by the reaction of lead-rich waters and limestone. Characteristically, cerussite appears as coatings on nodules containing inner layers of anglesite and central nuclei of galena. It is found also in a dense siliceous matrix, called "hard carbonate." Commonly it assumes crystalline form where deposited in cracks and vugs, evidently from descending solutions. In the central part of the Leadville district cerussite is a very valuable lead ore (Emmons, 1886, p. 546; Emmons, Irving, and Loughlin, 1927, p. 163) and occurs partly in the crystalline form, partly as massive coating like that described above, but largely as "sand carbonate." The crystalline and "sand carbonate" forms are generally lacking in the marginal parts of the Leadville district. The nearest deposits where these minerals were abundant are those of the Izzard group properties from which much silver-rich carbonate ore was mined. The Peerless mine on Peerless Mountain is also said to have supplied some quantities of "hard carbonate" consisting of cerussite cemented with silica (Emmons, 1886, pp. 533–534). Megascopically crystalline cerussite is more abundant in the central than in the marginal part of the district. In the Mount Sherman area small crystals of it line many of the vugs of cavernous smithsonite described below. Some of the high-level stopes in the Continental Chief and Hilltop mines are also said to have contained rich silver-bearing cerussite, largely coarsely crystalline.

Galena.—Sulfide of lead (PbS) is one of the most widespread primary ore minerals in the Leadville district. Because of the insolubility of its oxidation products, crystals of galena are highly resistant to chemical change even in the zone of strongest oxidation. In many deposits it is the only primary sulfide remaining after a long period of oxidation. Typically the galena occurs in cubes, but in a few places in the mesothermal ore bodies (for example, in the First National mine) twinned forms, suggesting those of Neudorf in the Harz region in Germany (Palache, Berman, and Frondel, 1944, fig. on p. 201), encrust masses of carbonate ore.

Galena in typical cubic crystals is disseminated along the bedding in the limestones of the district forming ill-defined and discontinuous but recognizable bands (fig. 64); this habit is especially characteristic of the ores more distant from their source.

Among sulfide minerals galena is one of the most delicate recorders of stress or deformation. Several features of the galena found in fissures are indicative of postmineral movement. For example, in the Hellena mine steel galena occurs in the Hellena fault fissure. In the same mine some galena was fractured along its cleavage planes, and the fractures were later filled with thin films of quartz. Much galena (for example, that of the Continental Chief mine) shows curved cleavage planes, indicating at least stress and probably renewed movement. Somewhat similar features have been described from the Coeur d'Alene district in Idaho (Waldschmidt, 1925, pp. 583–584), though the crushing there appears to have been more intense. Deformation of

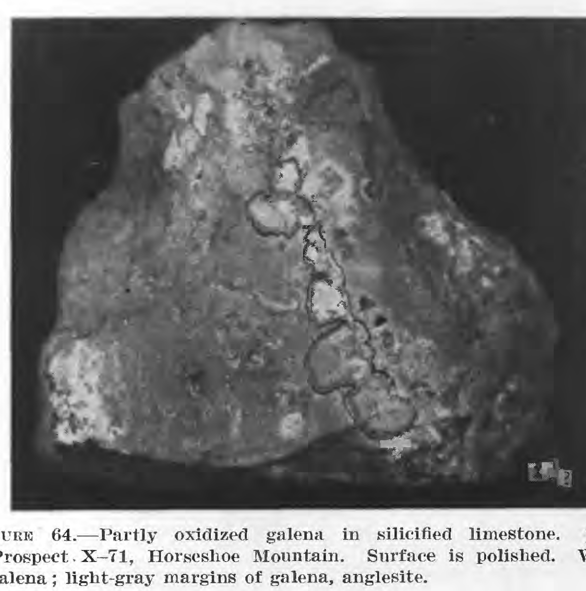

FIGURE 64.—Partly oxidized galena in silicified limestone. × ½ Prospect X–71, Horseshoe Mountain. Surface is polished. White, galena; light-gray margins of galena, anglesite.

this kind usually occurs along twin lamellae or cleavage planes (Schneiderhöhn and Ramdohr, 1931, pp. 249 and 254), but in the ore from the Hellena mine the cleavage planes themselves are deformed.

In some of the shaly beds of the Weber(?) formation, galena as small, poorly formed cubes is intergrown with sphalerite, the two occupying positions similar to metacrysts in a schist. In the Hellena mine, where such relations were observed, the shale has been pushed aside, rather than replaced, for its laminae have been bent around the crystals.

Pyromorphite.—Pyromorphite [$(PbCl)\ Pb_4P_3O_{12}$] is a mineral characteristic of the oxidized zone in lead deposits. Several of the older accounts of mining in Iowa Gulch mention pyromorphite, and the ore of the Waterloo mine in Strayhorse Gulch is said to have contained considerable pyromorphite as shown by recalculation of analyses of "carbonate" ore (Emmons, Irving, and Loughlin, 1927, pp. 164–165). None was observed by the writer in mines or dumps of the marginal part of the Leadville district, however, and it seems to be characteristic of the central area, mainly because of the absence of sources of phosphoric acid in the primary minerals of the outer part.

ZINC MINERALS

Aurichalcite.—Aurichalcite, a basic carbonate of zinc and copper [$2(Zn, Cu)CO_3{\cdot}3(Zn, Cu)OH_2$] is a beautiful light-blue mineral commonly found, at least in small amounts, as radiating fibers near most of the smaller veinlets and replacement deposits on Sherman Mountain and in several of the larger workings. It occurs also in druses or vugs in oxidized zinc ore on some of the dumps of the First National and Julia-Fisk groups. Its composition indicates that it is an oxidation product of zinciferous ores that contain some copper. Probably the copper was present in the primary ore in the form of chalcopyrite microscopically enclosed in sphalerite, as no megascopic chalcopyrite was seen. Observations reported in Professional Paper 148 indicate that aurichalcite is contemporaneous with calamine (the hydrous zinc silicate) but in specimens studied by the writer it appears to be slightly later.

Hemimorphite (Calamine).—Hemimorphite ($H_2Zn_2SiO_5$) occurs in two forms—(1) in typical crystals, generally embedded in gouge or in clayey material of other than tectonic origin, and (2) in porous, bonelike yellow to brown masses (the "dry-bone" of the miners) ranging up to 2 ft in diameter, generally surrounding slightly tarnished galena and sparse barite. Significantly, the crystals are distributed through the rock, as though it were a replacement product; the porous masses seem to be associated with open cavities.

Chalcophanite.—A dark-brown, drusy, botryoidal mineral, suggesting highly oxidized smithsonite but probably chalcophanite, was found in one of the higher stopes north of the incline in the "South workings" of the Continental Chief mine. The formula for chalcophanite is generally given as $(Mn, Zn)O{\cdot}2MnO_2{\cdot}2H_2O$. The mineral seems to be rare in the marginal parts of the district but moderately common in the more highly mineralized areas.

Goslarite.—In the deeper parts of the oxidized zone, the heat or the dryness of the air has locally evaporated the water from solutions of zinc sulfate, yielding goslarite ($ZnSO_4{\cdot}7H_2O$) in long, needlelike crystals, attached most commonly to the walls of old, dry stopes and drifts.

Hydrozincite.—Though observed in only small amounts, hydrozincite ($2ZnCO_3{\cdot}3Zn(OH)_2$) is fairly widespread on the dumps of prospects on the western slope of Mount Sherman. It is a white, chalky soft coating occasionally seen on the surface of smithsonite and commonly associated with aurichalcite.

Smithsonite.—Smithsonite, the common carbonate of zinc ($ZnCO_3$), is abundant in all the oxidized zinc ores of Leadville. A dense variety so closely resembles partly weathered, rusty limestone that it was long used mistakenly for limestone flux. Some smithsonite is lighter in color, approaching white or light yellow. These varieties rarely occur as druses.

In Iowa and Empire Gulches and in the Hilltop and Continental Chief mines, the masses of deeply oxidized zinc ore commonly show an ocher-colored, dense meshwork in which are embedded corroded, shattered, or regularly cubical crystals of galena, still mostly unoxidized. In the midst of these masses is fine-textured, highly honeycombed, much more cavernous ore which is commonly a light olive-gray (fig. 65). This honeycombed ore, like similar masses of hemimorphite, is called "dry bone ore" by the miners. Both the highly honeycombed ore and the more dense surrounding meshwork are varieties of smithsonite. The honeycomb structure is ascribed to preservation of smithsonite that

FIGURE 65.—Oxidized ore consisting of galena (polished, white) and limestone black, crossed by veinlets of gray smithsonite. × ½. Continental Chief mine.

filled cracks in limestone fragments, the limestone itself having been subsequently dissolved, much as has been assumed in the case of the development of boxwork silica (Lindgren, 1900, pp. 170–171, pls. 28, 30). This explanation seems valid, especially if it be assumed that the densest, meshlike parts of the smithsonite represent earlier vein-filling, implying two periods of fracturing and of smithsonite deposition. However, the curvilinear forms of the honeycombed plates do not resemble normal fractures.

Smithsonite is an ore mineral of the greatest importance even in the marginal district; indeed, in the high altitudes of the marginal Leadville region the drainage is excellent and the ground-water table so low that most of the deposits are in the zone of oxidation, and smithsonite is very abundant. The Hilltop mine is said to have produced mostly smithsonite ore. In the Continental Chief mine nearly all zinc has come from smithsonite ore and only the deepest levels contained much sphalerite; here local sphaleritic ores are crossed by smithsonite veinlets.

Sphalerite.—Sphalerite or zinc blende (ZnS) (fig. 66) is the only important primary zinc mineral. The common crystal forms are highly varied. In the mesothermal ores the sphalerite is commonly intergrown with pyrite or with galena, though rarely in such a way as to suggest contemporaneity between galena and pyrite. Generally in such ore the galena and sphalerite are intimately intergrown, suggesting contemporaneous formation, but some pyrite inclusions have been found in sphalerite, oriented as though they had resulted from unmixing. Somewhat rarely, in vugs, the sphalerite crystals are well terminated. Sphalerite of the mesothermal zone is dark-brown to black, with a high, resinous luster and is commonly called "marmatite." Analyses cited by Emmons, Irving, and Loughlin (1927) show a range in iron and manganese content of 12.1 to 17.8 percent; the iron is generally ascribed to the presence of FeS in isomorphous combination with the ZnS, as thin sections show no crystalline iron sulfide.

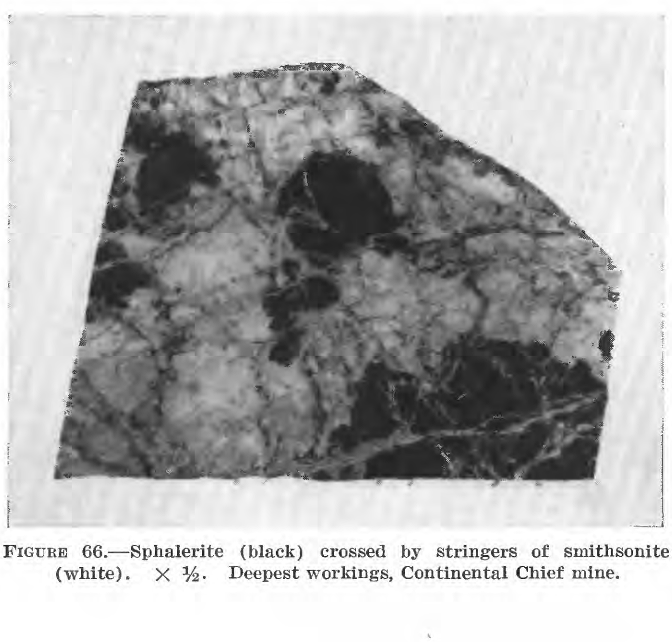

FIGURE 66.—Sphalerite (black) crossed by stringers of smithsonite (white). × ½. Deepest workings, Continental Chief mine.

Near the margins of the district the sphalerite has a quite different appearance. Galena is the only common associate and, as the sphalerite generally lacks the intimate intergrowth with other sulfides seen in the central part of the Leadville district, the crystals are commonly euthedral. Moreover, the sphalerite is generally much lighter in color than the typical marmatite of the central Leadville district; it is for the most part light olive-green. It is transparent in thin-sections, not translucent or nearly opaque as is commonly the case in the darker variety. Whatever the cause of the green color, it is generally retained even after the sphalerite has been converted to smithsonite. Sphalerite of this facies and galena commonly grow upon bladed barite crystals, filling the space between them.

Sauconite (zinciferous clay).—In the intermediate stopes northwest of the new incline of the Continental Chief mine, there is a firm, brownish, banded clay with conchoidal fracture, apparently the end product of hydrothermal alteration and oxidation of the Leadville dolomite. The percentage of zinc present sufficed to induce local prospecting, but zinc content was small and recovery too difficult to yield a profit. For a detailed discussion of the nature and origin of such clays, the reader is referred to Loughlin (1918, pp. 24–28) and Emmons, Irving, and Loughlin (1927, pp. 160–162, 264–270) and to a later article by Ross (1946, pp. 411–424).

COPPER MINERALS

Azurite.—Azurite, the blue basic copper carbonate ($2CuCO_3{\cdot}Cu(OH)_2$), is seen as thin coatings on some baritic lead or zinc ores, such as those found in the Dyer mine on Dyer Mountain and in the smaller workings on Mount Sherman between the Continental Chief mine and Hilltop Pass.

Chalcanthite.—Chalcanthite ($CuSO_4{\cdot}5H_2O$) is rarely seen at Leadville on account of the relatively high humidity in this district as compared with the desert or semiarid climates in which this mineral typically forms. Miners have found it occasionally, however, as stalactites attached to timbers and walls, especially during the winter, the season of lowest humidity inside the mines. It has not been observed by the writer in the course of these studies.

Chalcocite.—Chalcocite (Cu_2S) is commonly a product of secondary sulfide alteration, where chalcopyrite or other copper sulfides are present in the primary ore. Considerable quantities of chalcocite occur in the central part of the Leadville district, especially where primary copper sulfides are important constituents of the ore, but even in the South Ibex (Venir) mine, where copper is not abundant, thin films of sooty chalcocite, called "copper skin" by the miners, are plentiful.

In the marginal parts of the district here described, chalcopyrite and other primary copper minerals are rare, and most of the mining has been carried on in the oxidized zone, so that chalcocite is not commonly seen. A small quantity appeared in ore from the Hellena mine, presumably from the 5th level. It is of no economic importance.

Chalcopyrite.—The scarcity of chalcopyrite ($CuFeS_2$) in ores of both the marginal and the central areas of Leadville is striking, considering the wide variety and the intensity of mineralization. Inclusions of chalcopyrite in sphalerite are fairly widespread, but make up so small a part of the total mass of the ore as to be inconspicuous in most hand specimens. Chalcopyrite in relatively high proportions is found in Swanson's stope and in other ore shoots near it in the Ibex mine; here it is generally in close association with pyrite, occurring partly in definite veins and partly in irregular masses of highly varied size within the pyrite. It is especially conspicuous near the central and larger parts of the stope, as the ratio of zinc to copper increases marginally. Emmons, Irving, and Loughlin (1927, pp. 165–166) stated that generally chalcopyrite is richer in silver than the associated pyrite and that silica (mostly quartz) is the commonly associated gangue. Where chalcopyrite occurs with galena and sphalerite in the outlying areas it is partly older than the sphalerite, but invariably older than the galena.

In the marginal district, the ores here classified as mesothermal contain some chalcopyrite; Mr. E. P. Chapman (Personal communication, 1934) gave it as a conspicuous constituent of the rich ores in Printer Boy Hill. It is inconspicuous in ores of the Hellena mine, and small amounts of it appear with pyrite in the dump of Prospect C–103, south of the Best Friend group in Evans Amphitheater. In such occurrences the chalcopyrite is too intimately intergrown with gangue and other sulfides, especially sphalerite, to have well-terminated crystals. In the still more distant (epithermal) facies, as seen on Sherman, Dyer, and Peerless Mountains, chalcopyrite was nowhere actually found in the ore, but the widespread presence of stains of malachite and azurite point to widely disseminated but low percentages of primary copper minerals, most probably chalcopyrite.

Chrysocolla.—Chrysocolla is a bluish-green, amorphous, hydrous copper silicate ($CuSiO_3{\cdot}2H_2O$), and, like other copper minerals in this area, is widespread but does not occur in large proportions. It is present in oxidized ores, having essentially the same distribution as the copper carbonates, but is less common than malachite.

Covellite.—A bright peacock-blue iridescence found locally on sphalerite, especially in the more central part of the Leadville district, suggests thin coatings of covellite (CuS). This mineral, which is commonly associated with chalcocite, is generally formed during secondary sulfide enrichment—in part, at least, as a first step in the formation of chalcocite.

Enargite.—Enargite (Cu_3AsS_4), a sulfarsenate of copper, has been reported from several of the workings on the north and south sides of Iowa Gulch in the neighborhood of the Hellena mine, but ore found on the dumps showed none, and underground studies in the Hellena mine brought none to light. C. J. Moore (unpub. rept., 1902) recovered small amounts of enargite in the lower Little Troubadour tunnel, but specimens for examination are no longer available.

Malachite.—Malachite is a green mineral, widely distributed in the oxidized ore of the marginal part of the district. It is a close relative of azurite and the two differ mainly in chemical composition and in color; malachite has the formula $CuCO_3{\cdot}Cu(OH)_2$ and is the more highly hydrated and basic of the two common carbonates. In the epithermal ores it commonly appears in tiny botryoidal masses or acicular crystals on blades of barite but it is not present in commercial quantities.

In one of the workings on the Garbutt property malachite formed so rapidly on the floor of a stope and drift that a coating two inches thick accumulated in three years. The source seems to have been oxidized copper sulfate solution. The product is a highly cavernous, bright-green copper carbonate with scattered tiny white areas, evidently representing a kaolinlike compound.

Tennantite and tetrahedrite.—Gray copper ore—tennantite ($Cu_8As_2S_7$) and tetrahedrite ($Cu_8Sb_2S_7$)—has been reported by miners operating in Iowa Gulch or on the slopes to the north and south; the two minerals are so similar that decision as to their presence and their exact identification must await the examination of better material. Tennantite, however, has been definitely identified in ores of the Lillian mine. No sulfo-salts of copper were found in hand specimens or polished sections of any of the other ores from the marginal parts of the Leadville district.

SILVER MINERALS

Alaskite.—The bismuth-bearing mineral alaskite ($Ag_2S{\cdot}PbS{\cdot}Bi_2S_3$) was found in a single specimen (Chapman, 1941, p. 269) from the Lillian mine on Printer Boy Hill, associated with gold that is believed to be secondary. The alaskite is in small residues in nodules of oxidized ore.

Argentite.—Argentite (Ag_2S), found in various districts both as a primary mineral and as the product of secondary sulfide enrichment (Emmons, 1917, pp. 274–275) has been reported by C. J. Moore from the Ella Beeler mine (unpub. rept., 1909). It is probably also present, though not identifiable in the specimens available, in the silver-rich galena and its oxidized products found in the Hellena, First National, Belcher, and other mines of the mesothermal zone, and in the Continental Chief, Hilltop, and similar ore bodies of the marginal, epithermal zone. In such ore, the argentite is probably present as tiny inclusions, though some of the silver, as in other similar districts, may also occur in other forms, such as freibergite or native silver (Finlayson, 1910, p. 727; Singewald and Butler, 1931, p. 405; Sandberg, 1935, p. 501, fig. 6). In the oxidized ore argentite also occurs in small specks in the cerussite (Emmons, Irving, and Loughlin, 1927, p. 167). Its presence as a primary mineral in the marginal parts of the Leadville district is inferred from the high silver content of some of the ore.

Cerargyrite.—Cerargyrite (AgCl) is a product of oxidation. Though seldom very conspicuous, it is widespread at Leadville and accounts for most of the high silver content of oxidized ore. Cerargyrite occurred at the Peerless Maude and Hilltop mines in large quantities. How much of the "horn silver" of the older miners was true cerargyrite (AgCl), and how much was a salt of other halogens, such as bromyrite (AgBr) and iodyrite (AgI), is not known. All the "horn silver" seen by the writer was true cerargyrite.

Many miners designate malachite as "chloride," especially where it occurs as thin films, evidently regarding it as a high-grade silver ore.

Hessite.—Chapman (1941, p. 268) has reported finding hessite (Ag_2Te) in association with bismuth minerals in ore from the Greenback, Tucson, and Louisville mines and in some specimens of doubtful origin. It may be present in the deposits of Printer Boy Hill.

"Lillianite" and related minerals.—The problematic mineral "lillianite" was discussed in detail in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, p. 170), together with the minerals "kobellite," and "schapbachite." These minerals appear to be related both to bismuthinite (Bi_2S_3) and to galena (PbS), and intermediate forms from Leadville have been described by Chapman and Stevens (1933, pp. 680–685; 1941, p. 274) who showed that the "lillianite" of the Lillian and Greenback mines (the latter in the central Leadville district) is really an intergrowth of bismuthinite and argentite. Chapman and Stevens agree with the work of Emmons, Irving, and Loughlin (1927, p. 170) who arrived at a similar conclusion but regarded galena as another admixed ingredient, and mentioned "schapbachite" as having essentially the same composition. Though mineralogically interesting, the "lillianite" and its relatives in the marginal part of the Leadville district are of economic importance only on Printer Boy Hill.

Proustite.—Light ruby silver, proustite (Ag_3AsS_3), is reported from the lower tunnel of the Little Troubadour group. None was found on the dump, and its relation to the associated minerals is not known.

Silver, native.—Native silver in wires and in thin leaflets is reported from several deposits in the marginal parts of the Leadville district. Its common association with fissures in sulfide ores suggests that it was formed by precipitation from solutions as they ascended or descended along bodies of base-metal sulfides. Minute inclusions of silver(?) are found in galena as already indicated above.

GOLD MINERALS

Gold, native.—Native gold was commonly found in many mines located in the central part of the Leadville district. In the marginal parts it generally occurs where bismuth is found (Chapman, 1941, p. 272), notably in the mines of the Lillian group. It appears to coat earlier sulfides, or to occupy their cleavage cracks; rarely it is disseminated, as in the Lillian mines. These relations are similar to those at Gilman, Colo. They seem to indicate that gold, like the silver-bismuth compounds previously referred to, appeared late in the mineral sequence; in fact, Chapman has recognized a bismuth-gold stage very late in the precipitation of the metallic minerals.

Some of the ore once worked on the upper levels of the Hellena mine appears to belong to this stage and to have been very rich in gold, but this is exceptional. In the more distant ore deposits, such as those of Iowa and Empire Amphitheaters, no free gold was recognized in the ores; that which was present was probably in the form of minute inclusions in galena, pyrite, or blende, and remained residually concentrated upon oxidation. Presumably as the result of downward enrichment and transportation in chloride solutions, native gold also occurred in fissures in the pre-Cambrian rocks on the lower slopes of East Ball and West Sheridan Mountains. Placer gold has been worked on a small scale in the outlying parts of the Leadville district, but production has been far less than in California Gulch. The placer deposits derived from Iowa and Empire Gulches have been carried by glacial action to places nearer the axis of the Arkansas Valley.

IRON MINERALS

Goethite and turgite.—Goethite and turgite probably occur in the oxidized zone of all of the deposits, wherever pyrite, siderite, or even dark-colored zinc blende were present among the primary minerals. They are not readily distinguished, but turgite ($2Fe_2O_3{:}H_2O$) is commonly reddish or nearly black, whereas goethite ($Fe_2O_3 \cdot H_2O$) and its near relative limonite (generally written $2Fe_2O_33H_2O$) are generally brownish or yellowish.

The hydrous iron oxides are especially conspicuous in oxidized "contact" or "blanket" deposits. They are also characteristic as a stain on silicified limestone near faults. In some instances they have been transported, presumably in the colloidal state, and occupy tiny fissures in the country rock. They are especially noticeable along small gold veins in the areas of pre-Cambrian rocks.

Hematite.—Hematite (Fe_2O_3) is uncommon at Leadville as an associate of ore except where relatively high-temperature mesothermal, hypothermal, or contact-metamorphic minerals occur; it is especially typical of deposits formed at high temperatures. This is confirmed by the presence of specularite in the contact-metamorphic ores at the Ibex mine, described by Emmons, Irving, and Loughlin (1927, p. 150).

Scattered masses of magnetite and rock containing cloudy aggregates of fine, dusty hematite particles occur in the ground between the Mansfield shaft on the west, the First National shaft on the east, the crest of Printer Boy Hill on the north, and the bottom of Iowa Gulch.

The reddish colors in the oxidized parts of many of the "blanket" deposits are caused by the presence of turgite, rather than of hematite.

Jarosite.—Jarosite ($KFe_3S_2O_{11}·6H_2O$) is reported by Emmons (1886, pp. 549–550) to occur abundantly in an almost continuous layer under the rich ore bodies of Carbonate Hill. In a stope northwest of the incline on an intermediate level of the Continental Chief mine, partly oxidized galena is embedded in material unctuous to the touch, ocherous in color, and composed in part of tiny plates. No analyses were made, but the physical properties of the mineral suggest that it is jarosite.

Limonite.—Limonite, with which goethite and turgite may also be classed loosely, is characteristic of the oxide zone and develops as a result of the oxidation of ore minerals rich in iron. Its presence in large amounts along fissures strongly indicates locally intense mineralization. In regions where the country rock is homogeneous and not stratified, heavy, more or less linear, stains of hydrated iron oxide may be the only indication of fissuring and possible ore deposition.

Locally in the mine workings, hollow stalactites of limonite hang from the walls and timbers. They were formed by descending waters carrying iron from overlying bodies of pyrite, ferruginous sphalerite, or siderite, or possibly even from limonite.

Magnetite.—Magnetite (Fe_3O_4) appears in minor amounts in the area to the east of the Mansfield shaft. Here, like the hematite previously described, it replaces the limestone, forming lenses of dense black rock or crystals in vugs. A few specimens show well-formed octahedral crystals. Magnetite, like hematite, indicates mineral deposition at relatively high temperatures.

Melanterite.—Melanterite ($FeSO_4·7H_2O$) is formed wherever pyrite or other sulfides containing iron become oxidized. It is light-gray, yellowish, or light greenish, and transparent or translucent. Where the air is hot and not humid, it loses its water and dries to a chalky powder.

Pyrite.—Pyrite (FeS_2) is the commonest of the sulfides. It occurs as one of the chief constituents of the ores and in a variety of forms. At Breece and Printer Boy Hills it represents deposition of iron at a temperature below that at which the hematitic and magnetitic bodies were formed. Pyrite is found crustified with other minerals in veins, densely intergrown with galena or sphalerite or both in veins and replacement bodies, and disseminated in limestones, sandstones, quartzites, and porphyries (fig. 69). It is especially plentiful in the basal shales of the Weber(?) formation, in the form of concretions; these concretions, however, are probably of syngenetic, sedimentary origin. Some of the porphyry bodies of the Leadville district were locally so rich in pyrite as to be designated the

FIGURE 67.—A. Typical baritic ore, Canterbury tunnel. × ½.

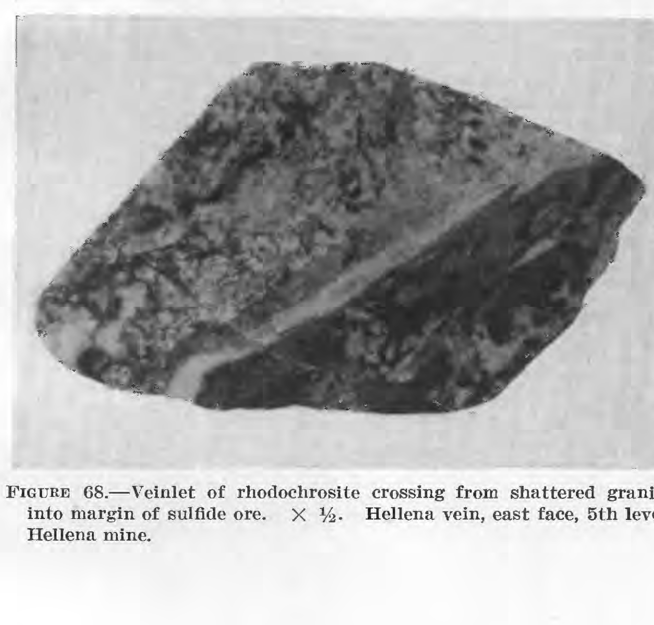

FIGURE 68.—Veinlet of rhodochrosite crossing from shattered granite into margin of sulfide ore. × ½. Hellena vein, east face, 5th level, Hellena mine.

FIGURE 69.—Breccia of White porphyry, cemented and partly replaced by pyrite. × ½. Dump of Julia-Fisk shaft.

"pyritiferous porphyry" and regarded as a distinct rock type in the earlier work of Emmons. In itself the pyrite has no economic value but some gold is believed to be associated with it. Its most common associate among the gangue minerals is quartz.

The pyritohedron is the most commonly observed form where crystals are well formed, though the cube is also common. Leadville is famous among mineralogists for its large, well-formed crystals of pyrite, which during the earlier years of wireless telegraphy sold at a premium because of their use in crystal radio sets. Some pyrite crystals measure 3 or 4 inches on an edge.

In contrast to the widespread occurrence of pyrite, marcasite has not been found in the Leadville district. This is significant, as Allen, Crenshaw, and Johnston (1912, pp. 169–236) have shown that pyrite tends to form from alkaline solutions at higher temperatures whereas marcasite is characteristically crystallized from acid solutions at lower temperatures; even in the deposits of lowest temperature of the greater Leadville region, such as those at Weston Pass (Behre, 1932, pp. 65–66), the rare iron sulfide is found only in the form of pyrite. As various kinds of mineralogic and geologic evidence in this area point to deposition at comparatively low temperature, and as no very complex structures exist, it may reasonably be assumed that the pyrite was deposited from alkaline to neutral rather than from acid solutions. The alkalinity of these solutions was probably maintained by reaction with the large amount of calcium-magnesium carbonate present in much of the sedimentary country rock.

MANGANESE MINERALS

Pyrolusite and psilomelane.—The Leadville district has long been an intermittent source of manganese ores, most of which consist of the minerals psilomelane ($H_4Mn_2O_5$) and pyrolusite (MnO_2), and possibly also the mineral cryptomelane KMn_8O_{16}, the complex formula of which is generalized (Fleischer and Richmond, 1943, pp. 273–274). Most of the output came from the central part of the district, particularly from mines on Carbonate Hill. In the region here described, however, little of either mineral could be identified, though certain bodies on Long and Derry Hill are said to have contained much manganiferous ore (Emmons, 1886, p. 509), including nodular masses of needlelike pyrolusite crystals. Several prospects on Rock Hill near the Nisi Prius were also manganiferous, as were the Florence tunnels, the highest large workings southwest of the crest of Printer Boy Hill, here included as part of the Lillian group.

A small amount of crystalline psilomelane has been found in pre-Cambrian granite between the northern peak of West Sheridan Mountain and Upper Long and Derry Hill.

Wad.—The impure, earthy manganese dioxide wad, is found in at least small amounts almost wherever hydrated iron oxides occur. It is especially conspicuous in the oxidized "blanket" or "contact" deposits.

MINERALS OF THE RARER METALS AND METALLOIDS

Arsenopyrite.—Arsenopyrite (FeAsS) has hitherto been reported from only two mines, the Moyer and Tucson. Considerable arsenopyrite was found, however, on the dump of the First National shaft, together with pyrite, small quantities of chalcopyrite, and manganosiderite. These minerals occur in vugs in a slightly cavernous block of dolomitic Leadville limestone. The arsenopyrite forms euhedral crystals 0.1 in. (2.5 mm) in longest dimensions; the conspicuous striated facies of m(110) yield pseudorhombohedrons with twinning. These crystals are largely intergrown with pyritohedrons of pyrite, and both sulfides are encrusted with manganosiderite. Chapman also has described manganosiderite that is later than arsenopyrite, and recognizes two generations of bismuth minerals, one earlier than the arsenopyrite, the other later.

Arsenopyrite is ordinarily formed at moderate to high temperatures. Its presence in the First National mine suggests that this region is nearer the source of mineralizing solutions than the region to the south and east.

Bismuth-bearing minerals.—Bismuth-bearing minerals have been reported in considerable amounts from several mines in the Leadville district, generally as intergrowths with argentite and galena, and various names have been applied to these intergrowths (Emmons, 1886, pp. 169–170). Chapman (1941, pp. 265–267) has recognized a widespread bismuth stage in mineralization, later in age than the main period of sulfide deposition. The minerals of the "bismuth period" are of economic interest because among them are silver compounds, native silver, tellurides, and native gold. Minerals of the "bismuth period" include the tellurides hessite (Ag_2Te) and altaite (PbTe), tennantite and chalcopyrite, aikinite ($Cu_2S \cdot 2PbS \cdot Bi_2S_3$), and galenobismutite ($PbS \cdot Bi_2S_3$) as the most prominent primary minerals, and argentite and native silver among the supergene derivatives. These minerals are conspicuous in the ore bodies of the Garbutt and other mines on Breece Hill; on the south side of Printer Boy Hill; in the Cord, Whitecap, Louisville, and Tucson mines on Iron Hill; in a drift on the Silent Friend claim east of South Evans Gulch; and in the Greenback mine at Graham Park. Gold is associated with hessite in the Tucson mine.

Although the preceding statements apply to the district as a whole, Chapman (1941, p. 269) devoted special attention to the ores of the Lillian mine, in which he found gold in association with alaskite ($Ag_2S \cdot PbS \cdot Bi_2S_3$), a mineral related to bismuthinite.

Molybdite.—Though the primary mineral, molybdenite (MoS_2), the chief source of molybdenum, has not been found in the Leadville district, its oxidation product molybdite (MoO_3) occurs in most deposits that have been thoroughly oxidized. The molybdite appears as a fine yellow powder commonly associated with galena, suggesting that the primary sources are probably minute inclusions of molybdenite in the galena crystals.

GANGUE MINERALS

Gangue minerals are those which do not yield a useful metal in noteworthy quantities, and also the carbonates of iron and manganese because these minerals are not here worked as sources of metals. There are also numerous other minerals in the rocks of the region. As fragments of such rocks are frequently present as inclusions or "horses" in veins or as relict parts of the original country rock in replacement deposits, they might be regarded as gangue minerals associated with the ores. In the following section, however, only such minerals will be listed as appear to have been formed together with the ore minerals, and are therefore essentially a product of the mineralizing processes.

Albite.—In the alteration of the Iowa Gulch porphyry, some of the feldspar was replaced by a highly sodic plagioclase, probably albite (see p. 56). Albitization was strongest in the greenish-gray alteration facies of the rock. This change appears to be correlated in turn with the mineralization of the district; areally, however, there is no correlation. Locally bodies of mineralized and of albitized rocks overlap, but this coincidence is not conspicuous. This sort of alteration has occurred in all of the porphyries, as already reported by Singewald (1932, pp. 25, 27–29); its results are generally most conspicuous in the groundmass. As albitization was not confined to fracture zones, Singewald regards it as essentially deuteric rather than hydrothermal. The two steps in rock alteration implied by his viewpoint are not sharply separable regionally by field inspection.

Aragonite.—Like calcite, the mineral aragonite has the composition $CaCO_3$. It occurs in some of the veins that appear to be later than those containing ore, but some of it may have been contemporaneous with them. Great blocks made up wholly of acicular crystals of aragonite are found on the western slope of the 12,065-ft knob northwest of Empire Hill, evidently from a nearby but unrecognized fissure.

Barite.—In the ores here classed as epithermal, barite ($BaSO_4$) is the most characteristic and widespread gangue mineral. It fills open veins and occurs in tabular crystals as much as an inch long. In some ore the space between these crystals is occupied by sulfides, commonly galena and sphalerite. Even more characteristic, however, is the tendency for barite to replace limestone in or near ore shoots. In places the feeding fissure is still outlined by the barite crystals; elsewhere it is completely sealed and the barite blades penetrate outward into the limestone in such a way as to destroy the fissure boundaries, yielding a type of replacement that may well be designated "baritization" (figs. 67, 70, 71).

The common association of barite with lead and zinc sulfides is especially characteristic of the epithermal and telethermal groups of ore deposits. Barium sulfide is soluble but barium sulfate is not, suggesting that although the precipitation of barite may be attributed in part to a reduction in temperature and pressure it may also be due to a slight oxidation of the mineralizing solutions. The formation of oxidized (sulfate) minerals in deposits predominantly sulfidic has been discussed at some length in earlier papers and was considered in detail by Butler (1919, pp. 581–609). However, Butler's conclusions may not apply to this area; instead, the oxidation of barium sulfide may have been caused by the admixture of descending cool waters.

Calcite.—Calcite ($CaCO_3$) is one of the widespread gangue minerals in the oxidized ore but is commonly not abundant. Dogtooth spar crystals (scalenohe-

FIGURE 70.—Baritic ore, showing a meshwork of barite blades (white) encrusted with galena (black) and smithsonite (light gray) × ½. Continental Chief mine.

FIGURE 71.—Barite blades disseminated in limestone. × ½. Stope under head of incline, Continental Chief mine.

drons) are most abundant, with some rather sharp-pointed rhombohedrons. Efforts to correlate these crystal forms with different conditions of deposition failed because of the scarcity of well-terminated crystals. Commonly the calcite crystals are found in partly leached masses rich in limonite and manganese dioxide.

A late change in virtually all the porphyries is their impregnation and partial replacement by calcite. As might be expected, this change has especially affected the plagioclase feldspars.

Chalcedony and jasperiod.—Finely granular quartz and cryptocrystalline silica, comprising chalcedony and jasperoid, are alteration products of the groundmass of porphyries in or near some of the ore bodies. Silicification in the calcareous country rocks, especially near the top of the Leadville dolomite, has produced a rock resembling quartzite. The microscope reveals it to be a finely granular quartz-rich rock, containing some cryptocrystalline silica. Such alteration apparently antedated ore deposition slightly, for the ore is found to extend to the siliceous rock and there stop, or it encroaches into the silica on a small scale along tiny cracks. Excellent examples of this type of siliceous barrier against mineralization are seen in the Evelyn mine.

Dolomite.—Dolomite, $(Mg{\cdot}Ca)CO_3$, is a more common gangue mineral than calcite. It is most abundant in the "zebra rock," which is commonly, though not invariably, found in the neighborhood of mineralized masses. The forms most commonly seen are rhombohedrons, which may be distinguished from those of calcite by the curved faces; the calcite effervesces freely in cold dilute acid whereas dolomite effervesces only if the mineral is powdered.

Epidote.—The presence of epidote $(HCa_2(AlFe)_3Si_3O_{13})$, especially as an alteration product of ferric or calcareous minerals, has been noted in the description of the porphyries. It is inconspicuous to the unaided eye, but is easily recognized under the microscope by its light-greenish color. Epidote is generally associated with either calcite or quartz or both. It may be regarded as either a deuteric or a hydrothermal mineral, the evidence resembling that presented by Singewald (1932, p. 23) in his discussion of secondary albite and associated minerals. Probably some of it is hydrothermal and may properly be considered a gangue mineral.

Fluorite.—A few cubes of fluorite (CaF_2) were found at the mine cabin in Miller's adit (Prospect C–91); presumably they had been found underground in one of the local prospects. This is the only report of fluorite from the Leadville district.

Gypsum.—Several miners reported finding small gypsum $(CaSO_4{\cdot}2H_2O)$ crystals in the mines of Iowa Gulch, but the writer was not able to confirm its presence by personal observation. The occurrence of gypsum in the oxidized zone in a region where the country rock is limestone and the ore minerals are sulfides, is not astonishing.

Kaolin or kaolin-like minerals.—Clay minerals are common in the "contact" bodies. Clays are extensively developed as gouge in fault zones, for example, along the Hellena fault. The clays are commonly iron-

FIGURE 72.—Oxidized manganosiderite (dark) in bladed crystals encrusting earlier carbonate (white). × ½. Dump, First National shaft.

stained, and some, as in the Nevada tunnel, contain noteworthy quantities of gold (pp. 62).

Manganosiderite.—Among the carbonates manganosiderite [(Mn.Fe) CO_3] indicates a higher temperature of formation than calcite or dolomite. It has been found in large amounts in ores at Leadville that clearly represent a more intense phase of mineralization than is characteristic of the marginal parts of the district where manganosiderite occurs only in some of the mines east of the Mansfield shaft and north of the Hellena mine, notably the Julia-Fisk and the First National (fig. 72); these mines are where temperatures during ore deposition may have been slightly higher than those in adjacent areas.

In the marginal districts around Leadville, crystallized manganosiderite commonly occurs as pseudo-cubic rhombohedrons and as flat scalenohedrons. Both crystal habits were observed in specimens from the First National and Julia-Fisk shafts but the flat scalenohedrons are somewhat more common and the surfaces of the normally white or light-gray mineral have been slightly oxidized and possess a coating of black, sooty manganese oxide. Large masses replacing the limestones are common in the central part of the district.

Muscovite and sericites.—The difference between muscovite [$(HK_2Al_3(SiO_4)_3)$] and sericite is not chemical or mineralogic but genetic. Sericite is a white mica produced by replacement or dynamic metamorphism, and muscovite, which is chemically identical, is the primary mineral. According to this definition, the rocks of the Leadville district that have undergone alteration contain sericite. The early White porphyry, as already described (p. 43), contains a conspicuous amount of sericite, partly as replacement of orthoclase and plagioclase phenocrysts, and partly as a felty aggregate in the groundmass. The optical properties of this mineral are those of sericite, but are also very much like those of paragonite ($H_2NaAl_3(SiO_4)_3$), and the two cannot be distinguished with certainty. It is observed that the sericite replaces the feldspar phenocrysts selectively, attacking plagioclase more strongly than orthoclase. Although it is not clear to what extent the plagioclase has already been albitized, the strong attack of the sericite on the plagioclase feldspars suggests a preponderance of potash in the earlier stages of the mineralizing solutions.

Quartz.—Quartz is the most widespread and the commonest of all of the gangue minerals. Though present in the deposits here regarded as epithermal, such as the "West Workings" of the Continental Chief mine, it is still more characteristic of mesothermal ores such as those of the Hellena mine. In the mesothermal ores the association of pyrite with quartz is very common; in the epithermal deposits the associated minerals are galena and sphalerite, and rarely barite. Quartz, chalcedony, and jasperoid are also found together in silicified porphyries and sedimentary rocks, especially in the upper beds of the Leadville dolomite.

The forms most commonly observed are prisms, generally long and slender. They are especially well developed in vugs. Crustified veins are singularly rare and comb quartz is therefore inconspicuous. Where quartz replaces the country rock it occurs in densely packed anhedral grains. Quartz in this form occurs in the Leadville dolomite and in one type of altered early White porphyry. A similar form is not uncommon in some of the cerussite ore, yielding "hard carbonate," which may contain as much as 20 percent lead; such ore was produced in the Peerless Maude mine.

Rhodochrosite.—Rhodochrosite ($MnCO_3$) is apparently similar to manganosiderite in genesis but seems to form at somewhat lower temperature. It is readily distinguished from the white or light-gray manganosiderite by its pink color. Emmons, Irving and Loughlin (1927, p. 176) reported the presence of rhodochrosite in a few of the mines of the central Leadville district, in the Mammoth mine in Evans Gulch, and in workings of the Ella Beeler and Clear Grit groups in Iowa Gulch (Singewald, 1932, p. 176). A discontinuous but well-marked vein of it was found in the Hellena workings on the third level. The largest body of rhodochrosite lay in the gouge of the Hellena fault, some distance away from the other vein minerals, so that its paragenetic relations could not be determined. The fracture that it filled was crustified. Elsewhere a thin seam of it bordered an irregular veinlet of blende and pyrite (fig. 68), suggesting that the rhodochrosite antedated the sulfides. In the absence of distinct crustification, the possibility must be recognized that the vein matter was torn from the wall of the fissure, and this marginal opening, formed subsequent to sulfide deposition, was then filled with rhodochrosite.

Rhodonite.—Rhodonite ($MnSiO_4$) has been reported from only one mine, the Ella Beeler, where it is described as having formed narrow parallel bands alternating with other minerals (Emmons, Irving, and Loughlin, 1927, p. 173). The mineral is commonly formed at considerably higher temperatures than generally prevailed during mineralization.

Serpentine.—A small quantity of serpentine, mostly opaque white but ranging to very light gray, occurs in the upper working of the Altoona adit. Magnetite, which occurs in association with the serpentine of the Penn mine and the old Breece iron mine, is not present in the upper Altoona workings in the immediate neighborhood of the altered dolomite (Emmons, Irving, and Loughlin, 1927, pp. 173–174). In prospects to the east and northeast of the Altoona adit, however, more highly silicified rock is associated with magnetite and cloudy aggregates of hematite.

Siderite.—Siderite ($FeCO_3$) was not identified in any of the deposits in the marginal parts of the Leadville district. Mineralogically it closely resembles dolomite, manganosiderite, and ankerite; as dolomite is widespread, siderite may possibly have been mistaken for it. Dolomitelike material (possibly ankerite) was found in the Hellena mine, stained yellowish-brown, as though it contained some ferrous iron which, upon oxidation and hydration, was converted to limonite. In this locality the mineral is not in contact with the sulfide ore, and hence its paragenetic relations could not be established.

FORMS OF ORE DEPOSITS

The ore deposits of the marginal parts of the Leadville district resemble those in the central part, except that the irregular masses of the contact-metamorphic facies described by Emmons, Irving, and Loughlin (1927, p. 177) are missing. The marginal ore bodies occur in two dominant forms—replacements of the "blanket" type, and fissure fillings.

REPLACEMENT DEPOSITS OF THE BLANKET TYPE

Replacement deposits generally are parallel to the bedding and thus tend to be tabular ore bodies having two long and one short dimension; hence they are called "blankets." They are most common at the contact of different kinds of rocks—a limestone and quartzite, or a sedimentary rock and a porphyry sill. Because of this juxtaposition of two kinds of rock, deposits of this category are often called "contact" ore bodies; it should be noted, however, that the use of this term does not connote that one of the rock-types involved is igneous.

Blankets or "contact" ore bodies are commonly flat above, as though a rising solution had been impeded or "ponded" by an impermeable barrier. These deposits taper downward to a point in vertical section; commonly their lowest projections follow fissures that appear to be the channels along which the ore-forming solutions traveled. In dimensions they vary greatly; those of the marginal parts of the district are smaller both vertically and horizontally than those of the central part. Some of the individual stoped blankets in the Continental Chief mine were 200 by 50 ft in plan and 12 ft high; in the same mine the Ice Palace stope is 220 by 105 ft in plan with a maximum height of 37 ft. These are two of the largest stopes of the marginal districts around Leadville which were accessible at the time of the field work, but some of the stopes of the Hilltop mine were even larger. In the Continental Chief and Liddia mines the caprock is a dark-gray shale that lies between the Leadville dolomite and the sill of early White porphyry. In some of the smaller prospects south of the Mitchell Ranch the ponding body is a quartzite layer at the top of the Leadville dolomite. Rarely, the blanket is in the Manitou dolomite, and in that position sills of Parting quartzite are the common ponding body. By far the most common caprock, however, is the sill of early White porphyry just above the Leadville dolomite.

FISSURE FILLINGS AND ASSOCIATED REPLACEMENT VEINS

Typical fissure veins may be developed in any kind of rock, if only the fracture gapes enough to admit the ore. Such ore bodies vary greatly in their dimensions. Commonly a fissure vein is marked by discontinuous ore shoots following an unpredictable pattern that is dependent on many factors. As is well known, the walls of a fault having a zigzag pattern involving two different directions in ground plan or vertical section may, after movement has taken place, match closely where the course of the fault follows one direction but gape widely in the other. This condition yields alternate wide open stretches and narrow tight stretches; in such faults, the ore shoots are generally confined to the wide sections.

Fissure veins are not limited to faults of large displacement. Indeed, at Leadville, wherever most faults of large displacement are of compressional origin and especially wherever they have relatively low dips, these fissures are generally the tightest and least productive of the premineral openings. On the contrary, related but smaller fissures are of greater economic importance. The relatively small number of low-angle reverse faults are of interest largely because their presence serves as a clue for favorable localities. Mineralization seems to be more extensive where the dip steepens on such veins.

Although vein deposits are typically fissure fillings, at least a moderate amount of replacement takes place at the borders of many fissures, even in the marginal districts around Leadville. There are good examples in the larger stopes of the Continental Chief mine. In the central Leadville district replacement fissures grade into replacement bodies of the blanket type. Such features are discussed in more detail below.

Dimensions of lodes in fissure and associated replacement veins vary greatly. The Hellena vein has been mined from the Hellena shaft at mine levels to a depth of 800 ft, and for a distance of 600 ft along the strike of the vein in this mine alone. If it is an extension of the vein worked in the Green Mountain and Sunday mines, its horizontal dimension is at least 4,000 ft, but it is not uniformly mineralized. Mineralized ground is less extensive along the main Mosquito fault in the Best Friend and adjacent workings; there it is 1,000 to 1,200 ft in length and has a known depth of about 800 ft. This size is more typical for the fissure veins than is the great Hellena vein.

TRANSITIONAL FORMS

The "contact" or "blanket" deposits are believed to have been formed by solutions fed from below (pp. 109–110), so it is natural that the feeding fissure should end against any contact, at least locally. In many places the original channel has been obliterated by subsequent mineralization; where it has not, as in some of the mines of the central district, the original fissure can still be traced across the main blanket ore body. The vein differs mineralogically as well as structurally from the associated blanket, generally containing ore richer in precious metals, as though precipitation of these metals had been the last stage in fissure filling and had resulted from interaction between the precious-metal solutions and the base-metal sulfides making up the blanket. Such ore bodies are thus a combination of fissure filling and blanketlike replacements.

Many of the fissure veins are bordered by replacement bodies of such extent that replacement rather than fissure filling was clearly the dominant mode of origin of the deposit. This is more particularly true if the rock traversed is a limestone or dolomite that is readily replaced. In such rock "selective replacement" has commonly been operative, some beds having been extensively replaced whereas beds above and below were less so. The vein then is bordered on one or both sides by small blankets at one or several horizons, but commonly the extent of a steeply inclined tabular ore body is along the vein itself. (See Continental Chief mine, p. 136, figs. 86, 87.)

In many ore bodies the longest dimension is clearly outlined by the vein, but the width and thickness differ with the degree to which wallrock has been replaced. For example, the main ore body of the Hilltop mine was stoped almost continuously for a distance of 1,450 ft; but it averages only 30 ft in width and thus was obviously determined by a fissure. The width of the fissure, however, is not regular; the fissure was swollen here and contracted there. Moreover, the upper surface of the deposit, like that of most "contact" deposits, was capped by a sill of early White porphyry or a basal quartzite bed of the Weber(?) formation. The ore body was thus intermediate between a true "contact" deposit and a fissure vein. Several of the smaller mines also exhibit this pattern in their stopes.

TEXTURE AND FINER STRUCTURE

In a general way a primary ore in the marginal parts of the Leadville district may be classified under one of five heads: (1) densely granular replacement ores, (2) lean replacement ores, (3) coarsely crystalline replacement ores, (4) breccia ores, and (5) crustified fissure ores.

Densely granular ores contain sulfides in most concentrated form. These ores occur in rich replacement bodies and in vein fillings. A conspicuous mineral in ores of this type is pyrite, but dark-colored blende, and finely granular but cubical galena are also present. The average grain diameter is only about 1/25 in. (1 mm), and the minerals are so closely interlocked, and even intergrown, that fine grinding would be necessary to obtain zinc and lead concentrates from this type of ore. Some of the sphalerite grains enclose minute blebs and grains of chalcopyrite too small in size and quantity to be separated. Finely granular quartz may be present in large percentages and greatly dilute the sulfides.

Most lean replacement ores are not generally worked. They are well represented in some of the lower levels of the Ibex mine, where sphalerite has replaced shale of the Peerless formation. Commonly ores of this type contain a larger proportion of zinc blende, in comparison with the other sulfides present, than do the densely granular ores. The grains of blende are disseminated through the rock in small, irregular masses and in separate crystals averaging about 1/10 in. (2.5 mm). Lean replacement ores tend to be monomineralic: pyrite tends to occur in the Parting quartzite or in Cambrian sandstone, the blende or galena in the various limestones. Ores of this kind require less crushing in order to free the desired sulfides and are generally amenable to tabling (or other forms of gravity separation, as distinguished from flotation) because intergrowths between minerals are less intimate.

Coarsely crystalline replacement ores are characterized by bladed barite, galena, and zinc blende, and rarely pyrite. Mineral grains are all fairly large, with minimum sizes for the sulfides of approximately 0.5 in. (12.5 mm) in most localities; these figures do not apply, however, to the oxidized minerals derived from the primary ores. Intergrowth is negligible and gravity separation without fine crushing is possible for much of the ore. Such ore occurs only in limestone or dolomite.

Typical breccia ore occurs in the Hellena fault in the Hellena mine. Fragments of the country rock are embedded in dense, finely crystalline ore composed of intimately intergrown lead and zinc sulfides, and rich in pyrite (fig. 73). Many cubes of galena in the Hellena ore are almost 1 in. (25 mm) in diameter, but most of the sulfide grains are much smaller. Pyrite and

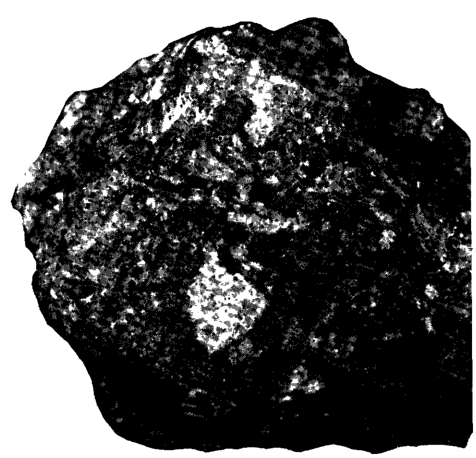

FIGURE 73.—Breccia ore from Hellena vein. × ½. From 4th level, Hellena mine. Fragments are altered porphyry embedded in mixed sulfides.

zinc blende may be present in large proportions. Milling is made difficult by the fineness and intergrowth of the sulfide grains, and by the abundance of quartz.

Crustified fissure ore consists of quartz, dolomite, rhodochrosite, and other gangue minerals, associated with any of the three common base-metal sulfides. Commonly, the veins are so small that selective stoping or underground cobbing cannot be applied to eliminate the waste before hoisting. Most fissure veins at Leadville are bordered by noteworthy replacement zones across which the ore becomes more pyritic and finegrained; beyond this rather densely pyritic zone the sulfide content becomes progressively less and finally disappears. Such ores commonly have the highest content of precious metals, and generally also of copper, in or very close to the fissure vein.

ORIGIN OF THE PRIMARY ORE

Emmons, Irving and Loughlin (1927, pp. 209–219) presented a careful outline of the origin of the ore. They discussed the deposits in the outlying areas to the extent warranted by the scant evidence available to them. The present report considers the origin of these outlying deposits more thoroughly, and summarizes the discussion of these earlier authors.

In Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 562–584) Emmons modified his views concerning the source and direction of movement of the mineralizing solutions. As a result of his earliest work at Leadville, Emmons thought that the ores are essentially the products of lateral secretion—that they were dissolved by circulating (probably descending) waters from the adjacent country-rocks, especially the porphyries, and deposited at favorable places. Emmons maintained (1) that the primary ores were chiefly sulfides, (2) that they were formed mainly by replacement of the country rock, rather than by cavity filling, and (3) that they were derived, at least in large part, from the adjacent porphyries. This theory was based on (1) the finding of at least minute quantities of the elements and minerals making up the ore and gangue in virtually all the rocks of the region (suggesting that these rocks might have been the source of the ore); (2) the absence of evidence (for lack of deeper workings) that the ore extended to great depths or appeared especially along channels that might be presumed to extend very deeply (an observation that seemed to favor a connection of ore genesis with near-surface agencies); and (3) the great extent of "contact" ore bodies, resulting in an overemphasis upon their genetic significance and a failure to recognize the importance of veins or ore channels along which the ore minerals were transmitted to the "contacts."

Later studies led Emmons and Irving to a complete change from the earlier ideas. The account given in Professional Paper 148, a further revision by Loughlin, is thus in full accord with the modern concepts of the genesis of ores of this general type. According to these ideas, the ore-forming solutions moved outward, in part perhaps from local deeper centers, but chiefly from the Breece Hill plug (now recognized as composed of Johnson Gulch porphyry, the latest member of the Gray porphyry group). Temperatures were high, and solutions or gaseous emanations were active in this plug and immediately adjacent to it. Here were deposited the ores formed under contact-metamorphic conditions, or at least at temperatures high in the ranges within which veins and replacements form. Farther out from the plug, the temperatures of the ore-forming solutions were lower, and in this region the higher ranges of mesothermal (moderate temperature) conditions prevailed. The ores here were sulfides, sulfo-salts, and certain high-temperature carbonates, in particular manganosiderite. Locally, where the fractures remained open to especially great depths, the solutions had relatively easy and rapid passage from the depths where they originated to the zone of deposition. In such open channels the gradient for a given length of channelway was less abrupt and conditions of deposition approximated those nearer the Breece Hill plug, despite greater distance from the source of the solution. Trunk channels of this deep type were in the broken ground along reverse faults, such as the Tucson-Maid, and some of the normal faults, such as those of the Garbutt and Winnie-Luema systems. Structural features still further modifying this relatively simple pattern are discussed on page 107.

Still farther away from places where the high mesothermal conditions prevailed, the solutions had been cooled even more and typical mesothermal ores were deposited; this is the stage represented in Iowa Gulch near the Hellena, Lillian, Ella Beeler, Mansfield, and Rex properties, and also along the northern edge of the area mapped—north and east of the Chicago Boy property, and in the floor of Evans Amphitheater.

At still greater distances from the Breece Hill center the ore and gangue minerals are those characteristic of epithermal (low-temperature) conditions, as recognized today by geologists. The solutions yielded deposits of lead, zinc, and iron sulfides, with silver (probably in the form of primary argentite and possibly of native silver) with a gangue of carbonates and barite.

At distances ranging from 3 to 10 miles from Breece Hill, ores of the coolest or telethermal zone are present, such as those of the Ruby mine at Weston Pass and several prospects west of Empire Hill. In these ores silver content is relatively low, pyrite is rare, and barite is lacking.

The relatively open channels mentioned, notably along the Tucson-Maid fault, resulted in the deposition of certain minerals farther from the source than might have been expected. Although the temperatures indicated are not generally as high and the mineralization not as intense as along the Tucson-Maid fault, a similar effect was produced around the intrusive plug near the Mansfield and Rex shafts, and it may be inferred that this small plug is related to a local center of rather intense mineralization from which the ores of the First National, Julia-Fisk, Hellena, Lillian, and Rex mines were derived. Thus, at least two probable centers of high-temperature mineralization are recognized in the Leadville district, and the picture becomes more complicated than the idealized picture of the regularly circular and concentric zoning.

The zoning pattern seems to point to sources of mineralization geographically near and probably beneath the large Breece Hill plug and the smaller plug near the Mansfield mine; possibly, also, to a third source beneath the general area of the First National mine (pp. 144–145). This idea—that the ore-depositing solutions at Leadville rose from deep sources from which the intrusives of the Gray porphyry group were also derived—was first urged by Blow (1890, pp. 173–181) as the result of careful analysis of the facts observed in the Iron Hill area; it was accepted in large part by Emmons and Irving (1907, pp. 60–72), then engaged in a restudy of the district.

The studies here reported have demonstrated an age sequence for the intrusives of the Gray porphyry group, in which the latest is the Johnson Gulch porphyry. This porphyry is the only one among the Gray porphyry group that appears largely as dikes, and is also the type constituting the two stocks mentioned above. Advance toward the surface by stocks of fair-sized horizontal cross-section involves considerable upthrusting and probably some stoping and assimilation of the country rock (Barrell, 1907, pp. 152, 156–157). This statement is not intended to face the much-discussed question whether the quantity of assimilated material is sufficient to change the composition of the intruding magma, as some have maintained (Grout, 1932, pp. 224–230), but merely to accept the most reasonable solution of the mechanical problem of making room for the advancing magma. Transgressive porphyry stocks of the Johnson Gulch type are manifestly more directly connected with deep magma reservoirs than the sills, which form so much more conspicuous a part of the total of the "Laramide" intrusions. Moreover, the stocks and dikes were intruded at a time much closer to that of ore deposition than the sills. The mineralizing solutions are believed to have been derived at depth from the same source as the Johnson Gulch porphyry.

The physical and chemical nature of the solutions from which the ores were deposited is of interest. The exact temperature of the solutions cannot be ascertained, but may be inferred from two lines of evidence. The temperatures of deposition of mineralogically similar ores may with reason be assumed as having the same general range. By an ingenious method, Newhouse (1933, p. 748) has shown that the lead-zinc-carbonate or lead-zinc-barite veins of Henry County, Kentucky, were formed at 70°–95° C.; those of the similar lead-zinc deposits of southwestern Wisconsin at 80°–105° C.; and those of the lead-zinc-carbonate-barite deposits of the Joplin district, in Missouri, at about 90°–135° C. The similar epithermal ores of the Leadville district were probably formed at temperatures of the same range.

Criteria for inferring the chemical nature of the mineralizing solutions are far better than those suggesting temperature of deposition. Questions regarding the chemistry of these solutions have long been debated. Bowen (1933, p. 119) argues for the presence in predominant quantities of HCl, HF, H_2S, CO_2, H_3BO_3, H_2SO_4 and other acids or their related ions, together with those bases that form volatile compounds with the acids mentioned. These views are confirmed by observations made at volcanoes by Zies (1929, pp. 4–5), by Georgalas, Liatsikas, and Reck (1936, pp. 78–79), and by others and by theoretical reasoning developed by Niggli (1929, pp. 14–27), Fenner (1933, pp. 77–80, 83–84), Bowen (1933, pp. 119–120, 124–127), and Ross (1928, pp. 880–881, 885). However, most traces of the strongly acid elements disappear after ore deposition, and they are not well represented in the minerals of the veins and replacement deposits with the exception of fluorite and barite; this is largely because many of the acid ions, such as chlorine and its relatives, react with the country rock, forming, for example, soluble chlorides, such as $CaCl_2$, which are carried far from the sites of ore deposition. The only available direct evidence for the former presence of halogens is offered by inclusions in the minerals themselves.

Newhouse (1932, pp. 430–431) was able to analyze the inclusions in galena and sphalerite from several districts, among them Leadville. The galena from Leadville, like that of the other districts studied, contains inclusions that carry the elements sodium, calcium, and chlorine, in strong concentrations. These inclusions are thought to represent remnants of the original solutions, caught by the sulfides as they were precipitated and crystallized, and clearly suggest that the mineralizing solutions were rich in chlorine and possibly also sodium. The calcium is probably best attributed to the action of the solvents on the limestone. In this process the chlorine itself may have been the solvent, or an agent acting to retain the salts of the metals in solution (presumably as sulfides) much as hydrochloric acid is used to increase the solubilities of certain metallic sulfides in chemical analysis.

Thus, both theory and observation indicate that the mineralizing solutions carried acid ions and the metals now present in the ores (especially lead, zinc, iron, and copper), whereas prominent acid radicals were the chloride and sulfide ions. Whatever their exact composition, the temperatures of the mineralizing solutions that formed the ores in the marginal parts of the district were too low to permit volatilization of the chief acid constituents at the pressures then existing; hence the solutions were liquid and aqueous, and the ore minerals were not deposited by mere loss of acid gases from solution. These solutions rose along fractures leading from cupolas or plugs connected with one or several igneous sources. The fractures were thrust faults, steeply dipping reverse faults, and premineral normal faults. In places where the faults were "tight" and did not serve as effective channels, the adjacent shattered zones or accessory tension fissures furnished channelways essentially parallel to the major faults themselves. Some movement of the solutions took place along bedding planes, especially where these planes permitted flow in an upward direction, toward places of lower pressure.

The solutions tended to lose their less soluble constituents as they moved laterally and upward, and came into contact with cooler rock farther from the source cupola or plugs and nearer the surface. However, this tendency to precipitate was not due solely to reduction of temperature. The abundant dolomitic limestones of the region and descending ground water, rich in calcium and magnesium bicarbonates dissolved from the country rock, reacted with the acids in the solutions. These reactions had the effect of dissolving the limestones and at the same time neutralizing the high acidity upon which the solubility of the metallic sulfides probably depended. The relatively insoluble sulfides were then deposited along the channelways (forming the fissure veins) or in the minute openings produced by solution of the limestone (forming replacement bodies which at Leadville take the form of "blankets" or "contact" deposits).

That deposition is largely a chemical process resulting from such reactions is amply demonstrated by the following fact: many of the noteworthy ore bodies at Leadville are developed only where a feeding fissure crosses soluble limestone beds. This seems to show not merely that the solution served to attack and corrode the country rock, but also that both the solution and the country rock were generally essential to the reaction that resulted in the precipitation of the metallic sulfides. If the action of the solution had been purely corrosive and precipitative, not all of the openings developed would have become filled with minerals as they are now. In order to account for the present lack of unoccupied openings it must be assumed that solution and deposition took place essentially simultaneously and were parts of a single process.

One more kind of evidence as to the nature of mineralizing solutions is available. It has been pointed out by Singewald (1932, pp. 27–29) that the distinction between deuteric changes, produced during the consolidation of the intrusive porphyries within the porphyries themselves, and hydrothermal alteration is not readily made. In the alteration of the porphyries, albitization generally took place during an early stage of alteration, especially in the early White porphyry; silicification and sericitization were more conspicuous, later changes. The preponderance of sericitization over albitization suggests that the hydrothermal solutions gradually changed in composition, with a relatively high concentration of potassium during the later stages of the process. The alteration of calcic, sodic, and purely silicic minerals by the substitution of potassium must have increased the amount of calcium, sodium, and silicon in the solutions. To the extent that silica was liberated, this process increased the acidity of the solution and its ability to deposit quartz.

A striking feature of the mineral deposits is the absence of extensive replacement bodies of quartz and other forms of silica in immediate association with the sulfides of the lower-temperature facies. The filling of fissures with quartz and sulfides was common, but the processes of silicification by replacement and the deposition of sulfide ores generally appear to have been mutually exclusive; jasperoid forms the margins of many ore shoots but usually contains only negligible quantities of metal. Gold and silver, however, may be present in silicified country rock. Lead and zinc ores are lacking in highly silicified rock except for deposits of silica and oxidized lead as in the so-called "hard carbonate" found at the Peerless Maude mine. Emmons, Irving, and Loughlin (1927, pp. 224, 229) ascribed the "hard" character of this oxidized ore to the original presence of large amounts—approximately 25 to 40 percent—of silica in the primary lead ore. Most of this silica appears to have been jasperoid and supports the theory that the original sulfide ore was deposited at relatively low temperatures.

Carbonates are conspicuous gangue minerals, despite evidence that the solutions were moderately acid. Among the acid ions listed by Bowen (1933, p. 119), $CO_3^{=}$ and Cl^- are present in large quantity in mineralizing solutions of the type here discussed. The alkalies, K and Na, are believed to have been present, as suggested above, whereas the alkaline earths, Ca and Mg, if present, were not conspicuous. Under these conditions the calcareous and dolomitic country rock should have been dissolved in the form of the bicarbonates, aided by the excess acid. Carbonates of the alkaline earths could be dissolved from lower horizons by rising hot solutions containing either acids or alkaline carbonates, as suggested by Hewett (1931, p. 67), Loughlin and Behre (1934, pp. 252–253), and others. There is strong evidence of this origin for the crystalline dolomite and rarer calcite found as gangue in the veins, and probably also for the small quantities of siderite and manganosiderite in the outlying deposits. Although the carbonate radical may have been derived from the mineralizing solutions, at least the positively charged ions in the carbonate minerals (Ca, Mg, Fe, and Mn) probably came in large part from the country rock. This is suggested by the moderately close agreement in composition between country rock and gangue minerals in the outlying areas. Thus, siderite and quartz are most abundant where the country rocks are ancient siliceous schists and granites, and quartz unaccompanied by carbonates is abundant where quartzites and sandstones preponderate. In dolomites and limestones dolomite and calcite are the chief gangue minerals.

The characteristic association of barite, galena, and sphalerite in the epithermal zone as here described merits at least a tentative explanation. One deposit of this facies occurs at such great distance from the Breece Hill plug as to nullify any appreciable increase in temperature assignable to the Breece Hill intrusion itself. The depth of barite-galena-sphalerite ores below the surface at the time of formation is estimated at not more than 3,000 feet, where, probably, the temperature was not more than 30° C. higher than at the surface—too little to change appreciably the solubilities of the minerals mentioned. The mineralizing solutions may be assumed to have contained $PbCl_2$, $ZnCl_2$, and $BaCl_2$, with an excess of negatively charged sulfur ions. As it approached the surface, the solution would cool and thus tend to deposit at least the sulfides, and there would probably be continuous reaction of chloride ions with the carbonate country-rocks and with descending solutions rich in Mg, Ca, and CO_2; this condition in turn would increase the deposition of PbS and ZnS through neutralization of chloride ions. Moreover, oxidation by descending waters would tend to convert the sulfides to sulfates, and in this process barium sulfide would be the first of the metallic sulfides to oxidize, because of its higher potentiality as indicated by its position in the electromotive series. The barium sulfide that was not oxidized in this way moved to higher horizons. The fact that it antedated the precipitation of the base-metal sulfides constitutes ample proof that the solutions were not sufficiently cooled and neutralized to precipitate galena and sphalerite until after the early oxidation of the barium sulfide. Thus was developed the association characteristic of the epithermal facies in the Leadville district.

FACTORS IN THE LOCALIZATION OF ORE

The geologic study of the outlying parts of the Leadville district had two principal purposes—to aid the individual mine operator to develop ore already discovered on his property, and to help find new ore deposits by revealing areas that merit exploration. Detailed descriptions of the mines given in a later section of this report should further the first objective; a discussion of the factors localizing the ore deposits should contribute toward the second. The following discussion deals in general terms with causes for localization of the ores.

Three factors appear to be of paramount importance in ore localization: large structures, such as folds and faults that directed the flow of solutions, the nearness of intrusive rocks (that served as sources or ponding agents for the solutions), and the permeability, solubility, and other pertinent properties of the particular country rock in which the ore was deposited.

STRUCTURAL FEATURES

FOLDS

Ore deposition in the Alma district was favored by an anticline, at least in the Mount Lincoln area (Singewald and Butler, 1933, p. 106; Loughlin, Butler, Burbank, Behre, and Singewald, 1936, pp. 439, 440), but in the Leadville district folds (other than small wrinkles caused by drag along faults) do not appear to have had any appreciable influence in the localizing of mineralization. Certain apparent exceptions prove, on closer examination, to conform to the rule. Ore in small quantities was found widely distributed in the western limb of the broad syncline extending approximately due south from the Mitchell Ranch, but it was localized along bedding faults. Some mineralization also took place in the western limb of the Empire syncline, but here too it is chiefly localized on eastward-trending faults. Ore occurs on the northern slope of Upper Long and Derry Hill, in what has been described as the Long and Derry syncline, but localization of mineralization here appears to have been due more to the local faulting than to folding. Much the same circumstance applies to the conspicuous ore deposits in the eastward-dipping monocline east of the Pilot-Mike fault complex, as exposed on the southern slope of Printer Boy Hill and on the northern slope of Long and Derry Hill, but without exception the ore bodies there are either in fault fissures or in blankets leading out from these fissures.

Two general observations may be made regarding the relations between folds and ore deposits throughout the Leadville district. One of these is the fact that country rocks of pre-Cambrian age are not favorable for mineralization. With the present degree of dissection, prominent anticlines are likely to bring pre-Cambrian rocks either to or near the surface, with a corresponding erosional thinning of the overlying favorable sedimentary rocks; hence anticlines are largely barren in the marginal, less mineralized parts of the Leadville district. This condition probably explains why as much ore occurs in association with synclines as with anticlines at Leadville, despite the expectation, for theoretical reasons (Newhouse, 1931, pp. 241–245), of the contrary.

The second general observation is related to the fact that most of the folds are actually drag-folds along the larger faults. Whether such faults were preceded by the folds or caused them is a matter of conjecture but, as the faults are generally the chief sites of mineralization, the ore deposits are best discussed as related to them.

FISSURES AND FAULTS

In general, large bodies of ore are not found between the walls of the faults having the largest displacement. The South Dyer, Weston, Ball Mountain, Iowa Gulch, and Mike faults which are of premineral age, at least in part, and which have large throws, are generally barren. The Liddia and Mosquito faults contain small amounts of ore, and only the Sunday and Hellena veins among the larger fractures are extensively mineralized.

Considerable difference of opinion exists as to which of the major faults truly antedated mineralization. Some of the faults hitherto regarded as postmineral (Emmons, Irving, and Loughlin, 1927, pl. 39) are now known to be premineral, although they have also been subjected to postmineral movement. Conspicuous among them is the Mosquito fault, but the South Dyer fault also was regarded, at least in part, as of postmineral age. No evidence was recognized that proved the South Dyer fault to be postmineral, but in the Mosquito fault ore minerals have been found to be slickensided, and this fact has been cited to prove that deposition took place before the fracture was first opened. In this connection it should be recalled that ore deposition rarely heals a rock fracture completely and that both sulfides and quartz are conspicuously brittle. Faults are commonly the sites of renewed movement and at Leadville many striations on fault surfaces cross one another, proving repeated movements. In the Hellena mine, evidence was found that is interpreted as indicating oppositely directed motion along the minor fault east of the shaft that contains a shale "dike" (pp. 64, 140). Both in the present study (p. 76) and as reported in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 77–79), the Weston fault was found to have a reversal of downthrow in different parts of its course, indicating two periods of displacement, the later directed oppositely to the earlier one. A similar explanation would reconcile also the disagreement in the interpretations of the Mosquito fault, described as postmineral in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 80–81), but as possibly premineral as well by Butler and Vanderwilt (Butler and Vanderwilt, 1931, pp. 332–334) and by the present author. In short, a premineral fracture, once opened, remains a plane of weakness even if cemented with ore. If the region is subjected to renewed stresses, such a fissure is very likely to be reopened after partial or complete cementation by ore. This process of recurrent opening and shattering probably accounts for the larger ore bodies found in some premineral reverse faults, such as that along the Hellena fault in the Hellena mine. As a consequence ore bodies may occur even in major faults.

More favorable places for mineralization, however, are the minor fractures that are either parallel or accessory to the major ones. Because of their great displacements and lengths, the master faults are presumed to be more continuous and to extend to the great depths from which the mineralizing solutions came. The accessory or parallel faults, however, contribute an irregular and discontinuously shattered zone bordering the larger planes of movement. Along such zones the mineralizing solutions can easily rise, even though the main fault itself is closed by gouge or has its opposite walls too tightly pressed against each other to serve as a channelway. This relationship between the major breaks and the more open accessory fractures probably accounts for the mineralization in fissures such as those near the Mosquito fault developed by the Best Friend, Dixie, and Kemble mines in Evans Amphitheater. The numerous ore bodies mined in Iowa Gulch east of the Mike-Pilot fault complex on the slopes of Long and Derry and Printer Boy Hills are further examples of the same sort.

Intense mineralization, such as that of the central Leadville district, yielded workable deposits even in slightly fissured ground. On the other hand, where the mineralizing solutions appear to have been farther from their source, less active, and less concentrated (as in the marginal parts of the Leadville district), they yielded ore in workable quantity only where the ground was considerably fractured. Examples are the intermediate stopes of the Continental Chief mine, where the Leadville dolomite is greatly shattered by subparallel fractures, and the deposits on the southern slope of Printer Boy Hill east of the Mike-Pilot fault complex.

A favorable locality for ore deposition is where fissures pass from one kind of rock to another; for example, in the northern head of Iowa Amphitheater, small fissures that extend from the Leadville dolomite to the overlying shale of the Weber(?) formation or early White porphyry sill generally contain ore below the contact. A decrease in permeability or brittleness from below upward appears to have localized the ore. Repeated observations have shown that dolomite shatters more easily and recrystallizes with greater difficulty when under stress than does limestone, a fact which may explain, at least in part, the well-known association of ore bodies with dolomite, rather than limestone in many districts (Hewett, 1931, pp. 2?–31).

The nature of the fractures is significant in another connection. In many places where the shattering is moderately intense, individual fractures are vertically short and stop after having crossed only one or two narrow beds, thus limiting the vertical extent of mineralization. The vertical extent or continuity of the fractures varies greatly with the kind of rock. Even within a series of dolomite layers, some beds are broken by short, discontinuous joints, whereas others are crossed by fissures that afford excellent channels for ore-forming solutions to pass continuously from bed to bed. This difference seems to be due in part to differences in the size of particles and the degree to which they interlock: the more closely spaced and finer the particles (or, as it is usually put, the more dense the texture) the less continuous the fractures. This contrast is well shown at the foot of the incline in the Continental Chief mine, where the fissures are conspicuously discontinuous in a dense, equigranular dolomite, though the next higher and more coarsely granular beds are broken by regular, continuous fissures.

A second factor in the continuity of the fractures is the continuity or thickness of shale partings between the beds of dolomitic limestone. In parts of the Dyer and in the lower part of Leadville dolomite, calcareous beds are separated by thin shaly members; each stratum when put under stress separates from its neighbor and the rock becomes broken by joints, fissures, or small faults which stop at the partings. In such rock, mineralizing solutions cease their flow at the partings or they follow tortuous zigzag paths upward, losing their mineralizing action at relatively deeper levels than would be the case if the channelway were a single, more nearly vertical fracture.

That deposition is likely to be richer at intersections of fissures, has been demonstrated in many mining districts. In the marginal deposits at Leadville such structures generally consist of a well-defined, essentially continuous major fissure, intersected by minor ones (feather fractures). The acute angles where the two intersect are promising areas of replacement, presumably because the mineralizing solutions attacked the rock in the acute angle more strongly and found a smaller volume here that needed to be removed; moreover, the wedge in the acute angle was doubtless rendered more permeable by many minute cracks. An excellent example is seen in the Hilltop mine at the intersection of the northwest-trending fissure that yielded the Lind stope with the main fissure on which the Leavick drift and corresponding stopes were driven (p. 154, fig. 98).

No discussion of the relation between ore deposition and fissuring would be complete that did not take into account the extensive bedding-plane faults that permitted mineralization to extend laterally parallel to gently dipping beds for appreciable distances from steeply dipping trunk channels. The slippage of beds upon one another has a beneficial effect in producing openings that may be followed by mineralization (Behre, 1937, pp. 512–529). Though difficultly recognizable, such planes of movement prove their true nature as faults by passing vertically into typical normal or reverse faults that cut the bedding. In the Continental Chief mine small faults of this type pass upward with essentially vertical dips through the uppermost beds of the Leadville dolomite, but curve sharply as they rise to the base of the overlying black shale of the Weber(?) formation and disappear into the parting plane separating shale above from dolomite below; the contact between dolomite and shale is locally slickensided. The Bowden fault, observed in the Ibex mine and described on page 80, rises across the steeply dipping beds in the northeast limb of a syncline but passes into the bedding as it crosses the axis and enters the gently dipping southwest limb. In the Greenback-Mikado workings a branch of the Tucson-Maid thrust can be followed upward along a thick gouge and breccia zone to a level where it gradually curves and passes into a bedding plane. Such faults serve as channelways to mineralizing solutions because of their openings along the planes of bedding, and they also induce the formation of accessory faults and fissures along which gash veins may be formed. Despite considerable "healing," there is much evidence that the feeding fissures of some of the larger blankets are bedding-plane fractures or faults.

Where veins of late mineralization cross replacement ore bodies a striking relationship exists as to relative richness: the replacement deposit (frequently a blanket) commonly consists of sphalerite-chalcopyrite-galena ore of only moderate grade, whereas the intersecting fissure is far richer, with an especially high content of gold and silver. In such examples the facts admit two possible interpretations. The ore may all have arisen from trunk veins, mineralization spreading laterally to yield the blankets and, at a late but gradational stage, depositing the richer ore that borders and fills the vein channel. Alternatively there may have been the following sequence of events: (1) the formation of the blanket by replacement, (2) shattering, and (3) deposition of the richer ores, the precious metals having apparently been precipitated by reaction between the base-metal sulfides and late rising solutions, or a similar relation could result from enrichment of the veins by descending meteoric water. Emmons, Irving and Loughlin (1927, pp. 184, 206–207) cited examples favoring the first of these interpretations. One of the most striking deposits is that in the Golden Eagle workings, where both blankets and veins were formed during one period. Studies of Swanson's stope in the Ibex mine (pp. 167–169) show that the vein and blanket ores are contemporaneous, but here too the vein and blanket differ somewhat in composition; the vein is richer in copper and in gold despite the absence of any evidence of secondary enrichment, whereas the blanket contains a far higher proportion of zinc to other metals.

The trend of the ore-bearing fissures is fairly constant locally. In general, both premineral and postmineral fractures strike N. 0°–30° E. A few of the major faults (the Mike, Weston, and Ball Mountain faults) strike north-northwest, but most smaller mineralized fractures have strikes between the limits indicated. There are, however, some conspicuous exceptions. At the Continental Chief mine, in the head of Iowa Amphitheater, the strikes of 77 premineral fissures average N. 40° E.; of 77 observed fissure strikes, only 10 are in the northwest quadrant of the azimuth circle (fig. 82). Farther south along the western slope of Mount Sherman the direction is more nearly N. 60°–75° E. Near the Hellena and Lillian mines, it is approximately due north. Intelligent prospecting requires a recognition of the regional trend, with the intention of driving exploratory tunnels as nearly as possible at right angles to the prevailing fissure strikes. It is emphasized, however, that it would be most unwise to assume that the strike of fissures will be constant for long distances; stresses vary considerably from place to place, even within a small area, especially if the rocks are not everywhere identical.

Gouge has a definite effect upon mineral deposition, acting much like a semipermeable membrane by "straining out" some constituents, but allowing others to pass through it. The fissures thus exert a differential effect on mineralization in ways other than as channels. For example, in the southern crosscut at the east end of recent workings of the Nevada Tunnel, gold in amounts up to 3 ounces per ton has been found in a dense, clayey gouge of sheared granite, deeply stained with brown iron oxide; locally the metal is visible in this gouge, and also in the sheared granite "horses" within the gouge zone. Whether this gold is primary or secondary in origin is uncertain; the oxidized state of the iron suggests that the gold is secondary, but the gold in the relatively unaltered granite inclusions at least appears to be primary.

NEARNESS TO INTRUSIVE BODIES

In the central part of the Leadville district high-temperature deposits surround the obscure intrusive stock of Breece Hill in zones (Emmons, Irving, and Loughlin, 1927, pp. 177–178; Loughlin and Behre, 1934, pp. 222–224), but no such high-temperature ores occur in the area described in the present report. This zoning, despite structural complications between the ores and the Breece Hill plug, is interpreted as indicating that the mineralizing solutions traveled laterally and upward from the same center as the Breece Hill plug, following the edges of the newly consolidated plug and spreading outward from it along available fault zones. Thus the Breece Hill plug may be regarded as marking the source of the mineralization.

No igneous masses in the marginal part of the Leadville district are clearly associated genetically with the ore. However, there is evidence that the Mansfield shaft was sunk in a plug of Johnson Gulch porphyry, which cuts the early White porphyry sill at the top of the Leadville dolomite. This plug is not clearly delimited at the surface because all of the rock in the vicinity is greatly bleached and altered (p. 139). From the Mansfield plug the ore-forming solutions apparently moved outward, in part following along the great Mike fault that lies to the east, and in part radiating in all directions through the sill of early White porphyry and the underlying Leadville dolomite. The great heat coming from this nearby irregular plug appears to have favored the serpentinization, local deposition of crystalline masses of magnetite, and impregnations of fine dusty hematite. These minerals are conspicuous in the Altoona workings and the adjacent area and extend as far east as the First National shaft. The plug of Johnson Gulch porphyry or a similar, more deeply buried, intrusive is believed to account for the arsenopyrite and manganosiderite found on the dump of the First National shaft.

The various porphyry sills were intruded before the cross-cutting plugs and were obviously not so closely related to the ore-forming solutions. Certain of the sills are very closely associated with large ore bodies, but this association is a structural feature to be considered below.

EFFECT OF PONDING AGENTS

Upward or lateral progress of solutions may be impeded or completely halted by impermeable rock masses. This stagnation generally favors deposition of the contained mineral matter in preexisting openings; similarly, ponding commonly affords a better opportunity for replacement. Conspicuously effective ponding barriers at Leadville are clay gouge in faults (already discussed above), porphyry sills and dikes, and shaly layers; locally silicified limestone strata and quartzitic beds have also been effective. Where such ponding layers are parallel to the beds, the replacement bodies developed are the "blankets" or "contacts" so typical of the district. In general, the most common ponding agents are sills of the Gray porphyry group or of the early White porphyry. In the central part of the Leadville district porphyry sills are abundant, especially in the Leadville dolomite. Sills are so numerous in some localities that, including one or two shaly beds that also act as barriers, as many as ten or eleven "contacts" are recognized (Emmons, Irving, and Loughlin, 1927, p. 190). However, such occurrences of multiple "contacts" are confined to the central part of the district; neither intrusive sills nor deposits of the blanket type are so plentiful in the marginal parts here described.

In the marginal parts of the Leadville district, the sill most commonly serving as a ponding agent is the great mass of early White porphyry that lies above the Leadville dolomite. This is well exposed in the vicinity of the Dyer mine and in the numerous prospects on the east wall of the Iowa Amphitheater. The sill can be readily traced westward far down Iowa Gulch: it is recognized on the southern slope of Printer Boy Hill and on the northern slope of Long and Derry Hill, west of the Hellena mine, and near the Mansfield shaft. In the northern part of the area mapped, from Little Ellen Hill and Evans Gulch northward, the chief ponding sills exposed in shallow workings are of Evans Gulch porphyry, as best seen on the southern slopes of Prospect Mountain. However, most of the higher-grade ore and the larger ore bodies in the northern area are those developed beneath the same sill of early White porphyry (here greatly thinned) above the Leadville dolomite; others occur beneath a thick sill of Johnson Gulch porphyry, wherever this lies directly above the top of the Leadville dolomite.

In the central part of the Leadville district the ponding agent is very commonly one of several shaly beds in the Peerless formation, as may be seen on the 7th and lower levels of the Ibex mine. In mines of the Mikado-Greenback group, shaly beds in the Parting quartzite act as ponding agents; where mineralization was intense in this ground, even the Parting quartzite itself is replaced to some extent by ore minerals. In the marginal parts of the district, however, the most generally effective shaly barrier is that at the very top of the Leadville dolomite, consisting of 5 to 35 ft of Pennsylvanian shale that locally lie between the base of the thick early White porphyry sill of Mount Sherman and the top of the dolomite. It is well exposed in the Continental Chief and Liddia mines, and may be present elsewhere, though it was not generally noted in earlier descriptions.

In many places one or several of the beds in the topmost 35 ft of the Leadville dolomite have been silicified, and such silicified rock is locally a constant guide horizon. One such area, in which the top 15 to 20 ft of the limestone are affected, is that near the crest of Sheridan Mountain; exposures are especially good on the southwestern slope. A second area of good exposures is near the Hilltop mine and still another is the region about 0.8 miles south of the Mitchell ranch. In all of these localities the altered rock is strongly quartzitic. Despite careful field work it has not been possible everywhere to determine whether the rock is the result of silicification of a limestone or is a true quartzite, such as is not uncommon in the lowest part of the Weber(?) formation, and was produced by the metamorphism of a clean but fine-grained quartzose sandstone. Mineralizing solutions have been ponded locally by such quartzites or pseudo-quartzites in the three localities mentioned above, though not on a scale that is now of commercial importance.

NATURE OF THE COUNTRY ROCK

Aside from the importance of fissures, the outstanding feature in the control and localization of ore deposition is the presence of limestone, especially the upper part of the Leadville dolomite, which is the predominant ore-bearing rock. The ore channels were better developed in the sedimentary rocks than in the igneous and metamorphic rocks of late Cretaceous or early Tertiary and of pre-Cambrian time because the bedding planes in the sedimentary rocks served as solution channels and helped to orient fissure formation. Although the preceding statement applies to the clastic rocks of the Cambrian, Ordovician, Devonian, and Pennsylvanian deposits as well as to the limestones and dolomitic limestones, the clastic rocks contain only a small proportion of the ore deposits. Such a discrepancy between calcareous rocks and all the others must have a basic reason; further, the cause seems to be mainly chemical, for the physical differences, if any, are not apparent. The upper part of the Leadville dolomite is more cherty than the lower part, but there is no obvious correlation of the chert with the degree of mineralization.

Repeated tests with dilute hydrochloric acid were made to detect chemical differences between the lower and upper beds of the Leadville dolomite in view of their contrast in degrees of mineralization. Such studies were especially detailed in several localities where exposures are good, particularly in the Evans, Dyer, Iowa, and Empire Amphitheaters.

Finally, a series of samples was systematically collected from the Leadville and Dyer dolomites. Sampling was started at the top beds of the Leadville dolomite, as exposed beneath the lowest sill of early White porphyry on the crest of West Dyer Mountain, and continued downward to the top of the Parting quartzite in the northwestern wall of the Dyer Amphitheater. The specimens were collected at actual stratigraphic intervals averaging about 11 ft, the lowest being 11 ft above the top of the Parting quartzite. The Leadville dolomite here has a normal thickness of 154 ft, but the Dyer dolomite member of the Chaffee formation is far thicker than average, attaining a total of 94 ft. Analyses showing the bases (CaO, MgO, and FeO) present in the carbonates of the limestone, together with the insoluble residues, are recorded in the following table:

Systematic sampling of Leadville dolomite and Dyer dolomite member of Chaffee formation, West Dyer Mountain

[E. T. Erickson, U. S. Geological Survey, Analyst]

1. Sample No.	2. Stratigraphic height above base of formation (feet)	3. Insoluble constituents (percent)	4. Soluble CaO (percent)	5. Soluble MgO (percent)	6. Soluble FeO (percent)	7. Molecular ratio of CaO	8. Molecular ratio of MgO	9. Molecular ratio of FeO	10. Ratio of molecular ratio of CaO to molecular ratios of MgO and FeO
				Leadville dolomite					
1	154	0.39	32.47	19.84	0.80	0.578	0.491	0.011	1.151
2	143	.24	31.01	19.85	.65	.552	.491	.009	1.104
3	132	.66	31.20	20.15	.41	.556	.499	.006	1.101
4	121	44.64	17.19	11.68	.41	.306	.289	.006	1.037
5	110	.52	31.95	21.31	.32	.569	.528	.004	1.070
6	99	.46	30.81	21.27	.28	.549	.527	.004	1.034
7	88	.67	31.20	20.27	.41	.556	.502	.006	1.094
8	77	.61	30.91	19.05	.37	.569	.472	.005	1.193
9	66	.72	30.80	19.72	.46	.549	.488	.006	1.111
10	55	1.04	32.16	18.49	.32	.573	.458	.004	1.240
11	44	.64	29.11	20.75	.32	.519	.514	.004	1.002
12	33	2.30	30.19	20.91	.32	.538	.518	.004	1.031
13	22	5.84	29.53	18.89	.32	.526	.468	.004	1.114
14	11	5.75	29.27	18.07	.28	.522	.448	.004	1.155
				Dyer dolomite					
15	94	6.82	29.75	17.27	0.41	0.530	0.428	0.006	1.221
16	88	8.23	29.30	18.13	.37	.522	.449	.005	1.150
17	77	13.22	27.42	16.69	.97	.489	.414	.013	1.145
18	66	15.48	27.57	15.51	1.01	.492	.384	.014	1.236
19	55	29.21	21.19	13.52	1.16	.378	.335	.016	1.077
20	44	5.96	29.78	19.21	.60	.531	.476	.008	1.097
21	33	4.78	29.59	18.99	.46	.527	.471	.006	1.103
22	22	5.73	29.47	17.08	.51	.525	.423	.007	1.221
23	11	18.65	25.57	15.21	.62	.456	.377	.009	1.181
24	Parting quartzite	----------	----------	----------	----------	----------	----------	----------	----------

In the Leadville district much of the dolomite in the dolomitic limestones contains ferrous iron in place of some of the magnesium. The recalculations of the analyses listed in columns 7, 8, and 9, of the above tabulation are simple molecular ratios computed by dividing the percent of a given oxide as reported in an analysis by the molecular weight of the oxide. If for a certain analysis the sums of molecular ratios of magnesia and ferrous iron oxide are less than the calcium oxide ratio given in column 7, this would suggest that the calcium oxide was not all used up in dolomite molecules but that a surplus exists which appears in the rock as calcite. The result of dividing the molecular ratio of calcium oxide available by the sum of the molecular ratios of magnesium oxide and ferrous iron oxide, as expressed in column 10 thus furnishes a relative measure of this surplus calcite indicated for the several stratigraphic horizons analyzed.

These calculations are subject to some qualifications. First, it is well known that dolomite may contain some calcite in solution within the dolomite space lattice; this calcite, though appearing in the calculations, is not as readily subject to attack by mineralizing solutions as ordinary calcite; generalizations concerning the susceptibility of a given bed to replacement, if based upon calculations such as the above, would be vitiated if this factor were ignored. Second, it is here assumed that the three basic ions are present only in the carbonate minerals, calcite and dolomite. Instead, they may be present in part in silicates or other compounds, not detectable without careful mineralogic and petrographic study. If one or another of these basic ions were liberated in quantity from a silicate during solution of the specimen for analysis, a false impression would arise regarding the ratios of the ions in the carbonate minerals assumed to be present. These possibilities do not seem likely but they compel a recognition of the somewhat tentative nature of the conclusions which follow.

In all the samples of the Leadville and Dyer dolomites, the ratio of CaO to MgO-plus-FeO is close to that of dolomite, as indicated in column 10, regardless of the percentage of insoluble material. In detail there is considerable variation, but assuming that the sampling is representative (and very effort was made to keep it so), there is no part of the section in which the ratio of CaO to MgO-plus-FeO is markedly greater than in any other part. Perhaps the lower part of the Leadville dolomite and the upper part of the Dyer dolomite together constitute the only significant exception, though the ratio is high in certain other samples irregularly distributed in the section. Calcite, in contrast to dolomite, does not seem to be unusually abundant in the upper part of the section sampled, even though that is where mineralization is most extensive. The three samples from the highest part of the Leadville dolomite contain no more calcite than samples 8, 9, and 10, from near the base of the formation, and no more than the average of samples from the Dyer dolomite. Indeed, the average ratio of the molecular ratio of CaO to the sums of the molecular ratios of ferrous oxide and magnesium oxide is higher in the Dyer dolomite than in the Leadville.

On this basis alone, in short, there is proportionally more calcite in the Dyer than in the Leadville dolomite. As calcite is more soluble and presumably more readily replaced by ore than dolomite, its percentages in the different beds have evidently had little to do with the localization of ore bodies.

At certain places in the central Leadville district large quantities of ore have been mined from the lower part of the Leadville dolomite and from the Dyer and Manitou dolomites, but even so, the dominance in number and size of the ore bodies in the upper part of the Leadville dolomite is very distinct (Emmons, Irving, and Loughlin, 1927, pl. 45). This dominance is even more striking in the outlying areas: in these outlying areas substantial quantities of ore from replacement deposits have come only from strata in the uppermost part of the Leadville dolomite. This statement applies to such relatively large mines as the Hilltop, Continental Chief, and Dyer. In other mines credited with large output, such as the Hellena, Clear Grit, and Lillian, the ore shoots occurred along fissures with which no noteworthy blanket deposits have been found to be related, either because the wall rocks are siliceous or because gouge along the margins of the fissures has prevented solutions from spreading into limestone or dolomite walls.

The lower part of the Leadville dolomite and the Dyer dolomite as a whole contain more insoluble material than do the uppermost beds of the Leadville, and may therefore have been left comparatively impermeable, especially in places far removed from faults. No porosity tests were made on the samples, as the degree of porosity both in the purer and the less pure beds is obviously very low.

The Manitou dolomite as a whole contains greater percentages of calcite and of insoluble material than the Leadville dolomite and about the same percentages as the least pure samples of the Dyer dolomite (Emmons, Irving, and Loughlin, 1927, pp. 28–29). Its many shaly partings render it still less subject to continuous open fracturing than are the other two formations.

The quartzites and sandstones in the outlying areas have been wholly unproductive, even though the sandstones appear to be more porous than the carbonate rocks. In a few places within the central area quartzite and sandstone have been replaced by small ore shoots where local shattering and other structural conditions rendered the rock unusually susceptible to attack. No matter how porous the siliceous rocks may be as a whole—including the pre-Cambrian rocks, Sawatch quartzite, Parting quartzite member of the Chaffee, and the Weber(?) formation—they are not extensively replaced under the conditions that commonly prevailed in the Leadville region. Some fissure veins in these rocks, particularly the pre-Cambrian, have been mined for their precious-metal contents, but their ore shoots are too small to justify mining for the base metals.

In brief, chemical data indicate that although the carbonate rocks were far more readily replaced than any of the siliceous rocks, there was no preference for beds containing relatively high or low percentages of calcite, and the large replacement bodies are essentially restricted to the uppermost part of the Leadville dolomite throughout the marginal areas by the structural conditions.

SECONDARY CHANGES IN THE ORES

GENERAL NATURE OF SECONDARY CHANGES

After an ore deposit has been formed by rising solutions, and the process of primary mineralization is completed, the ore and gangue minerals are likely to undergo changes. These primary minerals may be acted upon by descending cold waters containing oxidizing agents (such as oxygen and carbon dioxide) and by salts of metals leached from higher parts of the same primary ore body. New, secondary, minerals are formed: oxides, carbonates and sulfates, native metals, and certain sulfides. If the products are rich in oxygen, they are said to be oxidized minerals; if there is no increase in oxygen but new sulfides with a greater percentage of metals are formed, they are said to be secondarily enriched sulfides. Chemical conditions required by the process of secondary sulfide enrichment can exist only below the ground-water level prevailing at the time. In general, ground-water level will coincide with the boundary between the zone of oxidation and the zone of secondary sulfide enrichment but subsequent uplift or depression may change the position of the ground-water level. Minerals produced by oxidation may be brought below ground-water level and the products of secondary sulfide enrichment elevated above ground-water level. Oxidation products may be removed by glaciation or by stream erosion.

The secondary changes tend to separate iron and copper. The iron forms such insoluble compounds as limonite in the oxidized zone, and the dissolved copper is generally reprecipitated at depth as the secondary sulfides chalcocite and covellite. Similarly, once exposed to oxidation, zinc tends to migrate downward in solution, whereas oxidized lead minerals are relatively insoluble. Thus, two metals closely associated in the primary ore are likely to become separated in the process of secondary alteration.

SECONDARY CHANGES IN THE CENTRAL LEADVILLE DISTRICT

The nature and origin of the secondary changes in the ores of the central part of the district have been discussed in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 220–272). Oxidation was very extensive in the central Leadville district, and early production was mainly from oxidized ores. Manganosiderite yielded iron and manganese ores, but some primary iron pyrite, too, found use as flux in smelting. Siliceous pyritic ore rich in precious metals yielded siliceous gold and silver ores upon oxidation. Mixed sulfides were oxidized to form jarositic ores rich in lead and also to form various types of lead carbonate. Zinc blende was oxidized to zinc carbonates and silicates. Siliceous pyrite and chalcopyrite ores were oxidized to form copper ore (silicates and carbonates), and bismuth compounds yielded oxidized bismuth ores, but copper and bismuth ores are relatively scarce and of little economic importance in the Leadville district.

Iron and manganese ores of various grades were widely distributed, especially making up the so-called "vein material," but have been largely exhausted. A few small bodies of high-grade manganese ores have been formed.

Most siliceous gold-silver ores form irregular bodies below lead carbonate ore shoots. On Carbonate and Fryer Hills much of the silver occurred as cerargyrite along joints or pore spaces. Some ores on Iron and Breece Hills were rich in gold but in deeper workings they commonly passed abruptly to sulfides low in precious-metal content.

Oxidized lead ores include "hard carbonate" and "sand carbonate." Hard carbonate is formed where there is enough iron oxide or silica to cement the grains of lead carbonate into a hard but generally porous rock. Sand carbonate consists of granular cerussite crystals, typically not firmly cemented. Sand carbonates are gray to brownish; hard carbonates are commonly reddish or brownish, though rarely gray. Both types of oxidized lead ore are generally silver-bearing. Lead sulfate is of mineralogic interest but of no economic importance in the district. Jarositic ores consist of basic ferric sulfate with some lead in the molecule; they are ocherous, finely micaceous, and unctuous. They are generally lean in silver but rich in lead and gold. Jarosite is fairly common in the central part of the Leadville district but rare in the marginal sections.

Oxidized zinc ores are of four types: (1) gray carbonate ore, (2) brown carbonate ore, (3) brownish-black carbonate-silicate-oxide ore, and (4) dense zinciferous clay. The gray carbonate is the result of replacement of manganosiderite. The brown carbonate ore is highly varied in texture, porosity, and color; it represents partly a replacement, partly the filling of contraction cracks and other cavities containing zinc carbonate and silicate. The other two types of oxidized zinc ores lack economic importance.

Oxidized ore minerals in the central part of the district contrast greatly in vertical distribution. The primary lead and zinc minerals reacted differently to oxygen-bearing solutions. The zinc sulfide was oxidized to soluble sulfate and traveled downward in descending acid solutions to the point where, coming in contact with calcareous wallrock or with carbonate gangue minerals, the solution was neutralized and the zinc replaced the iron, manganese, or calcium in the carbonates of the country rock or gangue. Lead sulfide, however, undergoes only a very slow conversion to carbonate or is altered, likewise slowly, to sulfate by direct combination with oxygen. As both carbonate and sulfate are nearly insoluble, little lead was removed by solution from the primary ore; replacement of limestone or gangue, resembling the replacement by oxidized zinc minerals, is relatively slight. Thus, after oxidation an original blanket body of primary mixed lead-zinc ore is likely to be divided into an upper body of lead carbonate with remnants of primary galena, a thin layer of iron oxide and clay, and a lower body of zinc carbonate, commonly with some calamine. In veins the arrangement is essentially the same, with the lead carbonate and galena medial and the oxidized zinc minerals marginal. In general, the zinc carbonate ores occur beneath the ground-water level, and in some places even beneath sulfide ores.

The depth of oxidation in the central part of the Leadville district is greatly varied, in part because of differences in the permeability of the country rocks. This variation of depth is increased by the fact that rocks of contrasting permeability lie at approximately the same level. The old surface of most of the lower parts of the district (other than the valley floors) is covered by Pleistocene glacial deposits. Because most of the oxidation antedated glaciation, the top of the sulfide zone is more nearly parallel with the bottoms of the moraines rather than with the present surface (Emmons, Irving, and Loughlin, 1927, pp. 248–249).

The processes of oxidation and secondary sulfide enrichment have been closely studied in many districts, and their chemistry is well understood. Leadville differs from many other rich mining regions in the scarcity of primary copper ore. Copper minerals oxidize near the surface to form soluble copper salts which pass down into the zone of more sluggish circulation and of reducing conditions where they tend to be precipitated as secondary sulfides. Copper is the most sensitive of the common metals in this behavior but the low amount of copper in the Leadville ores precludes its use as an index of secondary sulfide enrichment. Zinc rarely (if at all) occurs as a distinctive sulfide and likewise is a poor criterion for recognition of the secondary sulfide zone. Lead, on the contrary, resists oxidation and solution. As a consequence, in lead-zinc ores boundaries between the oxidation zone, the secondary sulfide zone, and the primary sulfides are not only very irregular but also commonly hard to identify. The anomalous behavior of zinc carbonate, which is commonly carried below the level of sulfides produces an additional complication.

Thus, with respect to zones of oxidation and secondary sulfide enrichment, the central part of the Leadville district differs from other larger mining districts of the United States west of the Front Range.

SECONDARY CHANGES IN MARGINAL DISTRICTS

GENERAL FEATURES

Most of the larger mines in the marginal districts around Leadville are in areas such as the floors and slopes of the Empire, Iowa, Dyer, and Evans Amphitheaters that have been subjected to vigorous glaciation. Other mines, such as the Hellena, are in deeply glaciated valleys. In all these areas erosion has removed most of the thoroughly oxidized ores, and the mines are too few to yield dependable general information on the secondary changes in the ores. Furthermore, the ores are uniform and simple; copper minerals, the most sensitive indicators of secondary sulfide enrichment, are lacking, and silver salts are rarely visible. In short, there is little basis for a trustworthy concept of oxidation and secondary sulfide enrichment in the ore.

Nevertheless, the general mineralogical relations do not differ greatly from those reported for the central part of the district. The primary ores are the same, though leaner and very largely lacking both copper and gold, with smaller quantities also of manganosiderite; zinc and lead predominate, much as in the central district, but pyrite is far less conspicuous. The mineral assemblage, therefore, bears considerable resemblance to that of the central Leadville district, and the limits of oxidation and secondary enrichment are poorly defined in the marginal deposits, just as they are in the central Leadville district.

Few observations in deeper mines could be made in the present study, but depth to which the oxidized zone extends is evidently as greatly varied in the marginal as in the central Leadville region. In the Hellena mine in Iowa Gulch the effects of oxidation are negligible, as might have been inferred from the heavy flow of water encountered at all levels. These effects are also virtually absent from the Best Friend and other mines in the floor of Evans Amphitheater and from most of the mines on the valley floor of Iowa Gulch west of the Hellena mine. Most of the higher slopes of Long and Derry and Printer Boy Hills, however, revealed extensive oxidation to various depths. In the Continental Chief, Hilltop, Liddia, Peerless Maude, and Dyer mines oxidized zinc ores predominated, even in the deepest workings. The higher areas have been less affected by glacial erosion (see p. 11). As most of the oxidation of the ore antedated glaciation, the lower limits of the oxidized zone should be approximately parallel with the preglacial surface. Where, as in Iowa Gulch, Pleistocene streams and glaciers deeply eroded the surface, the oxidized zone may have been completely stripped. Where, as in the Peerless Maude and Dyer mines, the ore deposits lie (presumably) only 500 ft or less below the topographic level from which oxidation proceeded downward in preglacial times, at least a part of the oxidized zone should still be preserved.

Another factor affects the present depth of oxidation. Structural features such as faults, dikes, and impervious strata may produce irregularities in the depth of oxidation. Oxidizing waters can descend easily to unusual depths along faults, but are impeded by impervious beds or fault gouges.

Upon very strong evidence, the time of maximum oxidation has been placed in late Tertiary or early Pleistocene (Emmons, Irving, and Loughlin, 1927, fig. 83 and p. 272). Most faulting antedated the major oxidation so it is most unlikely that the present irregularities in the level of the bottom of the oxidized zone can be attributed to faulting and displacement of an oxidized zone having a previously uniform altitude.

OXIDATION OF SPECIFIC ORE MINERALS

Pyrite oxidizes readily through various ferrous and ferric sulfates to limonite and the related oxides, the commonest minerals of the oxidation group. Some of the pyrite, especially where as in the Continental Chief mine it lies near lead sulfides, forms small quantities of plumbojarosite. Manganosiderite is not widespread, but deposits of wad and other manganese oxides (especially pyrolusite and psilomelane, or cryptomelane) are found. They are most common in the "contact matter" between two beds. The absence of large quantities of manganosiderite suggests that the manganese oxides have been derived largely from manganiferous siderite or from manganiferous calcite. A little manganese is also present in such minerals as hetaerolite ($2ZnO{\cdot}2Mn_2O_3{\cdot}H_2O$) and chalcophanite [$(Mn, Zn)O{\cdot}2MnO_2{\cdot}2H_2O$], and in a brown zinciferous clay. Manganese in zinciferous clay was found in large quantity in one of the northwest stopes an intermediate distance down the incline in the east workings of the Continental Chief mine. Such manganiferous ores are common in the "contact" or blanket deposits. Large quantities, reported to contain much silver, occur in and near the Kenosha tunnel on Long and Derry Hill, and some has been produced from a tunnel situated about 1,000 ft east-southeast of the Himalaya mine. The dumps of the First National and Julia-Fisk groups show oxidized manganosiderite, but no production of manganese ore is recorded from these mines.

Films of oxidized copper minerals are common, but their conspicuous blue and green colors are likely to lead to overestimation of the quantity of primary copper minerals; in the marginal deposits they are almost wholly absent. Small quantities of malachite in minor prospects on the north slope of Mount Sherman are designated "chloride" (cerargyrite) by miners, but assays reveal very little silver.

Oxidized lead ores are conspicuous only locally, as on Printer Boy Hill, in the Peerless Maude mine on Peerless Mountain, and in several prospects situated about 1,000 feet north-northeast of the Liddia tunnel. Basic ferric sulfates containing lead (plumbojarosite) and rich in gold may have been mined to a small extent in workings of the Lillian group on the south slope of Printer Boy Hill; presumably these sulfates resembled those described by Emmons, Irving, and Loughlin (1927, pp. 230–231) but their relations to the other ores are not known. Probably the absence of extensive deposits of oxidized lead ores in the marginal Leadville district is due to the effects of glaciation. Most of the ore deposits are in valley bottoms or on the walls of cirques, where the oxidized lead ores were swept away by glacial erosion. Remnants of the preglacial topography, such as the crest of Peerless Mountain, are most likely to retain deposits of oxidized lead ores.

In the outer parts of the Leadville district the zinc ores are by far the most conspicuously oxidized. Hetaerolite and chalcophanite (complex oxides of zinc and manganese) have been mentioned. Chocolate-colored zinciferous clay is found locally, especially in "contact" deposits, but zinc cannot be extracted from it economically. By far the most common oxidized product from primary blende is smithsonite ("dry bone") in chocolate, yellowish, or gray cavernous masses suggesting partly decayed bone. It constitutes the dominant zinc ore in the Continental Chief and Liddia mines. Specimens shown the writer indicate that it was plentiful in the Hilltop mine, but that mine also contained considerable smithsonite or hydrozincite of a type described by the miners as a "chalky carbonate." Near the groundwater level the "dry bone" type of smithsonite commonly has inclusions of greenish to dark-brown blende with a striking resinous luster; such inclusions are commonly shattered and altered to smithsonite along the cracks. Remnants of galena, commonly enclosed in thin envelopes of oxidized lead minerals, are also preserved within the larger smithsonite masses. The caverns in the "dry bone" are commonly crustified with tiny crystals of calamine. In places small calamine crystals are enclosed in the smithsonite forming the walls of the cavernous "dry bone." In most oxidized bodies calamine seems to have been the more recent and less plentiful of the two common oxidized zinc minerals, though it is very widespread.

In the oxidized marginal ores of the Leadville district there is some native silver, some in combination with halogens (especially in the chloride, cerargyrite), and some as a sulfide. None of these three forms is visibly abundant or known in quantity, but a few silver wires, scales, or leaves are found. Rich silver ores in iron-stained flinty material that represented silicified Leadville dolomite were worked in several prospects in Little Evans Gulch about 1,000 to 1,500 ft north and northeast of the Chicago Boy mine. The proportion of primary to secondary silver has not been determined. The high degree of iron-staining of this ore and the occurrence of some of the silver in small, open fractures suggest that only oxidized silver or silver salts have been preserved.

Oxidized gold ores probably occur in what is described as "rusty" limonite in some oxidized veins, and also in iron-stained "contact" deposits. In numerous shallow fissures in the pre-Cambrian and Cambrian rocks gold has been found, commonly associated with considerable manganese stains; such small deposits are especially abundant in the pre-Cambrian rocks, and, though the small bodies that were worked were rich their aggregate output is not great. Examples are found in prospects on the slope of East Ball Mountain just west of the mouth of Dyer Amphitheater. In general, however, gold ores in the marginal parts of the district are lean. The gold reported in the west workings of the Continental Chief mine was partly in oxidized quartzose ore. The ore along the Mosquito fault or its subsidiaries in the southern arm of the Evans Amphitheater is apparently primary, as alteration of the associated blende and pyrite is negligible.

"Contact" or blanket deposits in the marginal parts of the district are small (in contrast with the great ones of the central parts) but they are nevertheless very conspicuous because they are deeply stained brown or black. The deposits commonly contain cerussite, smithsonite, silver minerals, and (more rarely), calamine and gold. In the marginal region they apparently result from local alteration of pyrite, sphalerite, or mixed ores.

OXIDATION OF GANGUE MINERALS

Manganosiderite is oxidized to iron and manganese oxides, and the other carbonates slowly dissolve, leaving a cavernous rock favorable to the deposition of smithsonite and calamine. Most of the carbonates appear to contain at least small quantities of iron carbonate in isomorphous combination with the carbonates of magnesium, calcium, and manganese; indeed, some of the mineral called dolomite may well be ankerite or siderite. Oxidation of the carbonates is therefore commonly accompanied by the formation of faint or conspicuous rusty coatings.

A special kind of oxidation process, commonly ascribed to the action of descending waters, is the solution of the cement between the grains of dolomite. The residue is a poorly consolidated or wholly free sand, called locally "dolomite sand." Examples are common at Gilman and Red Cliff, Colorado (Henderson and others, 1934, p. 75), and also in the central Leadville district (Emmons, Irving, and Loughlin, 1927, pp. 36–37).

Quartz in the oxidized ore also is commonly stained brown as the result of the oxidation of pyrite, and made cavernous in appearance by the solution of grains of pyrite and blende. Barite is highly insoluble and remains unaltered except that its normal bluish white color is changed to a creamy hue.

SECONDARY SULFIDE ENRICHMENT

Secondary sulfide enrichment consists of the oxidation of primary sulfides near the surface, their solution in descending waters, and their reprecipitation as secondary sulfides at depth. It is important in copper-rich deposits of the western United States, but not in the Leadville district where copper is negligible and lead and zinc are the dominant mineral constituents of the primary ores. Apparently, lead is rarely if ever reprecipitated as a sulfide at the ground-water level (Butler, 1913, p. 92; Emmons, 1917, p. 140). The theory of enrichment of zinc in ore deposits of the Leadville type on a large scale by secondary sulfide deposition is also not accepted by most observers and seems not to be supported by fact (Emmons, 1917, p. 271; Emmons, Irving, and Loughlin, 1927, p. 268). In some places silver is reprecipitated in commercial quantities, both as native silver and as argentite (Emmons, 1917, pp. 373–374). Gold, taken into solution as the chloride in the oxidized zone, may be precipitated as the native metal in the zone of secondary sulfide enrichment by reaction with certain sulfides or with constituents in the ground water (Emmons, Irving, and Loughlin, 1927; Emmons, 1912, pp. 25–28).

The writer found conclusive evidence of a secondary sulfide zone only in the South Ibex (Venir) mine, where chalcocite has stained otherwise fresh surfaces of pyrite.

The absence of copper in the ore and the complicated relation between ore zones and topography nullified every attempt to trace the relation between secondary sulfides and depth below the surface and makes impossible any regional generalizations about the depth of secondary enrichment in the marginal areas around Leadville; in short, secondary sulfide enrichment is not an important factor in these areas.

SUGGESTIONS FOR PROSPECTING IN THE OUTLYING AREAS

Attention has already been directed to the most promising areas of the central part of the Leadville district (Loughlin, 1926; Emmons, Irving, and Loughlin, 1927, pp. 323–326). In the following paragraphs suggestions are offered for selection of outlying areas that deserve more careful exploration. The recommendations are based on inferred geologic relations and upon explorations already carried out.

The principal centers of mineralization and the largest ore bodies are in the central Leadville district, but in the outlying areas there are minor centers that are likely to have somewhat smaller ore bodies. Such deposits are likely to be rich in lead, zinc and silver, and to contain some gold; they are most likely to occur as fissure veins, but replacement bodies in limestone may also be present. Preliminary exploration indicates that the outlying ore bodies are most abundant near the major premineral faults and are (1) most likely to pass from fissure fillings into replacement bodies (2) at the contacts between the upper Leadville dolomite and the overlying sill or if the sill is absent or does not rest directly on the dolomite, between the Leadville dolomite and the Weber(?) formation. The Hellena mine exemplifies the first of these and the Continental Chief and Hilltop mines the second. The deposits are characterized by silver in association with galena, sphalerite, and pyrite, and by such gangue minerals as carbonates, quartz, and barite. Within this broad pattern, a few suggestions may serve as a general guide in prospecting.

First, the most favorable zone is the upper part of the Leadville dolomite. This zone is preferable to lower parts of the same unit and to the Dyer and Manitou dolomites, particularly because it is more massive and more brittle than the slightly more shaly lower limestones, and because it is directly overlain by thick impervious rocks. These impervious rocks include the thick sill of early White porphyry and the lowest, shaly beds of the Weber(?) formation.

Second, the Leadville dolomite seems to be at least moderately recrystallized in the neighborhood of ore and this feature may, with care and due conservatism, be used as a guide to ore. The alteration product, known as "zebra rock" because of its alternating layers of fine-grained blue-gray and more coarsely crystalline white dolomite, is characteristic of regions where at least a little mineralization has taken place. Ore is not in all cases found near "zebra rock" but the presence of such markings suggests fracturing and the possible circulation of mineralizing solutions.

Third, the Johnson Gulch porphyry seems to be the facies of the Gray porphyry group most commonly associated with mineralization. This does not hold for many sill-like bodies but apparently it applies to dikes (such as those in Iowa Gulch near the Lillian mine) and to plugs, like those on Breece Hill and near the Rex and Mansfield mines.

Fourth, premineral fractures have been channels of mineralizing solutions. Most of them trend N. 0° to 30° E., but detailed study shows that the pattern varies greatly with the part of the district studied. Many of these premineral fractures are reverse faults that may not be mineralized themselves but do commonly contain some ore, or have related small ore-bearing fractures or replacement bodies. It is not everywhere possible to determine which faults are reverse and which are normal. Generally, at least in faults of larger displacement, the eastern side is raised. Most of the faults that dip eastward are reverse faults and, being premineral, have economic potentialities.

Fifth, many of the minor faults of the outlying districts—like parts of the Tucson, Colorado Prince, and Bowden faults of the central Leadville district—lie very nearly parallel with the bedding as essentially flat reverse faults, and are most probably of premineral origin. As expected, the related small fissures are highly productive in many places. They are structural features favorable to the occurrence of ore.

Sixth, in driving for ore, it is best to tunnel toward the uppermost beds of the Leadville dolomite. The geologic map of the region (pl. 1) will aid in finding places where these uppermost beds are cut by fractures that may have served as ore feeders. In these places exploratory tunneling should be planned, insofar as the topography and dip of the rocks will permit, to cross the largest number of fissures at right angles in order to reduce the cost of drifting in ground that is barren. It is generally preferable to tunnel in the upper Leadville dolomite rather than in the overlying Weber(?) formation, which slabs off badly. Commonly, the early White porphyry is likewise a difficult country rock in which to drift, especially where it has been slightly mineralized. Moreover, effects of mineralization, even if slight, are most readily recognized along fissures in the dolomite. Raises may then be put up along any such promising fissure to the desired zone in the uppermost, most productive part of the Leadville dolomite.

The question of drilling versus exploratory drifting furnishes a never-ending argument. Certainly at Leadville a narrow vein can best be followed by drifting, for it is very likely to pinch out locally with no clue as to its direction of continuation except a small unmineralized fissure, rarely visible in diamond drill cores and wholly unrecognizable in the cuttings of a churn or percussion drill. On the other hand, tabular deposits of the "contact" or blanket type, such as have been reported from the Kenosha and related openings near the crest and on the southern slope of Long and Derry Hill, are ideal among western lead-zinc ores for exploration with the drill. This statement is made with a full realization of the economic factors involved in deep drilling, the limitations caused by an alpine climate, and the problems involved in the interpretation of the drill cores or cuttings.

NORTHERN AREA

North of the central Leadville district the principal rocks exposed are sandstone and shale beds of the Weber(?) formation and sills of the Gray porphyry (pl. 1). Surface exploration is not feasible, as exposures are poor and there are but few distinctive limestones to serve as horizon markers. Detailed geologic structure, therefore, cannot thus be deciphered and drilling will be necessary to determine the positions of any productive beds, especially the Leadville dolomite and the Dyer dolomite member of the Chaffee formation.

Especially disappointing is the large area extending from the Board of Trade mine westward to Canterbury Hill. At the surface this area shows scant evidence of mineralization, but little could be expected as the surface cover consists almost wholly of unfavorable clastic beds of the Weber(?) formation. Search will necessarily have to be below the surface, and the writer considers exploration northward and eastward from the Yak tunnel toward the Great Eastern shaft and beyond, and also near the Diamond and Resurrection mines as most likely to discover ore. Unfortunately, the northeastward dip of the beds carries the most promising zone progressively deeper beneath the Yak level, increasing the difficulties of hauling and dewatering if ore is found.

MOSQUITO PASS, EVANS AMPHITHEATER, AND SOUTH EVANS GULCH

The Mosquito fault and its subsidiaries in this area are at least locally mineralized. Careful search along them is merited, especially where Leadville dolomite lies close to the main Mosquito fault or between two minor faults of the Mosquito fault zone, as in the northern end of the South Evans Amphitheater and in the floor of Evans Gulch half a mile east of the upper Leadville reservoir.

In the two areas designated, limestone "slivers" lie between two branches of the main Mosquito fault. The larger faults, such as the Mosquito fault, are commonly not mineralized because of their general tightness (see p. 67), but there are many open crevices and therefore favorable localities where (1) minor feather-fractures lead off from the main fracture or (2) branches separate from the main fault and rejoin it farther on. On these two criteria, the two areas mentioned hold much promise for exploration, especially in view of the ore found in the openings 1,000 ft north of the Best Friend tunnel and the extensive mineralization along the main Mosquito fault at Prospect C–103 south of the Best Friend group.

The southerly head of Evans Amphitheater also seems to merit careful examination, although showings there in the past have not been highly encouraging. As in other areas, the most favorable locations are at the contact between the Leadville dolomite and the overlying thin band of Weber(?) formation or the sills of porphyry. Of special interest here are minor workings about 1,500 ft northeast of the peak of West Dyer

Mountain (Prospect N–25). These workings have revealed considerable barite in the dolomitic country-rock, which suggests mineralization of the type found in the Continental Chief and Hilltop mines; but the workings developed are too low, lying only about 40 ft above the base of the Leadville dolomite. Important fissures were not noted here, but to the northwest there are several that strike northeast. Exploratory work should be directed into the northern slope of West Dyer Mountain. Drifts due west should gain depth, follow the top of the Leadville dolomite, and yet cross fissures nearly at right angles.

IOWA AMPHITHEATER

The Iowa Amphitheater area is more promising because the rocks are considerably shattered. The Dyer, Liddia, and South Dyer faults are major fractures and the last two have large displacements. The thrust faults on Mount Sherman, on the east wall of the northern head of Iowa Amphitheater, are noteworthy also; throughout most of its extent each is nearly parallel with the bedding planes and locally the walls have been mineralized. These thrust faults and the Liddie fault contain silver-lead-zinc ore with much barite. The high-grade ore produced in the Continental Chief mine indicates uncommonly intense mineralization for this area. Here, as elsewhere, exploratory mining consists of finding one or more northeast-trending mineralized fissures, and then raising or sinking along them to the top of the Leadville dolomite. Adits and crosscuts should be driven as nearly as practicable at right angles to the mineralized fissures, which trend N. 40° to 45° E. Similar suggestions apply to the vicinity of the Hilltop ore body, a mile and a quarter farther south. In that area the fissures are parallel in strike with those on the west slope of Mount Sherman.

On the northern slope of the northern West Sheridan Peak, on the southern slope of East Ball Mountain, and at a few other localities small bodies of gold ore have been mined. Commonly, they are characterized by narrow shear zones which are rusty and perhaps quartzose, but they do not contrast strikingly with the barren country rock. Mineral deposits of this type lie along fissures in pre-Cambrian and Cambrian rocks throughout the Mosquito Range. The ore bodies are commonly small, and locally very rich. Search for similar deposits by small-scale operations is suggested.

PEERLESS AND HORSESHOE MOUNTAINS

Along the crest of the range, from Mount Sheridan south to the north slope of Horseshoe Mountain, the ore has generally been found in small but productive deposits at the contact between the Leadville dolomite and either the early White porphyry or a highly silicified bed which marks the top of the dolomite. The most promising places for search are along the fractures that cut across the beds—fractures such as those near the Peerless Mountain and at the pits half a mile north of Horseshoe Mountain along the range crest. Especially interesting are the mineralized faults northeast of Prospect U–71 and near Prospect U–67. The ground there resembles that at the Continental Chief and Hilltop mines. At Prospect U–67, on Peerless Mountain, eastward-dipping Leadville dolomite is overlain by a White porphyry sill which may conceal promising ground. Fissures should be sought in the exposed part of the dolomite and in the overlying sill for productive bodies at the contact between the two rock units. Prospecting is made especially difficult by the altitude and ruggedness of this area; nevertheless, further exploration here is merited.

HEAD OF EMPIRE AMPHITHEATER

The territory at the head of Empire Amphitheater is less likely to contain ore than the others described, as the country rock is chiefly pre-Cambrian granite. Considerable prospecting has been done here, mainly and misguidedly along pegmatite dikes. Small gold veins have been discovered, mostly trending northeast, but evidently have not encouraged further prospecting.

EMPIRE GULCH BETWEEN MITCHELL RANCH AND EMPIRE HILL

There has been extensive prospecting in the area of Empire Gulch between Mitchell ranch and Empire Hill, especially along the Mike fault, north of its junction with the Union fault. This relatively inaccessible area is one of the most promising places in the marginal Leadville area. The area along the minor faults trending east on the western slope of Empire Hill should be prospected. The workings on the Eclipse claim (T–151) are of interest because rock in the dump is considerably iron-stained and ore reputedly of high grade was once mined here. However, ore in place is not available as the workings are caved.

The prospects about 1½ miles due west of the crest of Empire Hill are especially interesting. The Leadville dolomite, here beneath a sill of early White porphyry, is considerably shattered, not only by faults transverse to the strike but also along others, unquestionably of premineral age, that are parallel with the strike and almost parallel with the bedding planes. The structural situation is thus analogous to that on the northeastern wall of Iowa Amphitheater. Unfortunately, erosion has destroyed all but one small area of the early White porphyry caprock. Several "showings" of high-grade ore with silver-bearing galena are exposed in shallow workings or at the outcrop, but lack continuity.

IOWA GULCH BETWEEN CRESTS OF PRINTER BOY HILL AND LOWER LONG AND DERRY HILL

The area of Iowa Gulch between the crests of Printer Boy Hill and Lower Long and Derry Hill contains the

Lillian, Rex, and Mansfield workings. Of special promise is the region east of the Mike fault, for this fault is known to be of premineral age, and shattered ground along it may have provided channels for ore-forming solutions. Moreover, the area between the Mike fault and the Doris shaft, three-quarters of a mile east, is heavily shattered and cut by dikes of the Johnson Gulch porphyry, the member of the Gray porphyry group generally most closely associated in time and place with ore. Apparently a small plug of Johnson Gulch porphyry, similar to the Breece Hill stock to the north, cuts the sill of early White porphyry exposed west of the Mike fault. By analogy, fissures in or close to such a plug should be favorable for mineral deposits. The ore and gangue minerals at the Julia-Fisk and First National mines reflect the relatively high temperature and great intensity of mineralizing processes. A short distance to the north are the once highly profitable workings of the Lillian and Steel Spring mines, whose outputs included unusually large proportions of precious metals. The exposures are generally fair, and exploration at definite horizons is thus not difficult. The First National, Lillian and Steel Spring mines are located in the upper part of the Leadville dolomite and the Julia-Fisk mine follows a vein that cuts the overlying White porphyry and Weber(?) formation. The intensity of mineralization, however, justifies prospecting where dikes and premineral faults cut the lower formations.

On the south side of Iowa Gulch, the Belcher tunnel near the valley bottom and the Kenosha, Diana, and Porphyry prospects on higher ground have all been productive, at least on a small scale. Their records show that pockets of good ore have been mined. The Belcher and Kenosha tunnels are in the Manitou dolomite and Cambrian beds, the Diana and Porphyry prospects are in the upper part of the Leadville dolomite, and several prospects to the west are in the lower part of the Leadville, Dyer, and Manitou dolomites. Perhaps all the rocks from the base of the Weber(?) formation to the top of the pre-Cambrian have been somewhat mineralized. Certainly the highly stained silicified outcrops and the few showings of ore on the dumps of the prospects in their vicinity along the crest of Lower Long and Derry Hill merit some investigation.

The widespread mineralization indicates that the margins of the numerous dikes and the traces of the many faults that cut the quartzite and limestones on both sides of Iowa Gulch deserve careful search for more ore.

IOWA GULCH NEAR THE WESTON FAULT

From the Mosquito fault west to the Weston fault, the area bounded on the south by Upper Long and Derry Hill and on the north by the southern slope of Ball Mountain is of great interest. Within or closely adjacent to it are the Ontario, Hellena, Clear Grit, and other properties that were once extensively worked. Several of them, notably the Hellena, have yielded rich ore. The area from the Hellena mine northward along the Hellena vein especially merits exploration. From the Hellena mine south this fault was productive, and it is known to have extended to the American Continental workings, 600 ft north of the Hellena. As the Hellena fault was at least moderately well mineralized there, and as its northward continuation may be represented by the productive Sunday vein, exploration between the Sunday and American Continental mines appears to be merited; cover at the surface, however, would make underground exploration by test-pitting or shallow prospecting necessary. A lateral from the Yak tunnel would afford drainage down to approximately the 600-ft level of the Hellena mine. Such a lateral would reach the Sunday vein in about 4,500 ft, and the vein zone could be explored by drifts for a distance of 3,000 ft as far as the Hellena shaft.

The entire region of Iowa Gulch between the Ball Mountain and Hellena faults and north of the Iowa fault holds considerable hope for production below the Leadville dolomite, but very much water is likely to be encountered on any faults below Iowa Gulch. This difficulty may perhaps be reduced by preliminary diamond drilling, following careful planning.

Another area meriting exploration is that in the Leadville dolomite west of the Weston fault, where search should be directed at possible ore bodies below the thick sill of early White porphyry, the bedrock that underlies the gravel-covered floor of Iowa Gulch.

MINES AND PROSPECTS

PLAN OF DESCRIPTION

The excellent studies by Emmons, Irving, and Loughlin (1927), contain adequate descriptions of the surface geology, the mines, and the prospects of the central part of the Leadville district. The current report pictures in similar detail the surface geology and mines of the outer part of the district, beyond the limits shown on plate 13 of their report.

In this outer area there are probably more than 1,800 openings. Most of them are but shallow pits, shallow caved shafts, or short caved tunnels, which yielded little ore and are useful mainly because they furnish clues to the bedrock geology, and so are not described here. However, the dumps of a few minor inaccessible pits and tunnels which reveal ore minerals or other features encouraging to prospectors, are briefly described. Still others, such as the Hilltop Mine, are credited with a substantial output and may again become productive; though inaccessible, such mines are described as fully as is feasible on the basis of data collected from former operators and miners. Finally, several larger mines, and also the few smaller prospects that were in operation or at least accessible at the time of these studies, contain ore or exhibit the relations of ore bodies and are therefore described in considerable detail.

To facilitate finding the places, the large map (pl. 1) has been divided into sections on the basis of latitude and longitude. These sections are designated by letters. In each section the separate openings, or groups of openings where individual pits and tunnels lie close together, have been numbered. In general, the numbers begin in the upper left corner of each section, progressing toward the lower right. Any mine may thus be found by reference to its letter and number on this grid. The names of certain prominent mines appear on the map.

The descriptions of the mines of the marginal districts are arranged in geographic groups, as, for example, the Canterbury Hill group. Mines of the northwestern part of the mapped area are described first—then those of the northeastern, southeastern and southwestern parts.

Only a few mines in the central part of the Leadville district (shown on plate 13 of Professional Paper 148) that have been opened or greatly extended since 1927, are re-described. For convenience the original numbers of plate 13 are retained for mines of the central Leadville district, but the sections are lettered differently to make them consistent with sections of the marginal part of the district.

OUTLYING LEADVILLE AREA

CANTERBURY HILL

Very few mines or prospects on Canterbury Hill are now accessible, and the geology must be largely inferred from early reports and from the surface exposures. It is clear that the Mikado fault reaches the southwestern slope of Canterbury Hill, but it appears to be broken and repeatedly offset by branches of the later Pendery fault. Such branches were not recognized with certainty by Emmons, Irving, and Loughlin (1927), but the irregularities in outcrop pattern of the Leadville dolomite between the Chicago Boy mine and the Old St. Louis shaft cannot be explained satisfactorily unless faulting is postulated. Because the actual structural relations are not clear, faults and formation boundaries are indicated by dashed rather than by solid lines on the map (pl. 1).

A thick sill of Johnson Gulch porphyry overlying the Leadville dolomite crops out over much of the southern slope of Canterbury Hill. Stratigraphically above this sill and northeast of it are alternate thick beds of grits, thin shales, moderately thick limestones of the Weber (?) formation, and sills of Gray porphyry of various types; these rocks form the southwestern slope of Prospect Mountain. Shallow prospects in this region are not likely to show ore, as the Weber (?) formation shows little, if any, mineralization in the marginal part of the Leadville district.

There are only two important groups of workings on Canterbury Hill—the Canterbury tunnel (No. A–1) and the several workings of the Old St. Louis-Princeton-Little Blonde group, situated within 2,000 ft to the south and southwest of the Old St. Louis shaft.

CANTERBURY TUNNEL

The Canterbury tunnel (No. A–1), a community project intended to explore the land between Canterbury Hill and the Ibex mine and to drain the deeper workings of Breece Hill, was begun in 1921. It extends 4,170 feet in a S. 62° E. direction. Since 1926 no work has been done on it. A plan and section of the tunnel are given on plate 11. Starting in glacial and alluvial material, it enters altered porphyry 1,150 ft from the portal and for 300 ft exposes alternations of grits of the Weber (?) formation and porphyry. At 1,450 ft from the portal it crosses a major fault, beyond which it cuts successively the Peerless formation, the Parting quartzite and Dyer dolomite members of the Chaffee formation, and the Leadville dolomite; the Manitou dolomite is faulted out and the relations among the other formations are complicated by repeated faulting. Still farther southeast, a small anticline has brought Parting quartzite to the tunnel level, then Dyer dolomite and Leadville dolomite as the beds dip southeast on the southern limb of the fold. Approximately 3,200 ft from the portal the Canterbury tunnel crosses a conspicuous fault, probably the main Pendery fault, to judge from its position in the new deep-drainage tunnel driven in 1945. This fault strikes N. 70° E. and dips 75° NW., in contrast to its strike of N. 35° E. and dip of 67° NW. in the new tunnel. Beyond it the tunnel crosses Cambrian quartzite and small down-faulted blocks of the Peerless formation. Near the face of the tunnel the beds dip east to northeast, and this dip, coupled with a small fault, brings limestone to the level of the tunnel. The identity of this limestone is in doubt, some observers regarding it as Dyer or Leadville dolomite, but both its lithologic character and its position next to the Peerless formation favor its identification as Manitou dolomite.

Economically, this tunnel has been disappointing. Some high-grade ore in small bodies is said to have been found long ago in the Roseville (No. A–3) and Minneapolis (No. A–6) shafts before the tunnel was begun. Ore was found in the tunnel only at about 2,720–2,780 ft from the portal. The ore is in the margins of small fissures striking N. 55° to 80° E. and N. 60° W., and dipping variously. The northwest-striking fissure, exposed in a crosscut northeast of the tunnel line, has been the site of a little stoping. Most of the mineral matter here is barite that has replaced limestone bordering the fissure. A very small amount of galena that contains some silver is associated with the barite. A raise of 146 ft was put up 50 ft northeast of the tunnel, but no ore was found. Samples of ore, selected because relatively rich in sulfides, assayed 13 to 14.5 percent lead, 2.5 to 4.5 percent zinc, and 14 to 16.5 ounces of silver to the ton (Dickerman, personal communication, 1936). The limestone in the face of the tunnel, however, contains disseminated sulfides said to carry as much as 100 ounces of silver to the ton (Cortellini, personal communication, 1934), though the average content is 10 ounces of silver together with a small amount of zinc carbonate.

It thus appears that the Canterbury tunnel has so far not proved to be an encouraging venture. There is no evidence that any of the major premineral faults hitherto recognized intersect the tunnel. Surface mapping on the southwestern slope of Prospect Mountain (where the rock exposures are poor) indicates that an additional 6,300 ft of tunneling will be necessary to reach the Weston fault. However, there are two favorable indications. One is the presence of extensively mineralized ground along a line of prospects extending N. 35° E. up the southwestern slope of Prospect Mountain from a point about 2,000 ft east of the face of the tunnel. If results of further investigation are encouraging, extension of the tunnel beneath the prospect holes should be considered, as the top of the Leadville dolomite may not be far from tunnel level. The other favorable indication is the presence of oxidized ore rich in silver in the Pawnolos (No. F–6), shaft, as reported by E. P. Chapman (Personal communication, 1938). It occurs near the projected course of the east branch of the Iron fault, presumably along premineral fissures. The east branch of the Iron fault should be intersected about 1,000 ft beyond the Weston fault.

OLD ST. LOUIS SHAFT AND NEARBY WORKINGS

The sequence of rocks on the southwestern slope of Canterbury Hill near the Old St. Louis shaft (No. A–54) was outlined by Emmons in 1886 (p. 223). A thick sill of Johnson Gulch porphyry (the Gray porphyry of Emmons) overlies about 30 feet of early White porphyry. Below it is Leadville dolomite; this and older formations are exposed only locally in the region northwest of the Chicago Boy mine. The Leadville dolomite in this vicinity underlies a thick porphyry sill, a condition generally favorable, but there is little evidence of premineral faults which might have admitted ore-forming solutions. Moreover, the rocks here are poorly exposed and the favorable Leadville dolomite lies mostly under so thick a cover that it cannot be explored from the surface.

A feature of interest is the extensive silicification of the Leadville dolomite where it crops out north of the Chicago Boy mine. Here, presumably near the intersection of the Mikado fault with the several branches of the Pendery fault, the dolomite is brecciated, deeply iron-stained and silicified. This alteration is exemplified near the Little Blonde (No. A–85) and Princeton (No. A–84) tunnels. These facts alone suggest that this part of the Mikado fault was premineral near the larger, postmineral faults. It is also possible that small premineral faults were localized here but have not been recognized in the relatively sparse outcrops. Perhaps in this part of its course the Mikado fault is parallel to an older premineral fissure, as in the similar case in Graham Park (Emmons, Irving, and Loughlin, 1927, p. 92).

Some mines near here are said to have supplied appreciable quantities of native silver, apparently from oxidized ore, but only small amounts of sulfides are found in place today. This type of altered and mineralized ground extends a thousand feet east, north, and west, from the two mines mentioned. The silicified limestone is clearly restricted to the faulted areas and not to the contact between limestone and porphyry. Similar ore from the silicified upper part of the Leadville dolomite in the Evelyn mine in Graham Park (No. J–122), contained 8 to 9 ounces of silver to the ton (Chapman, personal communication); but generally beds that contained sulfides and constituted a good grade of ore where unsilicified declined abruptly in value where silicified. In such cases silicification apparently antedated ore deposition and converted the hitherto soluble limestone, favorable for ore, into an insoluble, difficultly replaced, and densely crystalline rock.

PROSPECT MOUNTAIN

Almost all of the rock exposed on Prospect Mountain is of the Weber(?) formation, which consists of grits and sandstones with smaller quantities of shale and thin-bedded limestone. The limestones, which contrast sharply with the rest of the strata and can be traced for a mile or more along the outcrop, are especially valuable as guides to the structure.

In addition to the Weber(?) formation, and the Leadville dolomite (which is exposed by faulting in a small area along shallow workings near the Uncle Sam shaft) the surface formations consist of several sills of porphyry belonging to the Gray porphyry group and one thin sill of early White porphyry. An especially conspicuous sill of Johnson Gulch porphyry with characteristic large phenocrysts of potash feldspar separates the uppermost Leadville dolomite from the lowest grits of the Weber(?) formation. A porphyry sill of the Evans Gulch type, 50 ft thick, forms a large outcrop in the Lake Isabelle basin, southeast of Prospect Mountain; the extent of this outcrop results, not from the exceptional thickness of the sill, but rather from the chance parallelism of the sill and the surface of the ground. It is significant that no dikes whatever are known in the area. A pipe of rhyolitic agglomerate, first found by R. T. Walker in a west crosscut from the Resurrection mine and later recognized by him at the surface, underlies the basins of the two small lakes northwest of the Resurrection mine.

There are faults of small displacement on Prospect Mountain but complete details are not known because exposures are poor. A continuation of the Winnie-Luema fault (which is mineralized farther south) extends slightly west of north from Little Evans Gulch for about 2,500 ft up Prospect Mountain. The Weston and Iron faults should intersect near Little Evans Gulch, as mapped. The Weston fault is mineralized farther south but the Iron fault is generally believed to be postmineral. The smaller faults on the sides of the amphitheater in which Lake Isabelle is situated do not appear to have favored mineralization. Two apparently unmineralized faults that seem to be related to those of the Pendery system are exposed at the west end of the south slope of Prospect Mountain.

Very few shafts and pits on Prospect Mountain, south as far as Little Evans Gulch and west to Canterbury Hill, are more than 75 ft deep. Most of the tunnels are short and, as the dips of the rocks are generally slight, do not expose very thick stratigraphic sections. The Weber(?) formation and the 250-ft sill of Johnson Gulch porphyry beneath it are equally unfavorable to mineralization; shallow holes on Prospect Mountain where these are the dominant surface rocks clearly offer little promise. The limestone beds within the Weber(?) formation are not thick enough nor sufficiently fractured to have been the places of large-scale mineralization. The only indications of mineralization, even in lower zones, are: the fairly general bleaching of the porphyry sills; the local silicification of some shale of the Weber(?) formation—for example, along the northeast-trending line of prospects (Nos. B–27, B–29, B–30, B–53, and B–52) that lies about 2,000 ft southwest of the crest of Prospect Mountain; and the small deposits of alteration minerals, such as epidote, found in lenses of limestone of the Weber(?) formation, which are exposed in several small tunnels, notably No. B–75, about 1,500 ft S. 65° E. from Lake Isabelle.

The striking alignment of two groups of prospects on the southwestern slope of Prospect Mountain suggests the presence of mineralized fractures. One group was mentioned above and the other (Nos. A–14, A–15, A–17, A–18, A–24, A–25, and A–26) extends along the gulch that separates the crest of Canterbury Hill from the western spur of Prospect Mountain. However, evidence obtained on the dumps is insufficient to prove that either line is located on a mineralized fissure, despite the arrangement which so strongly invites that interpretation.

UNCLE SAM SHAFT

The Uncle Sam shaft is no longer accessible. Emmons (1886, p. 260) describes it as 420 ft deep, passing through a very thin body of early White porphyry and penetrating successively the Leadville dolomite, the Dyer dolomite and Parting quartzite members of the Chaffee formation, the Manitou dolomite, and probably the Peerless formation. The Uncle Sam tunnel nearby penetrates only the Johnson Gulch porphyry, which is the surface rock. Nothing is known of the history of operations.

GREAT EASTERN SHAFT

The Great Eastern shaft, 1,500 ft south-southeast of Lake Isabelle, must have been a large operation—several buildings are still in place, and there is evidence of a campaign of exploration involving extensive core-drilling. It is said that the shaft is 116 ft deep and that a drill hole below it extended 500 ft more. Old maps show a small amount of drifting northeastward from the bottom of the shaft. Little else could be learned of its history, except that a well-defined "contact" deposit, 5 ft thick, was found at the bottom of the shaft; the contact is in the grits of the Weber(?) formation and dips in general southward parallel to the beds at an angle of 25 degrees. Assays showed small amounts of precious metals, especially silver, in oxidized ores rich in manganese and iron. The dump of this shaft reveals fine-grained porphyry of the Evans Gulch type, considerably bleached and silicified, and also a small amount of breccia of the same rock, greatly stained with iron and manganese oxides. As the drill cores found at the shaft collar are of Evans Gulch porphyry, it is inferred that this porphyry and Weber(?) strata extend to a depth of 616 ft below the surface.

BOARD OF TRADE AMPHITHEATER

The Board of Trade Amphitheater offers hope only for deep workings. No important faults are known to occur in it and the surface rocks are sills of the Evans Gulch and Lincoln porphyries and grit and shale beds of the Weber(?) formation with thin intercalations of limestone, locally a little silicified. Several shafts and shallow pits, none more than 100 ft deep, have been sunk in the bottom of the amphitheater. Some short tunnels have been driven into the steep slopes below the mouth of the amphitheater and also in the west wall.

It is not likely that ore can be developed under these openings merely by continuing the Yak tunnel in a N. 30° E. direction. As the beds dip eastward, and as the level of the Yak tunnel (at an altitude of about 10,430 ft) is above the top of the Leadville dolomite at the Diamond mine farther south, extension of the tunnel northeastward to a place near the Board of Trade Amphitheater would cut progressively higher strata and correspondingly less favorable rocks, stratigraphically well above the top of the Leadville dolomite (sec. A–A′, pl. 2). This conclusion was suggested by Emmons, Irving, and Loughlin (1927, pl. 14) and is amply borne out by the studies here reported.

BIRDSEYE GULCH AND ADJACENT SLOPES

HEAD OF BIRDSEYE GULCH

The Mosquito fault extends northward from the north branch of Evans Amphitheater into the head of Birdseye Gulch, along the western slope of the range. The escarpment along that slope is virtually a fault scarp with the lower part of the Paleozoic section exposed on the upthrown side of the fault. East of this escarpment there are several distributive faults, approximately parallel to the Mosquito fault and somewhat similarly mineralized. No faults that might offer encouragement to vein mining are known west of the Mosquito fault near the head of Birdseye Gulch and mining would have to be carried to depths corresponding to an altitude of about 10,200 ft, where the top of the Leadville dolomite would be reached. Mining at such a depth would involve a long extension of the Yak tunnel and the sinking of winzes for 230 ft or more below the tunnel level; or the sinking of shafts to depths of 1,600 ft or more, depending upon their location.

It is reported that at some prospects at the very head of Birdseye Gulch, small fissure veins in the grits of the Weber(?) formation contain some gold (Youe, personal communication, 1929).

LITTLE CORINNE AND NEARBY PROSPECTS

In an area east of Birdseye Gulch on the western slope of the Mosquito Range, and northeast of the area shown on the main geologic map (pl. 1) there are the Little Corinne and several other small mines and prospects; all except one of them have been abandoned (fig. 74). They are of interest because they lie between the Mosquito and London faults, and near their junction. Both of the faults—especially the London—are mineralized to the south. The writer spent two days studying the western slope of the range just west of Mosquito Mountain and prepared a geologic map of the area. Much of the crest of the range west of the London fault is covered with rubble and therefore the geology must be inferred. No topographic map was available and locations are approximate. A claim map was kindly furnished by Mr. F. J. McNair of Leadville.

The Little Corinne mine, on the northern slope of Mosquito Mountain, was developed by two tunnels on the Little Corinne claim; the upper was near the top of the Leadville dolomite, the lower in Manitou dolomite. Both are now abandoned. The country rock is intensely shattered and the Leadville dolomite is considerably stained by iron oxides and copper carbonate. The mining properties lie in a triangle formed by the main London fault, an intersecting fault to the west, and a fault trending east which forms the southern border of the triangle. The Little Corinne mine is said to have been highly productive, but records of shipments are not available.

Several adits have been driven eastward from the western slope of Corinne and Mosquito Mountains, but generally they do not follow fissures. The adits trend northeast to east, whereas the three faults recognized on the surface west of the London fault trend southeast, as shown on figure 74. A caved adit on the Governor claim evidently started with an east-northeast trend, then followed the accessory thrust fault that lies west of the London fault; material from this accessory fault is represented on the dump by breccia cemented with pyrite and siderite.

The Killarney adit, southernmost of four openings on the Prince Frederick claim, has a course generally eastward through Leadville dolomite and a sill of rock belonging to the Gray porphyry group. About 640 ft from the portal the adit passes through upturned westward-dipping beds that may be indicative of drag along the same thrust fault as that followed by the Governor tunnel, or perhaps along the London fault itself. This adit had been extended intermittently for about 10 years previous to 1930 but cut neither the faults nor any ore bodies.

EVANS AMPHITHEATER

North of the point where the Mosquito fault crosses the saddle between West Dyer Mountain and Little Ellen Hill it follows a north-northeasterly course across Evans Amphitheater. There is but little faulting on the west or downthrown side, though one accessory fault lies subparallel to the major fault plane. The rocks exposed are the clastic beds of the Weber(?) formation with a few thin limestone strata and sills of Lincoln, Evans Gulch, and Johnson Gulch porphyries. Thrusting from the east has sharply upturned the Weber(?) strata against the Mosquito fault and has apparently broken away and dragged up a mass of Leadville dolomite, bounded on the west by the accessory fault. This fragment is nearly 1 mile long and 500 ft wide. East of this fragment, and also farther north and south along the outcrop of the Mosquito fault, the rock succession on the upthrown side is fairly regular, with the beds dipping generally east or southeast, as shown in the head and in the eastern wall of the Evans Amphitheater (fig. 75). Pre-Cambrian rocks form the eastern wall of the fault and farther east the strata exposed include all formations up to the grits and shales of the Weber(?) formation, which cap the crest of Mount Evans. This upthrown side is broken by several faults having strikes similar to that of the Mosquito fault. Only one fault of this group has a throw of as much as 100 ft. The dips of only a few of the fault planes are determinable. Generally the western side is downthrown, as also along the Mosquito fault.

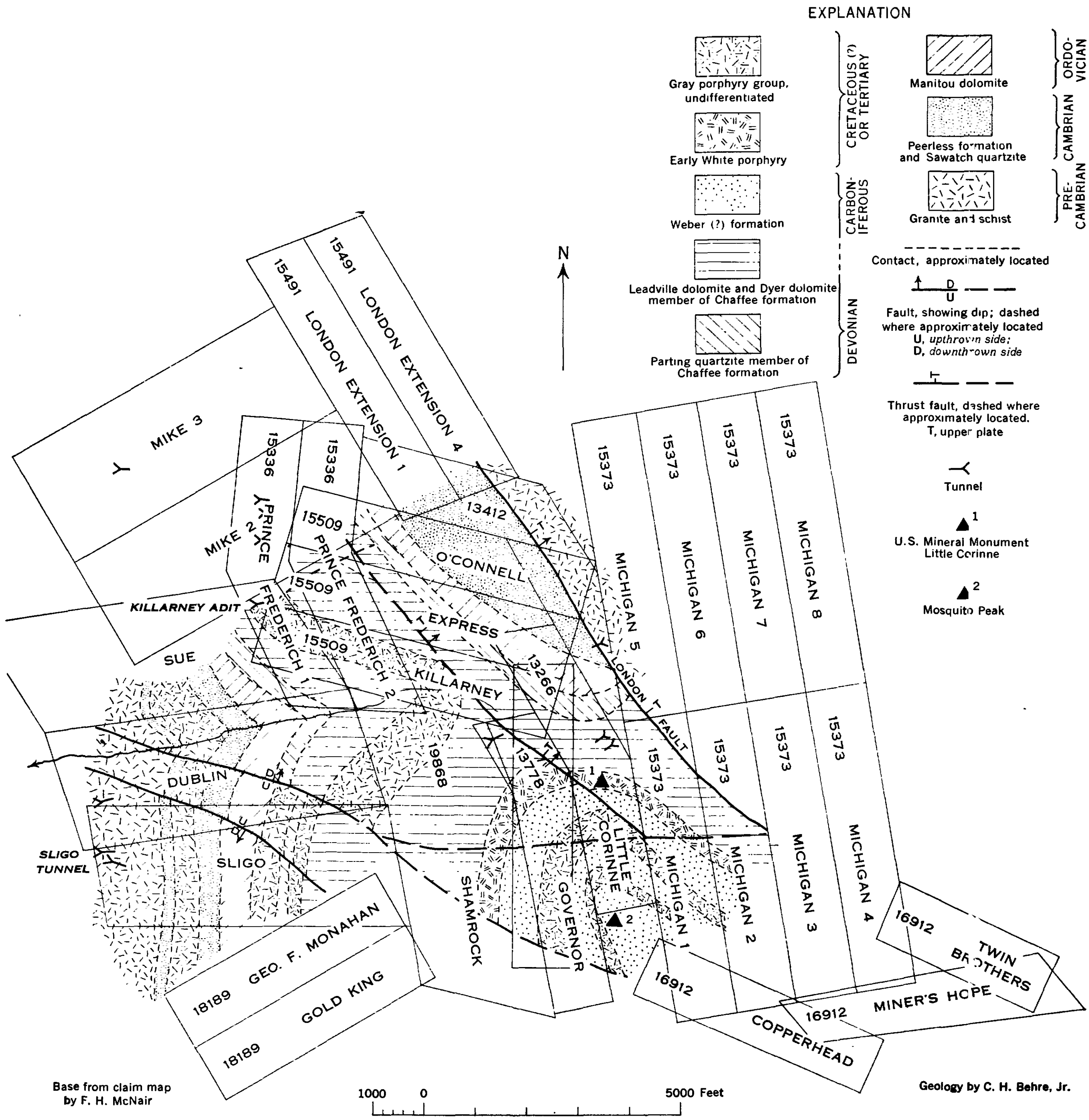

FIGURE 74.—Map showing geology near Killarney and Little Corinne workings. In part after F. H. McNair.

Four groups of prospects in Evans Amphitheater merit description. They are the Daisy-Kemble group, the Miller group, the Best Friend group, and the group of prospects and mines at the southern head of the Evans Amphitheater.

DAISY-KEMBLE GROUP

At the extreme northern end of the Evans Amphitheater the several faults with strikes of N. 15° to 50° E. are subordinate, locally show much drag of the adjacent beds, and are apparently related to the great Mosquito fault. They are clearly exposed near a group of prospect tunnels and shafts (Nos. C–59, C–60, C–61, and C–62) situated between the 12,250-ft and 12,500-ft contours. The short tunnels, now largely caved, were driven into the hillside along the zones of shattered, iron-stained rock bordering the faults.

The easternmost tunnel of the group (No. C–60), situated on the Kemble claim, is 150 ft long and has a shallow shaft near its end. The rock penetrated is bleached Dyer dolomite a short distance above the Parting quartzite. The tunnel apparently follows a fissure striking N. 25° E.; along it there has been a small

FIGURE 75.—Floor and walls of southern head, Evans Amphitheater; rock glacier in left middle distance; laccolithic sill of Dyer Mountain in background; note later white porphyry dike (*Tlw*) in saddle and, *Ts*, Sacramento porphyry in Dyer Mountain; *Tew*, early White porphyry; Є, Cambrian; *Om*, Manitou dolomite; *Dp*, Peerless shale; *Dd*, Dyer dolomite; *Cl*, Leadville dolomite; *Cw*, Weber (?) formation.

amount of stoping. About 50 ft higher is a short adit just east of the fissure; at its portal the beds of Dyer dolomite are dragged sharply up along a fault whose west wall is upthrown.

The workings of the Daisy mine (No. C–62), 800 ft northwest of the Kemble tunnel, are caved, but apparently are along a small fault trending northeast in the upper part of the Dyer dolomite.

Three shafts (No. C–59), situated at an altitude of 12,050 ft and 110 ft S. 35° W. from the Daisy tunnel, have been sunk to depths of 100 ft or less in brecciated granite, pegmatite, and schist. On one of the dumps there are much coarsely crystalline dolomite and small quantities of pyrite and sphalerite. Apparently the shafts were sunk along a fault fissure, here trending N. 40° E., that is continuous with that of the Daisy mine.

MILLER GROUP

Along the western flank of Evans Mountain and on the cliffs rising to that peak there are numerous small tunnels and shafts or pits, none of which has yielded appreciable quantities of ore. Several tunnels that have been driven in the Dyer dolomite and the Leadville dolomite are the most promising.

The northernmost opening of the group (No. C–74, north adit) is situated about 1,500 ft south of the Daisy mine. It represents some 300 ft of workings in the Gray porphyry group and early White porphyry and Dyer dolomite (fig. 76). The structural relations are complicated by several minor faults that do not reach the surface, but are seen to strike north or northeast in the adit. The faults generally have the west side dropped and are only weakly mineralized, containing mainly coarsely crystalline dolomite.

About 1,500 ft south of opening C–74 are two other openings (No. C–91); only Miller's adit, the lower of them, is accessible (see fig. 77). It is driven chiefly just below the contact between the Peerless formation and the Sawatch quartzite (and at a lower altitude than

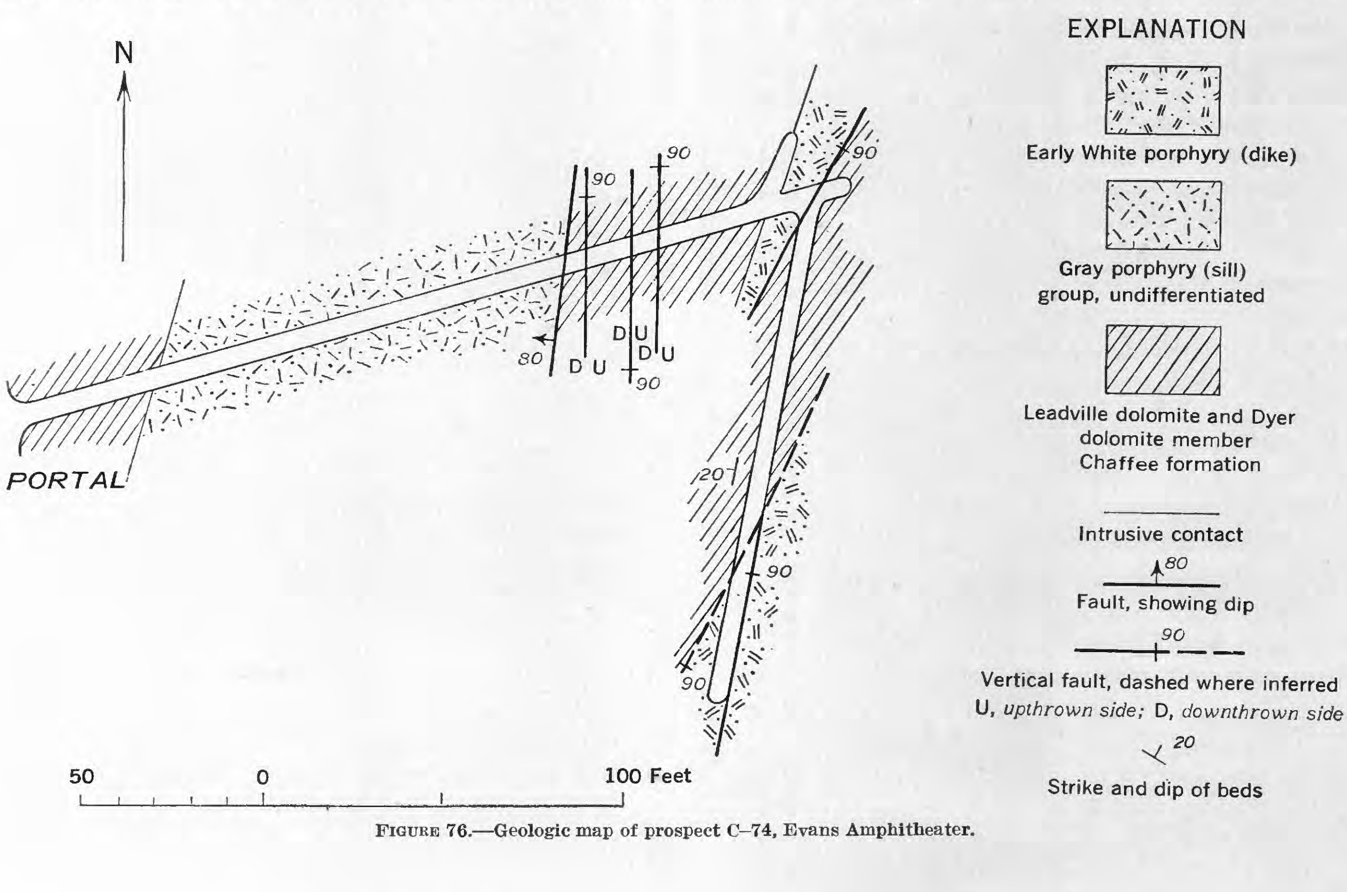

FIGURE 76.—Geologic map of prospect C–74, Evans Amphitheater.

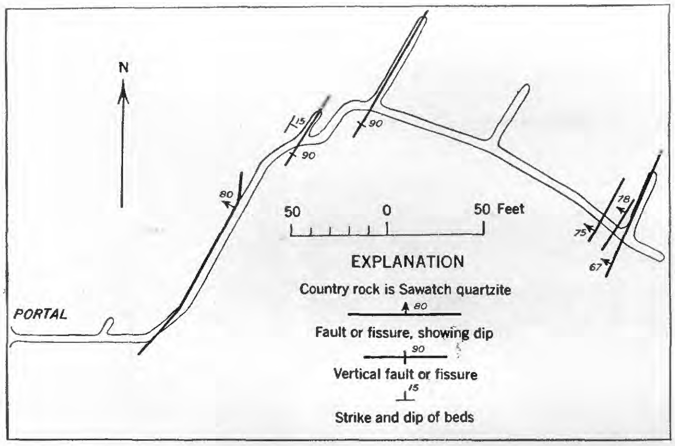

FIGURE 77.—Geologic map of Miller's adit. Note dominance of faults with northeast trend.

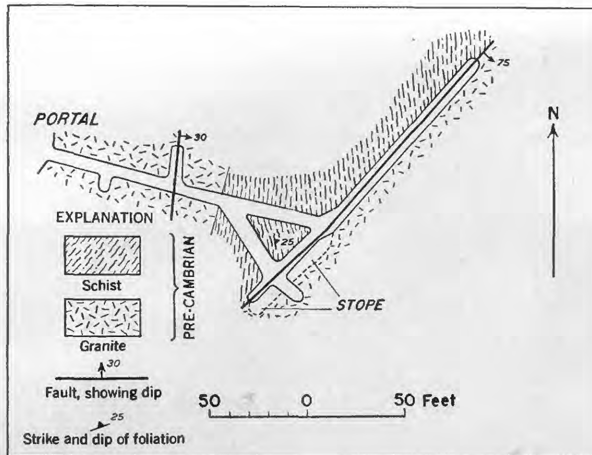

FIGURE 78.—Geologic map of prospect C–80.

no. C–74) (fig. 77). Like C–74, Miller's adit has revealed numerous small northeastward-trending faults that are vertical or dip steeply west and generally have the west side down-thrown. They are not mineralized and, except for a small amount of fluorite found on the dump, there is little here to encourage prospecting. Work here was carried on in 1927–30.

South of the above prospect several tunnels on the western slope of Mount Evans seem to have courses about due east along a series of joints or small faults. No evidence of mineralization remains, but it is said that several of these fissures contained very small but rich pockets of native gold.

BEST FRIEND GROUP

Many attempts have been made to explore the main Mosquito fault in its course across the Evans Amphitheater. The prospects are here grouped together although they lie on several properties.

The northernmost of the openings, an isolated tunnel (No. C–77), is in the pre-Cambrian rocks just east of the Mosquito fault. Here brecciated schist forms the walls of a subsidiary fissure about 200 ft east of the probable location of the fault. The breccia is cemented by pyrite and galena, and is somewhat copper-stained. A shaft is located close to this tunnel.

About 1,500 ft southwest of this tunnel is a group of workings (No. C–80) which comprises three shafts and an adit. The adit (fig. 78) follows a northeasterly vein and fault contact that dips 75° SE., and has brought pre-Cambrian schist on the northwest against granite on the southeast; the walls of the fault are locally silicified, and bear strong vertical striae. Rocks on the dump of this and the neighboring shafts are somewhat epidotized, silicified, and iron-stained, and contain a little pyrite; a few pieces of granite contain vugs lined with sphalerite. These workings are said (John Harvey, oral communication, 1939) to have yielded ore containing 100 to 200 ounces of silver and 0.40 ounce of gold to the ton, presumably from the vein mentioned.

The Best Friend tunnel (No. C–88), now caved, is said to be 300 ft long and to trend south-southwest, evidently along the Mosquito fault. Its dump contains fragments of Leadville dolomite and grit of the Weber(?) formation from the downthrown wall of the fault and of pre-Cambrian granite from the opposite wall. There is a little mineralized material containing pyrite and chalcopyrite, but no massive ore could be found on the dump. This tunnel is said to have disclosed pockets of high-grade ore in the fault. Previous to 1893, the operators are reported to have mined ore valued at $100,000, chiefly gold but also considerable silver (Harvey, oral communication, 1939).

A short distance east are two shallow shafts and a tunnel (No. C–89). The tunnel is in pre-Cambrian granite east of the fault. It shows no fissure, but both shafts, now inaccessible, have on their dumps fragments containing veinlets of galena, sphalerite, pyrite, and chalcopyrite crustified upon earlier quartz. In general the mineralized rock occurs along a small fissure approximately parallel to the main Mosquito fault; there is, however, no good evidence of such a fissure in the scattered surface outcrops of granite.

About 1,200 ft southwest along the trace of the Mosquito fault are a shaft and two small pits (No. C–103). The depth of the shaft is estimated to be 85 to 100 ft. The dumps here contain heavily mineralized granite, with vugs containing siderite, quartz, and pyrite, with a little sphalerite and some galena. Crustified veinlets prove that the pyrite was earlier than the siderite. This operation is said to have yielded $100,000, chiefly in gold and silver (Harvey, personal communication, 1938).

PROSPECTS AT HEAD OF EVANS AMPHITHEATER

One shaft and two tunnels with an adjoining cabin (No. N–24) are located at an altitude of 12,200 ft at the head of Evans Amphitheater. All the development work was done in the Peerless formation and hence is not well located for discovery of ore.

About 800 ft south of the cabin of Prospect N–24, on the northern slope from the saddle connecting West Dyer and Dyer Mountains, are three tunnels (No. N–25) driven in the upper part of the Dyer dolomite or just above it. Barite is disseminated in the limestone country rock and fills small fissures. The mineralization resembles that in the Continental Chief mine (pp. 133–136) and seems to justify more careful prospecting, especially at a higher horizon.

LITTLE ELLEN HILL AND ADJACENT PARTS OF EVANS GULCH

Sills of various porphyries of the Gray porphyry group alternating with beds of the Weber(?) formation are exposed on Little Ellen Hill. The Mosquito fault passes between Little Ellen Hill and West Dyer Mountain (fig. 79). On the southern slope of Little Ellen Hill and the northwestern slope of West Dyer Mountain the beds of the downthrown block are dragged up so sharply that their dips are generally as high as 55° and locally 70°. Elsewhere, however, the structure is gentle and the beds dip gently eastward or northeastward. This gentle dip of the rocks is also seen in Evans Gulch, between the Board of Trade Amphitheater and Little Ellen Hill, and here, too, the surface rocks are grits and shales of the Weber(?) formation and sills of rocks of the Gray porphyry group, continuous with those of Little Ellen Hill.

PUZZLER GROUP

The Puzzler group of prospects (Nos. C–117, C–118, and related openings) and the Diamond mine are the principal workings of economic interest on Little Ellen Hill and the adjacent parts of Evans Gulch. These workings disclosed lenses of slightly silicified limestone in the Weber(?) formation. The Leadville dolomite, however, lies too deeply buried to be readily

FIGURE 79.—Trace of mineralized Mosquito fault near the south head of Evans Amphitheater, looking southwest. Barren Weber(?) formation (*Cw*) and Tertiary porphyry (*Tge*) exposed on Little Ellen Hill over the potentially productive Leadville dolomite, which passes beneath the valley to the right. Rocks exposed on slopes of West Dyer Mountain include the Leadville dolomite (*Cl*), early Paleozoic formations (*P*), and pre-Cambrian rocks (*p€*).

accessible from the surface, and the limestones of the Weber(?) formation are not sufficiently mineralized to justify exploration.

The Izzard (No. M–14) and other mines just southwest of the Puzzler group, are outside the area here described and also inaccessible, but they may indicate the nature of mineralization at depth in the Puzzler and related claims. Lessees working in these mines discovered many small fractures, along which ore has replaced Leadville dolomite below the basal shale of the Weber(?) formation (John Harvey, oral communication, 1939). As suggested to the writer by E. P. Chapman, the Puzzler area thus gains in interest, and the geologic conditions appear to justify further exploration at depth.

DIAMOND MINE

According to data assembled by E. P. Chapman (Personal communication, 1936), the Diamond mine (No. D–2) was opened in mineralized ground that may be regarded as a single, almost continuous shoot extending northward from the Little Ellen incline (No. M–9) to the Diamond mine. This shoot was a "contact" body at the top of the Leadville dolomite, here covered by a sill of early White porphyry about 100 ft thick (Emmons, Irving, and Loughlin, 1927, pl. 15). As mining was carried progressively farther north, past the Resurrection No. 2 shaft and into the Diamond claim, the northeasterly dip of the beds compelled progressively deeper mining, largely below the level of the Yak tunnel. This in turn necessitated hoisting through several winzes; moreover, it is said that pumping, handicapped as it was by the indirect course of the openings, became expensive, although it amounted to only 350 gallons per minute. These factors, together with a decrease in the size of the ore body, finally brought an end to the operations about 1917. The ore mined was apparently ferruginous, largely oxidized, and rich in lead. Some ore was found in the Manitou dolomite, but it was more siliceous, contained considerable zinc and less lead, and was but little oxidized.

The area northeast of the Diamond shaft may justify further exploration, but this exploration would have to be carried on below the level of the Yak tunnel and, almost certainly, large volumes of water would be encountered. Exploratory deep drilling might be successful but it would have to be carried to depths of 1,000 ft at the Diamond shaft, with an increase in depth of about 120 ft for every 500 ft of horizontal advance northeast of that shaft.

BALL MOUNTAIN AND SOUTH EVANS GULCH

North of the spur connecting East Ball Mountain with Ball Mountain, the geology is relatively simple. The conspicuous features here are the Mosquito fault and several somewhat similar and subparallel faults in the head of South Evans Gulch. A block exposing parts of the Leadville and Dyer dolomites and part of a sill of early White porphyry lies between the Mosquito fault to the east and a subsidiary fault to the west; this block is noteworthy for its similarity to the one west of the Best Friend mine (p. 126).

South and southwest of the saddle at the head of the Alps Gulch the structure is more complicated. The main Ball Mountain fault extends north-northwestward from Iowa Gulch, crossing Ball Mountain just a little west of its crest. Its course is marked by a highly silicified and altered breccia zone, in places attaining a width of as much as 300 ft. East of it are several minor subparallel faults. On the eastern slope of Ball Mountain, east of the minor faults, an eastward pitching anticline with axis trending about N. 80° E. is cut along its crest and on its north limb by numerous dikes of Johnson Gulch porphyry. In vertical sections at right angles to the axis of the fold, these dike fractures radiate outward from the central part of the fold and are chiefly on the crest of its northerly, more gently dipping limb. Two faults north of the fold trend northeastward in the direction of Alps Gulch, but surface evidences of their northward extension are lost in the Weber(?) formation near the middle of the gulch. Along its southern limb also the anticline is broken by a fault that dies out northeastward toward the Mosquito fault.

Within the boundaries of the area here described, three blocks of ground are of possible economic interest. One is in the group of prospects near U. S. Land Monument Alpha (Prospects N–80 and N–82) another is about 1,500 ft farther north near Prospects N–62 and N–68, adjacent to subsidiary faulting on the Defiance and nearby claims; the third is near the Way Up No. 1 claim, in the region of Prospect N–17, in the block of "Blue" limestones between the Mosquito fault and the subsidiary fault that passes northeast of the notch between East Ball and Ball mountains.

PROSPECTS NEAR U. S. LAND MONUMENT ALPHA

The prospects and shafts (Nos. N–78, N–81, N–82, N–90, N–128, and O–129) east of the Ball Mountain fault near Land Monument Alpha are of interest because of their stratigraphic and structural position. Several are near the contact between the Leadville dolomite and the overlying thick sill of early White porphyry. All are within 1,000 ft of the great Mosquito fault, along which mineralizing solutions rose and formed the ore deposits of the Best Friend and other mines in the more northerly part of the Leadville district. Although conditions are similar in this area, no surface evidence of mineralization was found, perhaps because of the absence of fractures other than the Mosquito fault itself along which mineralizing solutions could rise, and possibly because the quantity or concentration of the solutions rising along the fault was less here than farther north.

The Mosquito fault is premineral in this area. A caved tunnel (No. N–128) situated about 700 ft east-southeast from U. S. Land Monument Alpha and driven directly on the Mosquito fault is inaccessible, but the Leadville dolomite on the dump is largely replaced by pyrite. As at several other localities in Evans Amphitheater, similar evidence indicates that the Mosquito is a premineral fault. The writer suggests that it be explored where it passes through the Leadville dolomite.

DEFIANCE AND ADJACENT CLAIMS

There is some mineralized ground in and near the small fault trending northeast along the south limb of the anticline situated east of Ball Mountain. Mineralized material found on the dump of the prospect pit of group No. N–70, consists chiefly of iron-stained, baritized limestone. A tunnel located 1,500 ft from the summit of Ball Mountain in a direction S. 43° E. and west of the Ball Mountain fault cuts pyritized Johnson Gulch porphyry.

The dumped material from several minor openings in this area is heavily iron-stained, which indicates the oxidation of disseminated pyrite and, possibly, the presence of other sulfides. Nothing could be learned of the history of operations in these localities, however, and none of the openings is large enough to indicate that large ore bodies had been present. The Ball Mountain fault is definitely premineral, but the surface rocks on both sides of it in this immediate locality are not especially susceptible to mineralization as they consist of the Weber (?) formation, Sawatch quartzite, Peerless formation, and porphyry.

WAY UP NO. 1 CLAIM

Several small openings (Nos. N–14, N–15, and adjacent claims) in the block of Leadville and Dyer dolomites lying west of the Mosquito fault expose Leadville dolomite which is deeply stained by oxidized iron pyrite. The Mosquito fault, which forms the eastern boundary of the block, is mineralized at points 2,000 ft to the north and 3,500 ft to the south; moreover, the branch of the Mosquito fault that forms the western boundary of this block is probably mineralized. The block of limestone between the faults therefore merits prospecting, and some evidence of mineralization is exposed in Prospects C–113 and N–16. The top of the Leadville dolomite, however, has been removed by erosion. The normal depth to the top of the Leadville dolomite along the western wall of the fault should be 1,800 to 2,300 ft. These depths are respectively about 400 and 950 ft below the nearest point on the Yak tunnel from which a lateral could be driven to this block of ground. Ore and water would therefore have to be raised to the Yak tunnel level. Moreover, the length of such a lateral would approximate a mile. Exploratory mining in the downthrown block west of the fault should be undertaken only if preliminary exploratory drilling from the surface clearly indicates that such mining would be worthwhile.

EAST BALL MOUNTAIN

PROSPECTS ON SOUTHERN SLOPE

In the pre-Cambrian and Cambrian rocks west of the mouth of Dyer Amphitheater and east of the Mosquito fault, there are several small openings (Nos. N–83 to N–89) at altitudes between 11,600 and 12,000 ft. The rocks exposed here are just beneath the South Dyer thrust, and most of the prospects are located on small fissures, in part true faults, which strike N. 0°–45° E. and dip westward or vertically. Evidence of mineralization consists of iron and manganese staining along these fractures. Some of the openings are in sills of early White porphyry, some are in pre-Cambrian granite, but most are in dense, massive, white Cambrian quartzite. The two largest adits lie at altitudes slightly above and below 11,900 ft respectively. They are nearly parallel, trending approximately due north along a well-marked fault that dips 50°–70°W., and displaces the South Dyer thrust fault. It is characterized by a quartz filling accompanied by limonite, pseudomorphic after pyrite; accessory fissures seen in the openings meet the fault at a small angle, striking similarly but dipping only 40° W. The lowest pits on the southern slope of East Ball Mountain are openings in the lateral moraine of the Dyer-Iowa valley glacier; they do not enter bedrock. There is some development work also along a dike of quartz-diorite porphyry that crops out along the western slope near the crest of East Ball Mountain.

Prospects of this group are said to have been operated largely for gold. No evidence remains that gold was ever found here but fissure walls are commonly stained with manganese oxide, and possibly, as inferred by mining men familiar with the area, there was enough gold to support small-scale operations.

PROSPECTS ON CREST AND EASTERN SLOPE

Several small openings on the crest of East Ball Mountain were driven along faults that trend N. 15° E. The faults displace the contact between Cambrian and pre-Cambrian rocks or intervening sills at many places and are occupied by dikes of later white porphyry. Farther northeast an adit (No. N–43) about 10 ft long is driven along a fracture trending N. 30° W. These openings and others of the same kind nearby were located on iron-stained fractures in Cambrian quartzite; apparently they were driven in search of gold ore but there are no evident results.

DYER AMPHITHEATER AND DYER MOUNTAIN

The area near the mouth of Dyer Amphitheater and the southern slope of Dyer Mountain forms a structural unit. The South Dyer reverse fault dipping northeast breaks across the local rock sequence, lifting the block composing Dyer Mountain and Dyer Amphitheater and advancing this block southward with respect to the block beneath Iowa Gulch. The sequence of rocks exposed above the fault in Dyer Amphitheater and on Dyer Mountain is normal. It consists of pre-Cambrian rocks forming the floor of the amphitheater and overlain by the usual succession. A thick sill of Sacramento porphyry some distance above the base of the Weber(?) formation caps the crest of Dyer Mountain.

In addition to the South Dyer thrust, this region shows two noteworthy faults, the Liddia and Dyer. The former is not mineralized, but premineral fissures near it control the positions of ore bodies in the Liddia mine. No ore has so far been discovered along the Dyer fault.

There are three groups of prospects and mines of interest in this area: the tunnels on the west slope of Dyer Mountain near the Kitty and Dyer group of claims, the prospects on the southwestern spur of Dyer Mountain near the Revenue and Tingle-Tangle claims. and the Liddia mine and nearby openings.

KITTY AND DYER GROUPS

The Kitty prospects (N–43a) include three small openings in vuggy upper part of the Leadville dolomite, stratigraphically about 50 ft below the base of the early White porphyry sill. These prospects are favorably located near the projected trace of a small fault that crosses Dyer Mountain about 1,000 ft north of its summit. This fault is presumably premineral, to judge by its course and its stained walls, but no mineral deposits have been discovered along it. A tunnel about 2,000 ft due south of the Kitty claim is in much the same geologic position.

Six openings on the Dyer or Dyer Extension claims (No. N–42) lie about 1,500 ft south of the Kitty claim. The three larger ones are adits; two of the smaller openings are short tunnels or shallow pits; the sixth is a shallow shaft. One of the adits begins along a fault striking N. 80° E. and dipping 40° S.; on it the vertical displacement is 6 in. down on the southeast. All of these openings are either in the lower part of the Leadville dolomite or near the top of the Dyer dolomite. No ore is exposed in the accessible workings, but ore appears on all of the dumps; it consists chiefly of limestone replaced by scattered large crystals of barite, between which are small vugs or unreplaced remnants of limestone. In the vugs crystals of light-brown to yellow sphalerite and less commonly of galena rest on the barite. Some copper stain is seen.

This ore and its geologic environment strongly suggest conditions in the Continental Chief mine.

The main and lowest Dyer adit (No. N–42) is still accessible (fig. 80). The workings are not extensive, but include at least two stopes. The ore bodies lay on or near a northeastward-trending fissure, not seen at the surface. They consisted of two small "contact" bodies, that, is replacements parallel to the bedding, one on the lower level under a shaly layer near the top of the Dyer dolomite, and the other and larger one on the upper level under a shaly layer a few feet above the base of the Leadville dolomite.

Little is known of the history of the Dyer and Dyer Extension mine. Emmons (1886, p. 213) says it is one of the first mines of the district but that it was worked only intermittently because of its inaccessibility. He states also (p. 616) that some of the ore consisted of "flint, impregnated with galena"; this ore is in striking contrast with that now seen on the dump.

REVENUE AND TINGLE-TANGLE CLAIMS

The small openings near the Revenue and Tingle-Tangle claims (Nos. N–90 and N–91) are along the contact between the Leadville dolomite and the overlying sill of early White porphyry. The Leadville dolomite in them is appreciably iron-stained along discontinuous fissures trending generally north. They are of interest chiefly because they indicate that the

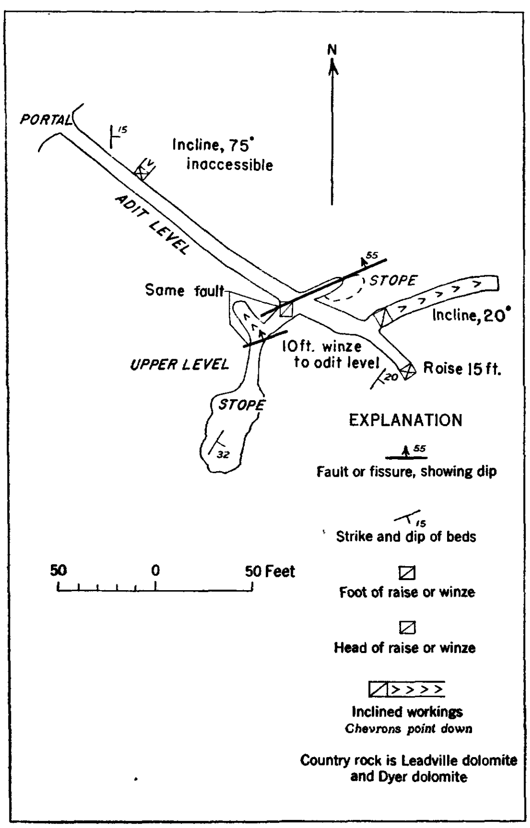

FIGURE 80.—Geologic map of main lowest Dyer adit. Upper level and stope in Leadville dolomite; lower level and incline in Dyer dolomite member of the Chaffee formation.

top of the Leadville dolomite along Dyer Mountain should be explored.

LIDDIA MINE AND NEARBY OPENINGS

The course of the Liddia fault is generally N. 25° E., uphill a little west of the portals of the two Liddia tunnels. Pre-Cambrian crystalline rocks are faulted against Leadville dolomite (pl. 1) with a vertical displacement of 530 feet near the Liddia mine. The Liddia fault can be traced by a breccia across the southern slope of Dyer Mountain, but openings directly in the fault zone (such as the several small prospects about 100 ft higher than the upper Liddia tunnel) show no mineralized ground.

The Liddia mine (No. N–94) (fig. 81) consists of two adits connected by a raise. The lower adit enters pre-Cambrian Silver Plume(?) granite and is driven N. 36° W. in this rock. About 240 ft from the portal a gouge zone, 10 ft wide, appears, striking N. 10° E., and dipping 65° NW. This is the Liddia fault. Both of its walls are sharply bounded against the gouge but are not striated. Beyond this fault zone Leadville dolomite with typical "zebra" markings appears, strongly recrystallized. The dip of the dolomite is uniformly and gently northeast. At three places within 100 ft of the breast of the tunnel the bedrock is broken by faults trending N. 20°–30° E. and dipping vertically or steeply eastward. Their west sides are down thrown, but the displacement can be measured only at the northernmost point, where it amounts to 17 ft of stratigraphic throw. The lower tunnel shows no trace of ore, even along the faults, but the dolomite is somewhat silicified, a distinct band of silica being noticeable on the northwestern side of the northern fault mentioned above. The recurrence of this silicified zone in the raise to the upper level shows the amount of displacement on that fault.

The upper adit extends for 50 ft through Sawatch quartzite, crosses the Liddia fault, and enters the upper beds of the Leadville dolomite. There it connects with a series of alternate crosscuts and gently sloping inclines. The highest point on this level is the portal at 13,000 ft above sea level; its lowest point, 12,928 ft, is at the head of the winze connecting it with the lower level. Some 70 ft southeast of the winze the upper level crosses a fault having 8 ft of upthrow to the southeast. South of the fault this level enters a discontinuous replacement ore body lying above the silicified zone that is exposed in the winze. Directly above the silicified zone is a rather dense blue-gray limestone whose upper beds contain the ore which has supplied most of the output of the mine. As seen in a winze situated about a third of the distance from the portal to the main connecting winze at the breast, the gray, productive limestone is overlain by 7 ft of dense silicified rock, and by a thin bed of black shale of the

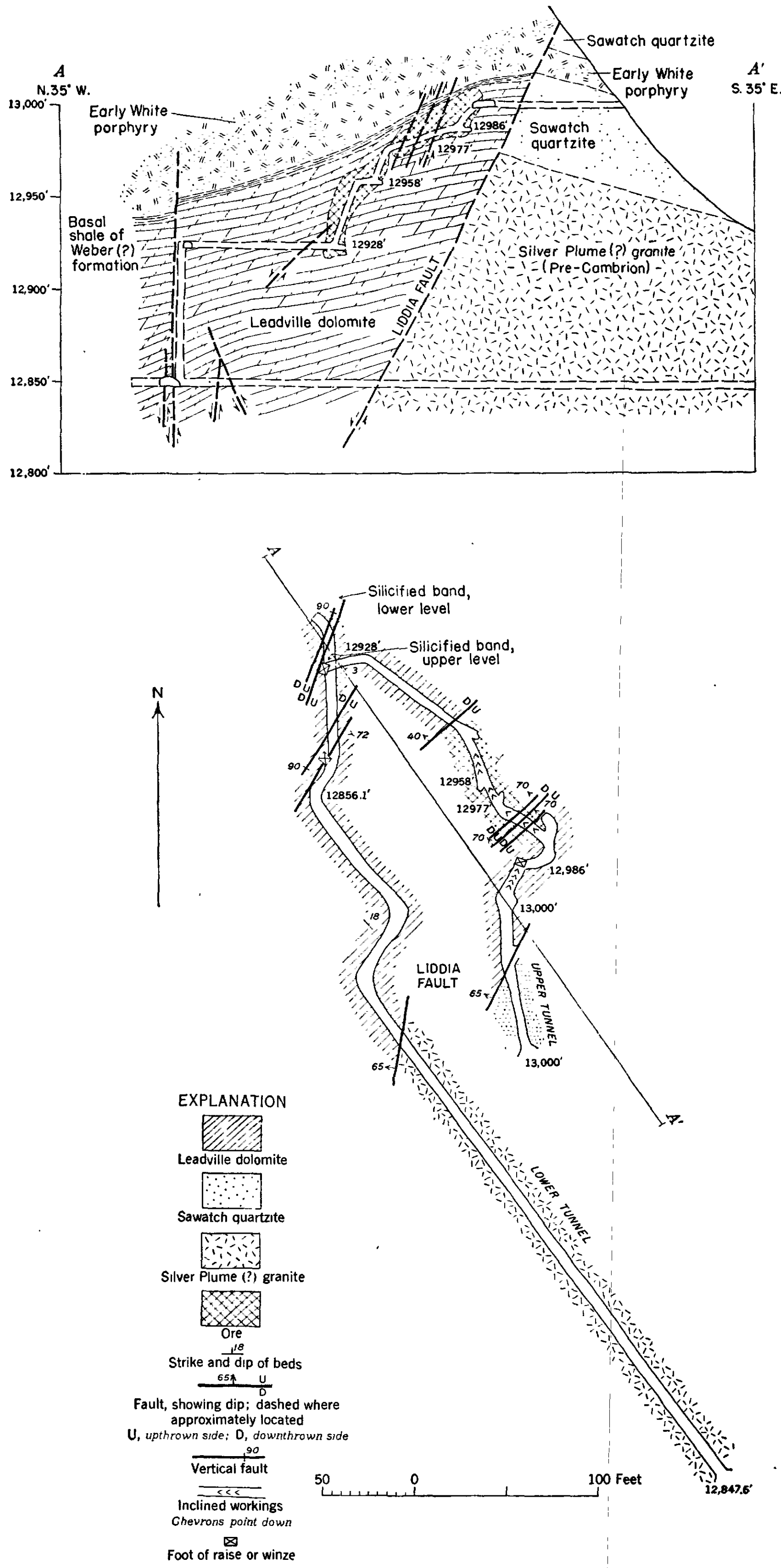

FIGURE 81.—Geologic map and section of the Liddia mine.

Weber(?) formation, which evidently had a ponding effect not unlike that observed in the Continental Chief mine (p. 134). A few raises through this shale strike the overlying sill of early White porphyry.

The ore zone has been stoped discontinuously (fig. 81) southward from a point about 180 ft north of the portal nearly to the crossing of the Liddia fault, 135 ft farther south along the upper level. The shoot is thus at least 100 ft long. Apparently, much of the ore was oxidized, and was called "ocher ore". The ore mineral is chiefly cerussite stained slightly by films of malachite, azurite, and aurichalcite. The primary ore is not conspicuous; its most important mineral is galena; barite and some very fine grained silica are especially conspicuous in the gangue. The oxidized ore seen is deeply iron-stained and almost every trace of its original pyrite content has disappeared, except casts surrounded by poorly terminated crystalline quartz. Despite the copper staining mentioned, no chalcopyrite has been found. Typical assays are cited below (Karl Norberg, personal communication, 1929):

Assays of ore from Liddia mine

Descriptions	Lead (percent)	Silver (ounces)	Gold (dollars)
1. "Ocher ore" from upper level	15. 0	5. 0	2. 00
2. Primary(?) ore from stope	40. 0	12. 0	2. 50
3. Oxidized seams without visible lead sulfide	4. 5	4. 2	-------
4. Ore from face of stope, upper level	13. 5	4. 0	-------
5. High-grade ore, locality uncertain	40. 0	15. 0	-------

In general, the ore increases in richness upward, including the primary ore, and is especially rich at the black shale that forms its "cap." The history of the mine is not known.

The Liddia fault can be traced about 300 ft north of the portal of the Liddia upper tunnel. There it branches (pl. 1), and although the western or main branch is undeveloped, a caved shaft (No. N–38, sometimes designated the Mammoth) and several smaller pits on the Hoosier Girl claim were dug near or along it. The Leadville dolomite on the dump of the shaft is considerably brecciated and largely replaced by calcium carbonate. The distribution of these openings east of the Liddia fault and the general resemblance of their ores to those in the Liddia mine suggest that the Liddia and Hoosier Girl ore shoots were once continuous but that the Hoosier Girl shoot was lifted about 525 ft vertically by faulting after mineralization.

About 500 ft to the southeast a short tunnel (No. N–96) has revealed somewhat iron-stained, fissured Dyer dolomite which gives no indication of ore although small bodies of oxidized lead ore rich in silver are said to have been mined here prior to 1921.

IOWA AMPHITHEATER, NORTHERN PART

The valley of Iowa Amphitheater and the head of Iowa Gulch form a T, the amphitheater representing the cross-piece and the valley representing the axis. At the junction, the South Dyer reverse fault is offset by the Liddia fault. To the northeast the sequence of formations is normal. There are sills of early White porphyry in the Cambrian quartzite and a thick sill of the same rock above the Leadville dolomite. The crest of the range east and northeast of this area is made up of Sacramento porphyry, the Weber(?) formation, and early White porphyry, named in stratigraphically descending order.

Several faults serve to complicate the structure of this area. The Dyer fault trends west-northwestward and, close to the buildings of the Continental Chief mine at the head of Iowa Amphitheater, it is normal and drops the southwestern side about 50 ft. Several minor faults strike northeastward. They extend from the northern edge of outcrops of pre-Cambrian rocks in the Iowa Amphitheater to the Dyer fault; these minor faults break the formations into slivers or elongate blocks, some of which were lifted by the faulting, some depressed. On the eastern wall of the amphitheater two distinct types of faults occur: (1) steeply dipping faults with trace roughly east up the slope of Mount Sherman, and having only small displacement and (2) low-angle thrust faults with larger displacements, whose traces extend northward.

Mines and prospects of economic interest are the openings on the Umatilla and adjacent claims, the Continental Chief mine, the McGuire workings, and several small tunnels on the eastern wall of the amphitheater approximately a mile south of the Continental Chief mine.

UMATILLA GROUP AND NEARBY WORKINGS

Three tunnels are located on the Umatilla group of claims. The western one (No. N–98) is a short adit that trends N. 50° W. and crosses a fracture zone that trends N. 40° E. in Leadville dolomite. The northern tunnel (No. N–36) is 350 ft long and trends generally north-northwest in Leadville dolomite along a fault that dips steeply east and raises the eastern side about 4 ft. This fault has a branch trending northeastward near the northern end of the workings. Both faults slightly displace a dike of early(?) White porphyry. No ore is exposed.

The southern tunnel (No. N–37) includes 500 ft of drifting in an easterly direction in coarsely crystalline Dyer dolomite, cutting through the basal conglomerate of the Leadville dolomite about 170 ft from its portal. Some "dolomite sand," probably formed by the solution of the calcareous cement between the dolomite grains by acid surface waters (Emmons, Irving, and

Loughlin, 1927, p. 36), appears close to the portal. The breast of the tunnel is in Leadville dolomite which contains some "zebra" rock, but there is little evidence of mineralization.

In all of the Umatilla workings numerous small faults striking N. 0°–40° E. show no trace of ore and are evidently of postmineral age. They are comparable in strike, in lack of mineralization, and in age, with the Liddia fault (pp. 130, 132).

CONTINENTAL CHIEF MINE

In the northeastern head of Iowa Amphitheater, just above the Leadville dolomite, a 5-ft zone of black shaly beds contains pyrite concretions. It forms the base of the Weber(?) formation, but because the shale is so thin, it is not practicable to differentiate it from the Leadville dolomite on the geologic map. The shale is separated from the rest of the Weber(?) formation by the thick sill of early White porphyry that forms the upper slopes on both walls of the northern head of Iowa Amphitheater. This shale, like that in the Liddia mine (p. 131), forms a cap over the ore-bearing limestone beds. A similar but lighter-colored shaly bed, 2 to 5 ft thick, lies 12 to 15 ft below the top of the Leadville dolomite and likewise seems to have induced ore deposition beneath it.

The gentle folding seems to have caused some movement along the contacts of both shales and the more brittle Leadville dolomite. These movements produced small openings along the bedding planes above and below the shaly layers. Hence, along the western slope of the range, from the northern head of Iowa Gulch south to Mount Sheridan, a 25-ft zone directly below the thick sill of early White porphyry is locally mineralized. Many tunnels have been driven into this zone, most of them within 2,500 ft of the Continental Chief mine. These tunnels are largely inaccessible. Some are filled with ice, but most of them are full of caved black shale and White porphyry. However, the dumps contain blocks of porphyry and shale, pieces of ore, and many fragments of typical blue-gray limestone. The limestone is seamed with white dolomite and quartz veinlets, and partly replaced by bladed crystals of barite. Metallic minerals present include galena, light-colored sphalerite, and small amounts of pyrite, stained somewhat by iron and copper films. As is usual in this type of ore, the sulfides appear to have been deposited later than the nonmetallic minerals.

The Continental Chief mine (No. N–99) is the only large operation in such deposits in the Iowa Amphitheater. It consists (pl. 12) of an adit driven approximately due east for 125 ft and thence branching so that one arm (the "north drift") leads northeastward and forms with the adjacent stopes the "west working", whereas the other (the "south drift") follows an east-northeasterly course, leading toward the "east" or "main workings." Some older mining was carried out from the northeast-leading branch, which is driven in the upper part of the Leadville dolomite just below the gray shale horizon. The limestone along this branch is broken by fissures and faults of small throw, of trends N. 5°–50° E., and, generally, of steep dips. Quartz has been deposited along the fractures and has also replaced some of the limestone. The ore is quartz-rich and contains pyrite, smaller amounts of galena, and still less sphalerite of local occurrence. Locally, the oxidized ore contains large quantities of cerussite and a little limonite. Stoping has proceeded along the fractures, especially where the ore is oxidized, and in some places the back or roof, partly made up of black shale of the Weber(?) formation, has caved, filling the passage. The oxidized quartzose ore is said to have had a high content of gold and silver. Samples collected in the stope walls—at two points within 75 ft of the northeast breast—contained respectively 4.4 and 1.4 ounces of silver to the ton, and traces of gold, according to J. R. Fyfe & Co., Leadville Assayers (courtesy of C. N. Larson, 1929).

The east workings consist of two generally separate parts. One of them lies at about the level of the main or south drift. This includes the Ice Palace stope and adjacent workings.

Approximately 300 ft from the point where the north and south drifts separate is the head of an incline. Most of the stoping was done along the incline or along subordinate drifts spaced at irregular intervals. This mining opened a series of stopes trending N. 30°–40° E., generally following fissures that dip steeply northwest or southeast (figs. 82 and 83). The small displacements along these fissures are mainly horizontal. In the lowest workings near the incline, and at a few other places, the mineralized ground is coextensive with a large number of such fissures, so closely spaced as to shatter the ground thoroughly. In places the mineralized fractures are offset by others of postmineral age.

Approximately 1,000 ft east-northeast from the portal a large body of ore was found in the deeper part of the mine (fig. 84). This elongate shoot trends due east and thus differs conspicuously from the other large shoots of the mine. To develop this body further a crosscut was driven southeastward from the bottom of the incline, but the mineralized ground at this depth was disappointing; it apparently ended eastward against a fault striking N. 2° W., and little ore was found beyond.

The detailed stratigraphic sequence downward from the sill of early White porphyry, exposed in the cliffs

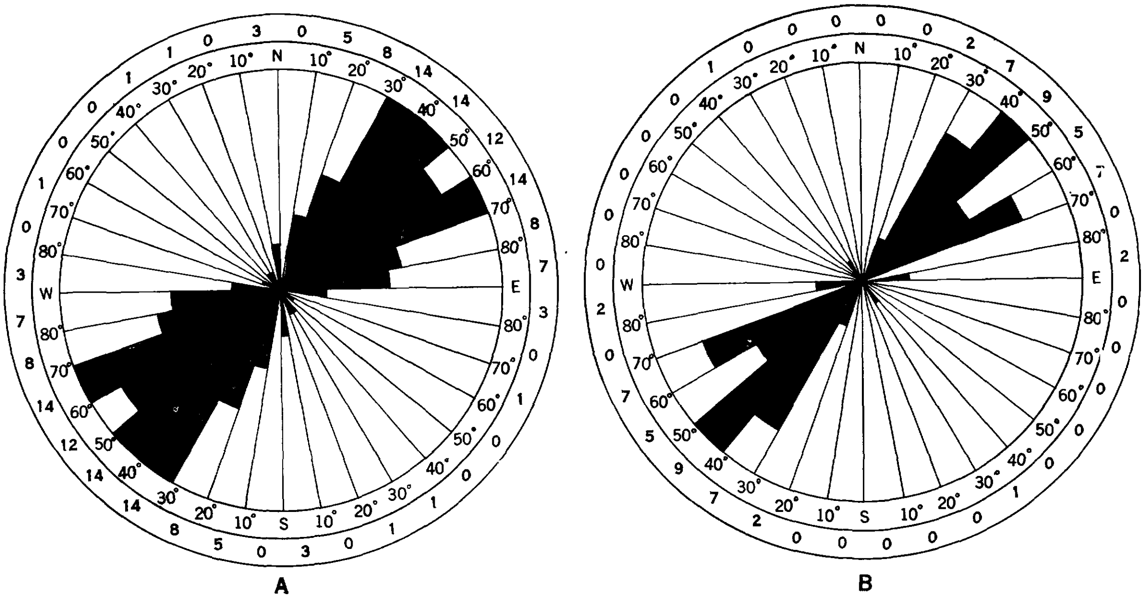

FIGURE 82.—Strikes of fissures and faults in Continental Chief mine. Lengths of radii are proportional to total number of observations. All data plotted to within 10° of the true azimuth reading. Numbers on inner dials give degrees azimuth east or west of true north and south; those on outer dials give the number of observed fissures having the indicated azimuth reading. *A*, All fissures observed (91 observations). *B*, Definitely mineralized fissures (33 observations).

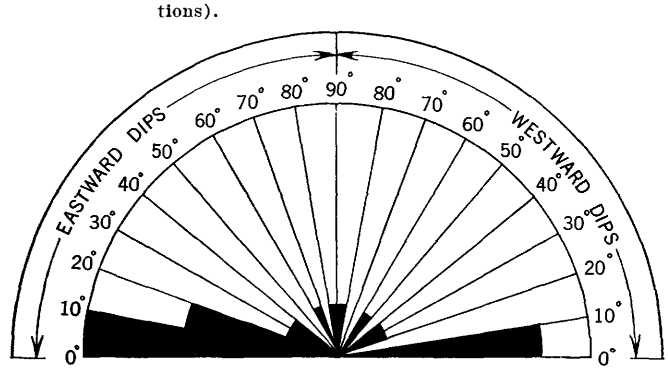

FIGURE 83.—Inclinations of striae along faults observed in Continental Chief mine. Length of shaded segments proportional to number of observations. Note dominance of nearly horizontal as opposed to nearly vertical readings.

a few feet higher than the portal of the main adit, is as follows:

	Feet
7. Early White porphyry.	
6. Shale, black, carbonaceous with a few pyritic concretions; very slabby and plastic	2–8
5. Limestone, coarsely crystalline blue-gray dolomitic, with few traces of fossils; locally characterized by secondary veinlets of white dolomite ("zebra" rock)	10
4. Shale, gray to blue-gray, slabby; not highly plastic; fossiliferous	2–5
3. Limestone, dense, light blue-gray dolomitic	2
2. Limestone, coarsely crystalline blue-gray dolomitic; "zebra" markings common; fracturing irregular	20±
1. Limestone, finely crystalline, light blue-gray, dolomitic.	

The black shale (bed 6) with overlying porphyry is found wherever stoping or exploration have been extended high enough. Faulting has raised or lowered these key horizons irregularly; a few faults pass upward into the shaly beds and are lost, apparently by dissipation of movements along bedding planes.

Although the premineral fissures were an important source of ore, by far the greater part of the output was from replacement bodies. Most of the fissures are fairly tight and few are wide enough to have been worth mining for their own ore content alone (fig. 85). The large stopes along the incline, the Ice Palace stope at the head of the incline in the south workings, and the "northeast" stope in the northeastern end of the mine represent ore bodies of impressive size, formed chiefly by replacement. The Ice Palace shoot (even with the lower boundary arbitrarily placed at the level of the main southwest adit) is 250 ft long, its width ranges from 30 to 60 ft, and its height is as much as 45 ft. In general such bodies are elliptical in vertical cross-section, with the longer axis of the ellipse parallel to the mineralized fissures. These bodies (see figs. 86 and 87) are mass replacements of limestone that began along fissures, either closely spaced or isolated.

A significant feature of such replacement is that it is clearly preferential. The coarsely crystalline limestone, such as beds 2 and 5 in the stratigraphic column above, is distinctly more susceptible to replacement than the finely crystalline rock of beds 1 and 3. The two limestones do not differ in solubility, as chemical analyses indicate that both are dolomitic limestones of about the same composition. The difference is attributable to three other factors: (1) the occurrence of ponding beds, notably the black shale, No. 6, above the upper limestone, as in so many of the Leadville "contact" deposits; (2) the greater porosity of the recrystallized, cellular limestones; and (3) the mode of fracture. The

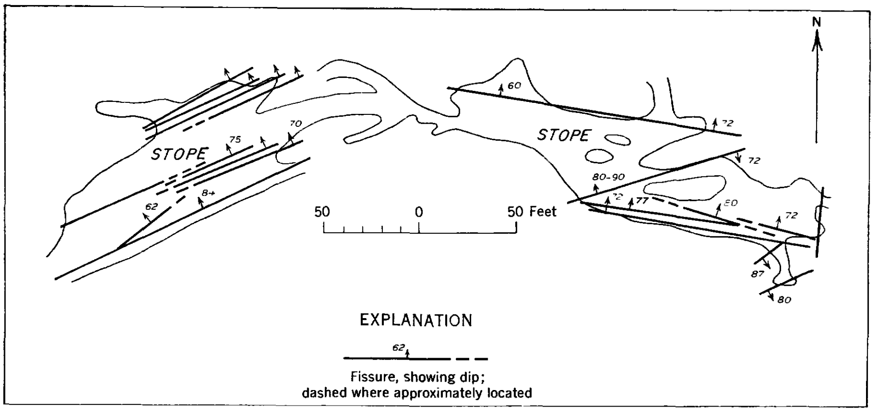

FIGURE 84.—Lowest large stopes at foot of new incline, Continental Chief mine, showing prominence of fissures and their apparent relation to mineralization.

dense limestone generally develops clean-cut fractures which tend to be conchoidal and discontinuous; for this reason it is frequently given the very graphic designations of "short-fracturing dolomite" or "short lime." In contrast, the coarsely crystalline limestone breaks along wider shattered zones, and the resulting angular fragments are more readily attacked from all sides. Moreover, the thinner beds of the dense limestone act as limits to the continuity of fractures across the bedding, whereas the more massive beds of the coarsely crystalline rock are cut by continuous fractures along which solutions should be able to move with greater freedom. These factors and the greater porosity of the coarsely crystalline limestone and hence its greater susceptibility to penetration and to replacement readily explain the preferential mineralization of this kind of rock.

Most of the ore occurred as replacement bodies of considerable vertical thickness about fissures that served as channelways, but some was found in small, flat bodies, essentially true "contacts." Thus along the old incline a blanket of this type formed a small shoot lying west of the main ore body and 25 ft below the shales; the present stope is about 20 ft square and from 5 to 6 ft high. Like most similar bodies it resulted from selective replacement of a bed, but a few bodies actually lie along bedding-plane faults. (See Behre, 1937, pp. 512–529.)

One of the mistakes made in development work in the Continental Chief mine resulted from a failure to grasp the importance of the stratigraphy in determining the location of the ore. The incline has an average dip of 19°–21° to the northeast. The average dip of the beds is 12°–21°, but varies greatly from place to place, and in the lower parts of the incline the strike is generally almost parallel to the direction of the incline; the component of the bedding dip along the incline is thus very low, averaging much less than 10°. Hence, as the incline loses altitude, it passes gradually from the productive beds into the underlying, denser dolomite, which is generally less favorable to ore deposition.

The mineral composition of the ores is fairly simple. Apparently, the chief primary ore minerals were galena, sphalerite, and pyrite, in a gangue consisting of dolomite, barite, and quartz. The most conspicuous ore mineral is galena, and the ore is largely rich in silver, especially where the sulfide has been slightly ox-

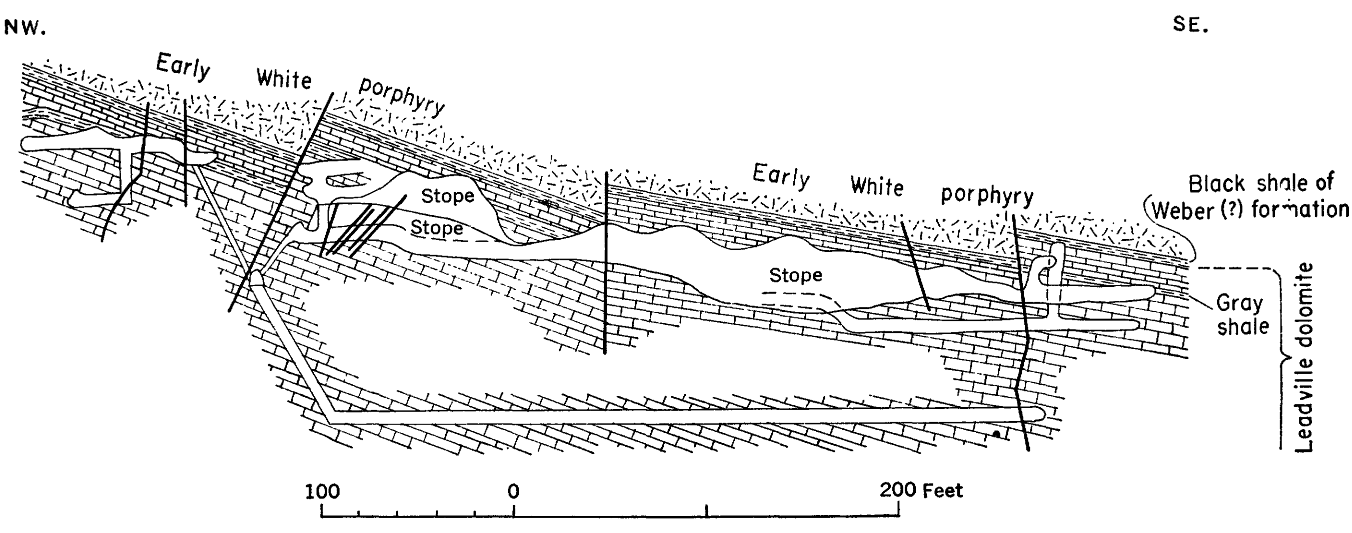

FIGURE 85.—Vertical section through larger stopes near foot of incline, Continental Chief mine.

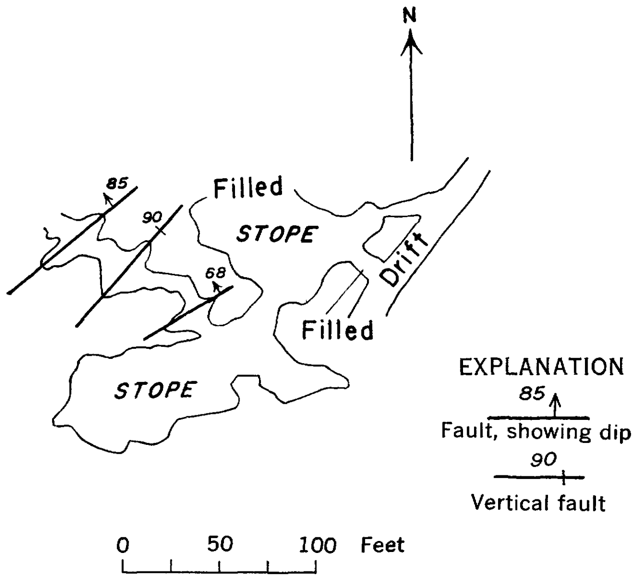

FIGURE 86.—Stopes in sacking-ore developed in limestone along fissures. Plan of part of southwest stope in East Workings, Continental Chief mine.

idized to cerussite. Galena is more conspicuous in the upper workings, and sphalerite and its alteration products in the lower, but there is no marked contrast in the quantity of the primary and secondary minerals containing the lead and zinc. Pyrite and quartz seem to have been associated with the ore that was richest in precious metals; much of the "sacking" or high-grade, precious metal ore, mined locally in the west workings and in the stopes on the level immediately below the head of the incline, was partly oxidized pyritic material. Most of the zinc recovered from the base-metal ore came from oxidation products, especially smithsonite of the "dry bone" type; some hetaerolite was found, and hydrozincite was common. Completely unoxidized sphalerite is rare and generally of a distinctive olive-gray color; large masses have been found only in the deeper parts of the mine, most of it in the lowest stopes east of the foot of the incline. Small amounts of aurichalcite and a few stains of malachite indicate that chalcopyrite or some other copper mineral was present. These products of oxidation are found even in the deepest workings, which are well above the ground-water table.

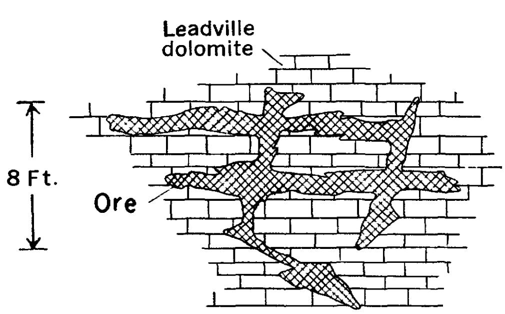

FIGURE. 87.—Preferential or selective replacement of certain beds adjacent to fissures. Wall of stope under head of incline, Continental Chief mine.

The metal contents of three samples collected by the writer are shown in the following table:

Assays of samples from the Continental Chief mine

[J. R. Fyfe & Co., Leadville, Assayers. Courtesy of C. N. Larson, 1929]

No.	*Gold (ounces)*	*Silver (ounces)*	*Lead (percent)*	*Zinc (percent)*
1		5. 6	19. 8	13. 6
2	Trace	2. 4	14. 1	1. 4
3				17. 3

Sample 1 is from one of the deeper stopes about 125 ft up the incline from its lower end. Sample 2 is from sacked ore in the stopes immediately under the head of the incline. Sample 3 represents smithsonite ore found in a short drift branching southeastward from the north workings.

It is said that the Continental Chief mine was first opened in 1884, after a landslide had uncovered some of the western lode in the cliffs. This body of ore led to other shoots farther in the side of the mountain, and in order to remain below the early White porphyry sill an incline was started—the so-called "old incline"; later the new incline was driven to simplify haulage. Work was continued from this new incline and the total output up to about 1920 is said to have had a gross value of $3,000,000. The mine was shut down for a period, but operations were resumed in 1926 by the East Butte Exploration Co. Production methods (according to E. P. Chapman, who supplied most of the data) were modernized, and diamond drilling was used for exploration. These changes resulted in some production, chiefly from the lower part of the new incline and the stope at the far northeastern end of the mine. Most of the mineralized ground, however, ended against the fault striking N. 2° W. and bounding the northeastern stope along its eastern end. The maximum vertical displacement along this fault is estimated to be 12 to 25 feet. A so-called "dike" along this fault is merely the calcareous gouge and breccia derived from the dolomitic limestone. Evidently, efforts to find the offset extension of the ore body (or the productive zone) failed, and it appears that the ore body originally ended about where the fault crossed it. Work was abandoned by this company in 1928.

In 1930–31 exploration was resumed by a Denver company. Efforts were directed not at development work at depth, with its difficulties in haulage and ventilation, but at discovering new bodies near the surface to the south. As most of the mineralized fractures strike northeast and the beds generally also dip northeast, drifting was begun in a southeasterly direction, with the object of maintaining an approximately constant stratigraphic horizon and, at the same time, transecting as many fissures as possible. The management planned a raise on each vein as found, up to the sill of early White porphyry, at the base of which ore was reasonably expected. The work was begun southeast of the Ice Palace stope. A small northeast-trending vein was found 250 ft south of the incline, and a raise put up on it, but little ore was discovered. The same procedure was followed with a second vein 100 ft farther south, with no better results. A third vein was found 75 ft farther south, but again a raise yielded no promising ore, and work was stopped. This very well planned prospecting campaign could be resumed and supplemented by other prospecting northward from the incline, at a point where the productive beds are stratigraphically about 20 ft higher than those at the bottom of the incline.

McGUIRE TUNNELS

The two small prospect adits (No. N–106) of the McGuire property lie close together, some 1,600 ft due south of the entrance to the Continental Chief mine. The portal of the upper tunnel is about 75 ft above that of the lower tunnel and 300 ft southeast of it. The upper tunnel is caved and inaccessible. The lower tunnel trends generally S. 70° E. for a total length of about 550 ft; at its end an inclined raise, 48 ft long as measured on a slope of 55°, gives access to about 20 ft of exploratory work in "Blue" dolomite. The main level is in the Manitou dolomite and the Parting quartzite and Dyer dolomite members of the Chaffee formation. The general strike of these rocks ranges from N. 10° E. to N. 20° W., and the dip is predominantly eastward, but 13 faults could be mapped in this short tunnel, and relations in the section exposed in the tunnel are not simple. The section is of interest chiefly because of the light it sheds on the structure typical of the western slope of Mount Sherman. Many of the faults are normal, but there are at least three thrust faults whose presence is indicated by drag of the beds in addition to the common gouge or breccia. Despite this extreme shattering, the only indications of ore are several pieces found on the dump, containing a small amount of pyrite, galena, and barite, and the presence of conspicuous dolomite veins along some of the faults.

To the north and south along the western slope of Mount Sherman, within a distance of 1,200 ft of the McGuire tunnels, there are several other prospects. They are shallow pits and tunnels, driven either along joints or small fractures that trend roughly due east or northeast or along irregular thrust faults. Most of them are not accessible, but the material on the dumps is characterized by small amounts of galena, rare gray-green sphalerite, smithsonite of the cavernous type, and barite, all of which were formed by replacement of the Leadville and Dyer dolomites; vein material composed of quartz and pyrite is also found.

It is clear that the structural relations and mineral composition of these small deposits are essentially like those of the Continental Chief mine. Their mineralized fissures have northeasterly or easterly trends; ore occurs where these fissures cut the contact between the Leadville limestone and the overlying sill of early White porphyry. None of these prospects, however, seems to have shown enough ore to have encouraged extensive work nor to have left a record of production.

PROSPECTS ON EASTERN WALL OF IOWA AMPHITHEATER ON AND NEAR EQUATOR CLAIM

Approximately a mile S. 10° W. of the portal of the Continental Chief mine, on the western slope of the spur extending from Mount Sherman toward Hilltop Pass and Mount Sheridan, there are openings (No. N–171) comprising several tunnels, shallow pits, and one shaft. They are on or near the Equator, Klondike, and adjacent claims. Like the McGuire tunnels and the Continental Chief mine, these openings lie along the contact between the Leadville dolomite and the overlying sill of early White porphyry. They are largely caved and inaccessible, but a study of their dumps suggests that the carbonaceous shale seen in the Continental Chief mine separates the porphyry from the Leadville dolomite here also. There are no indications of definite fissures that governed the localization of ore. The scattered fragments of ore found on the dumps consist of limestone, which is partly silicified, or iron-stained, or replaced by barite. The barite contains small quantities of sulfides, mostly galena, and some zinc carbonate of the "dry-bone" type. Despite these indications of ore, the area lacks the fissures which might have guided mineralization and so is not as promising as that farther north near the Continental Chief mine.

IOWA AMPHITHEATER, SOUTHERN PART

South of the region where the northern and southern branches of Iowa Amphitheater join to drain westward through Iowa Gulch, the rocks exposed are mainly Cambrian and younger. The Liddia fault (p. 69), its east side upthrown, is the cause of a marked difference on the eastern side of the southern head of Iowa Amphitheater. This part of the amphitheater is floored with pre-Cambrian rocks and its walls and higher slopes are made up largely of Cambrian and Ordovician strata and intruded sills, which west of the fault appear only in the floor of the amphitheater. The numerous southerly branches of the Liddia fault produced several offsets, which are visible in the southern walls of the amphitheater; along most of these faults the eastern side is upthrown, as along the main fault. The South Dyer reverse fault, readily recognizable on the southern spur of Dyer Mountain, is less conspicuous in the pre-Cambrian rocks immediately east of the Liddia fault, reduced in throw in the lower Paleozoic rocks farther southeast, and split up into a series of faults that pass into sharp folds stratigraphically higher on the southeastern wall of the Iowa Amphitheater just west of Hilltop Pass. The South Dyer fault is not recognizable along the crest of the range to the east. Perhaps its discontinuity is linked to a change in the thickness of a sill of early White porphyry just below the Manitou dolomite, the intrusion of the sill having accompanied the faulting. Considerable ore might have been deposited along these branches had the faults reached the contact between the Leadville dolomite and the overlying sill of early White porphyry. Nevertheless, there are some fairly attractive prospects along the traces or the southeastward projections of the branches of the South Dyer fault.

Two groups of prospects in the southern part of Iowa Amphitheater deserve mention—the prospects on or near the Liddia fault and those on the northern slope of Sheridan Mountain.

PROSPECTS NEAR LIDDIA FAULT

Some pits omitted from the map, on the floor of the amphitheater near the Liddia fault, have revealed no mineralized rock and it seems that the fault itself is not mineralized. It is only coincidence that the Mammoth (Nos. N–38 and N–96) and Liddia (No. N–94) mines are near the Liddia fault. It is rumored that a little gold was found in these prospects, but there is neither evidence nor likelihood of this.

PROSPECTS ON NORTHERN SLOPE OF MOUNT SHERIDAN

Along the northern slope of Mount Sheridan, the general sequence of rocks, in descending stratigraphic order, is as follows:

	Feet
5. Thick sill of early White Porphyry	200
4. Black shales of Weber(?) formation	25
3. Thin sill of early White Porphyry (locally pinches out completely)	0–15
2. Blue-gray quartzite, basal Weber(?) formation	10
1. Uppermost part of Leadville dolomite	—

Ore occurs in fractures or breccia zones of the quartzite (bed 2), or as replacement bodies or fissure fillings in the uppermost beds of limestone (bed 1). Mineralized ground is thus confined mainly to a zone stratigraphically about 30 ft thick, near the top of the Leadville dolomite. The dump of virtually every tunnel driven along this zone shows small quantities of ore minerals, chiefly smithsonite, cerussite, and galena, with some copper staining, and with barite and quartz as gangue minerals.

Two important groups of prospects (Nos. U–22 and U–23) are situated about 1,000 ft southwest of the 13,184-ft knob at Hilltop Pass. This was once apparently fairly active property, as shown by a cabin, traces of a shaft and seven tunnels. The quartzite in this vicinity has locally been replaced by barite, and the associated ore resembles the baritic ore of the Continental Chief mine. However, the ore seems to have been leaner because the quartzitic host rock is less favorable to ore deposition than dolomite.

The more western of the two prospects designated U–33 on the map is a tunnel driven along a fault zone. The basal quartzite of the Weber(?) formation exposed in this opening has been shattered to a breccia and then recemented by barite; there has also been replacement of the country rock by barite. Between barite blades are small amounts of galena.

UPPER IOWA GULCH, EAST OF HELLENA MINE

In the marginal part of the Leadville district, the only area rivaling the one between the Hellena mine and the Mansfield and Rex shafts in the complexity of its geology is in upper Iowa Gulch, between the Iowa Amphitheater and the Hellena mine. The traces of the Mosquito and Ball Mountain faults are well exposed on Upper Long and Derry Hill, cross upper Iowa Gulch, and rise toward Ball Mountain and East Ball Mountain. The Mosquito fault has its downthrow on the west, bringing pre-Cambrian rocks on the east against Dyer dolomite on the west. The Ball Mountain fault north of its junction with the Iowa fault also has the western side downthrown, an almost equal amount. Between the two there are minor faults, along most of which the western side is downthrown; in part they are occupied by dikes of Johnson Gulch porphyry. The Iowa fault apparently ends eastward against the Ball Mountain fault.

Many prospects lie between the two major faults. Some, such as N–146 and N–148, are relatively near the Mosquito fault; others, such as N–140 and N–141, are on the inferred trace of the Ball Mountain fault. Yet, only on the dump of the eastern tunnel of the western part of group N–134 has mineralized material been found. Even on the dumps only a small amount of pyritic ore was seen. Some of the workings—for example, the three shafts at N–142—give evidence of fairly extensive exploratory work but with no indications of mineralized ground.

East of the Mosquito fault several short tunnels were driven along fissures in the pre-Cambrian granite—for example, about half a mile northwest, or an equal distance northeast of the crest of the northern peak of West Sheridan Mountain (Nos. N–117, N–118, N–119, and N–163). The fissures trend northwestward, contrary to the general structural pattern of this region. The mineral matter consists of quartz veinlets with iron and manganese oxides from which, it is rumored, small pockets of high-grade ore were mined.

LOWER IOWA GULCH AND SOUTHERN SLOPE OF PRINTER BOY HILL

Rock exposures are few in the valley of Iowa Gulch west of Hellena mine. The overburden of glacial and alluvial material and the heavy influx of water have made mining in the valley bottom very difficult. Despite reasonable expectation of mineralized ground, therefore, exploration has not been extensive though the prospects are numerous. Therefore, the bedrock geology in the valley bottom is not known in detail and must be inferred largely from rock exposures on the higher slopes.

Perhaps the most complicated surface geology of the marginal area is that along the Hellena-Weston-Union fault complex, near the Hellena mine. The fault relations here are of special interest because ground along the branches of the Weston fault is considerably mineralized. Several interpretations have been offered for the geological relations known for the area between the three great faults—the Union, Weston, and Iowa faults (p. 75). The interpretation accepted and reviewed below takes into account the trend, the direction of displacement, the amount of throw of each fault, and also data obtained at surface and underground exposures by the writer and others who studied this region.

On the southern slope of Upper Long and Derry Hill the Union fault, trending north-northeast, breaks up into several smaller faults. These faults are clearly revealed by offsets of the contact between the Cambrian beds and the pre-Cambrian on the cliffs overlooking Iowa Gulch. They offset the Weston fault repeatedly along the southern slope and crest of Long and Derry Hill. North of the intersection of the Union and Weston faults, the Weston fault forks, the main fault trending about N. 20° W., and an easterly branch, the Hellena fault, striking approximately due north and dipping steeply eastward. The Hellena fault has been traced northward about 1,500 ft. from the stream in Iowa Gulch. Beyond this point the rocks in the hanging wall and footwall are too similar to reveal its position at the surface. The main Weston fault also forks near the southern end of the Clear Grit claim, and a western branch extends across Iowa Gulch almost parallel to the main fault, and reuniting with it a little farther north. At the surface the western wall of the main Weston fault consists of a thick sill of early White porphyry with lenses of the uppermost beds of Leadville dolomite.

Near the middle of Iowa Gulch the Hellena fault brings pre-Cambrian granite on the west against Weber(?) strata on the east. The Hellena is a reverse fault farther south, so this condition can be explained only by assuming the presence of the Iowa fault—an east-west fault along which shales and grits of the Weber(?) formation are thrown down to the north against the pre-Cambrian rocks at the south. This fault must be assumed to exist both in the block between the main Weston fault and the Hellena fault, and in the block between the Hellena fault and the Ball Mountain fault farther east.

From the vein complex of the Hellena mine westward to the neighborhood of the Rex shaft (where the Mike fault crosses Iowa Gulch) the succession is fairly regular, and the rocks crossed in a westward traverse are progressively older beds. The easternmost exposures are sills of early White porphyry with intercalations of quartzites and grits of the Weber(?) formation and of upper beds of Leadville dolomite. Westward are successively exposed the Leadville dolomite, the Dyer dolomite and Parting quartzite members of the Chaffee formation, the upper part of the Manitou dolomite, and, farthest west, a sill of Iowa Gulch porphyry. All these rocks dip uniformly eastward. The structure is complicated by many faults, all trending approximately northward and nearly all having the western side downthrown. Along these faults are dikes of Johnson Gulch porphyry, near which the rocks are commonly mineralized. The crest of Printer Boy Hill is made up of early White porphyry, this being the sill above the Leadville dolomite which appears also on the crest of Long and Derry Hill at and above the 11,500-ft contour.

In the ground between the Mansfield shaft, the First National shaft, the crest of Printer Boy Hill, and the bottom of Iowa Gulch, the effects of mineralization are such as to suggest higher temperatures than in adjacent regions (p. 48). Probably a plug of Johnson Gulch porphyry (forming a minor center of mineralization) came close to the present surface here, and the exposed dikes of this rock are offshoots from it.

A similar plug is exposed about the Mansfield shaft, west of the Mike fault. Little is known about the bedrock geology owing to the cover of lateral moraines on the lower, western continuations of Printer Boy and Long and Derry Hills. Farther west, between the Dome and Iron faults, the bedrock in Iowa Gulch seems to consist chiefly of Leadville dolomite and an overlying sill of early White porphyry, but these relationships are only inferred.

In lower Iowa Gulch and on the southern slope of Printer Boy Hill there are eight mines or groups of workings. In lower Iowa Gulch are (1) the Hellena mine, (2) the First National and Julia-Fisk group, (3) the Ontario-Lou Dillon group, (4) the Lillian mine, and (5) the Mansfield mine. On the southern slope of Printer Boy Hill are (1) the Doris group, (2) the Clear Grit-Ella Beeler group, and (3) the Rex shaft.

HELLENA MINE

The Hellena (pl. 13) was the only large mine in Iowa Gulch accessible at the time of these studies. Previous to 1909, operations at relatively shallow depths are said to have yielded $100,000 worth of ore. This work was stopped largely because of water trouble. The mine was again in operation in 1928 and 1929, but administrative difficulties between the operating company and land owners, together with increased costs of pumping, forced the operating company to close down in 1930.

The Hellena shaft was sunk on the outcrop of the Hellena fault. Its depth in 1930 was 766 ft. Earlier work developed five levels (pl. 13), at depths respectively of 99, 195 (first level), 272, 290 (second level), and 400 ft (third level) below the collar of the shaft. The operations in 1928–30 were chiefly on still deeper levels: at 501 (fifth level), 605 (sixth level), and 700 ft (seventh level). Work was most extensive on the 501-ft level where long crosscuts were driven east and west from the shaft, whereas the higher levels were chiefly along the fault itself (the locus of most of the ore). This fault (fig. 88) is exposed on every accessible level, striking generally N. 15° E.–N. 5° W., and dipping east at angles ranging from 62°–85°. The steeper dips and the northeasterly ones are nearer the surface. The fault was opened into a widely gaping fissure on the 195- and 290-ft levels, but not at the deeper levels (fig. 91). The parts of the vein having a northeasterly trend and a relatively shallow depth are coextensive with the better grade and greater quantity of ore. This relationship may signify that the premineral shearing thrust that produced the Weston fault had a component on the east side of the fault that was directed southward as well as upward. This interpretation is consistent with the displacement of the Iowa fault south of the mine shaft (see pl. 1) but, on the other hand, all the striae observed along the fault on the 290-ft level dip gently southeastward in the fault plane. They may be due to renewed but opposite movement on the same fault planes, as suggested on pages 63–64. The fault fissure itself contains much breccia; on the 290-ft level rhyolite, rhyolite agglomerate, and breccia are found along the edges of the fault, as though rhyolite had been forced out along the fault but had been somewhat shattered by subsequent movement. On the 400-ft level the Hellena fault contains a large block of pre-Cambrian granite between walls of early White porphyry and grit of the Weber (?) formation; here the rocks in the footwall of the fault dip westward as through dragged up by the elevation of the hanging wall. Fragments of country rock are cemented by ore (fig. 73), indicating that part of the movement was of premineral age.

The work extends far east of the Hellena fault only on the 501-ft level. The east wall of the fault below the 290-ft level is made up of early White porphyry that forms a thick sill lying under grit beds of the Weber (?) formation and presumably just above Leadville dolomite. This White porphyry mass has been generally identified as a dike, but the east wall of the Hellena fault consists of grit beds on the 195- and 290-ft levels. Peculiar structural features on the east drift east of the Hellena fault are the several "clay dikes" (p. 64). At the extreme eastern end of this level "Blue" limestone was reported to have been found in drilling, but shortly thereafter this drift was no longer accessible and confirmation was thus prevented.

West of the shaft on the 501-ft level, the rocks are a series of sills of Johnson Gulch porphyry, intercalated with grits and sandstones of the Weber (?) formation. About 625 ft west of the shaft a zone of breccia and gouge, approximately 20 ft wide, and bordered by walls that show striae dipping 30° toward the southeast was cut; these walls strike N. 15°–45° W. and dip 55°–65° NE. Beyond this fault zone is Parting quartzite, dipping 55°–80° W., greatly shattered and yielding much water; its dip decreases westward, and 75 ft beyond the fault the overlying Dyer dolomite appears. The latest working is said to have struck more quartzite, representing either the Parting again or the thin quartzite at the base of the Leadville dolomite, but the mine was abandoned before this new exposure could be studied.

All strongly mineralized ground seen in the Hellena mine is confined to the Hellena fault and the immediately adjacent rocks, and this fault is clearly the trunk channel (fig. 89). Where it is full of gouge or sheeted rock, the ore is absent or lean; where it is more open, gash veins in the sheeted rocks or in the gouge flanking the fault are common; where there is no gouge in it, the ore shoots are strong and are the chief source of ore. Locally, as on the 195-ft level north and the 501-ft level east, small replacement bodies adjacent to the fault have been stoped. Rhodochrosite is a conspicuous gangue mineral here, and also farther south along the Hellena fault (fig. 90). The chief ore minerals are galena and sphalerite; in the higher workings, according to reports, some of their oxidation products occur. There is also much pyrite, especially in tiny veinlets in the country rock. During the years 1928–30 about 25 tons of ore were obtained from the Hellena vein or from a small branch vein on the 290-ft level. This ore averaged 0.18 ounce gold and 8.0 ounces silver per ton, 23.1 percent lead, and 7.1 percent zinc; 500 tons of milling ore were recovered, assaying 0.14 ounce gold and 5.0 ounces silver per ton, and 7.0 percent lead and 6.0 percent zinc (H. H. Wallower, personal communication, 1930). Data furnished by U. S. Bureau of Mines and compiled by R. D. Longyear and G. M. Schwartz show that in 1906–12 and in 1924 the mine produced 1,113 short tons of ore, having a value of $45,104 and averaging as follows: 0.16 ounce gold and 10.42 ounces silver to the ton, 29.5 percent lead and 0.03 percent copper.

In 1930 five holes were sunk with a churn drill west of the Hellena workings. Some ore containing a moderate percentage of galena and sphalerite and considerable pyrite was found in two of the holes.

Two points are of special interest in connection with the Hellena workings. One of them is the type of ore that locally contains considerable quantities of gold and rhodochrosite; these minerals indicate a temperature slightly higher than that generally prevailing during ore deposition in the marginal part of the Leadville district. A second point of interest is that, despite the

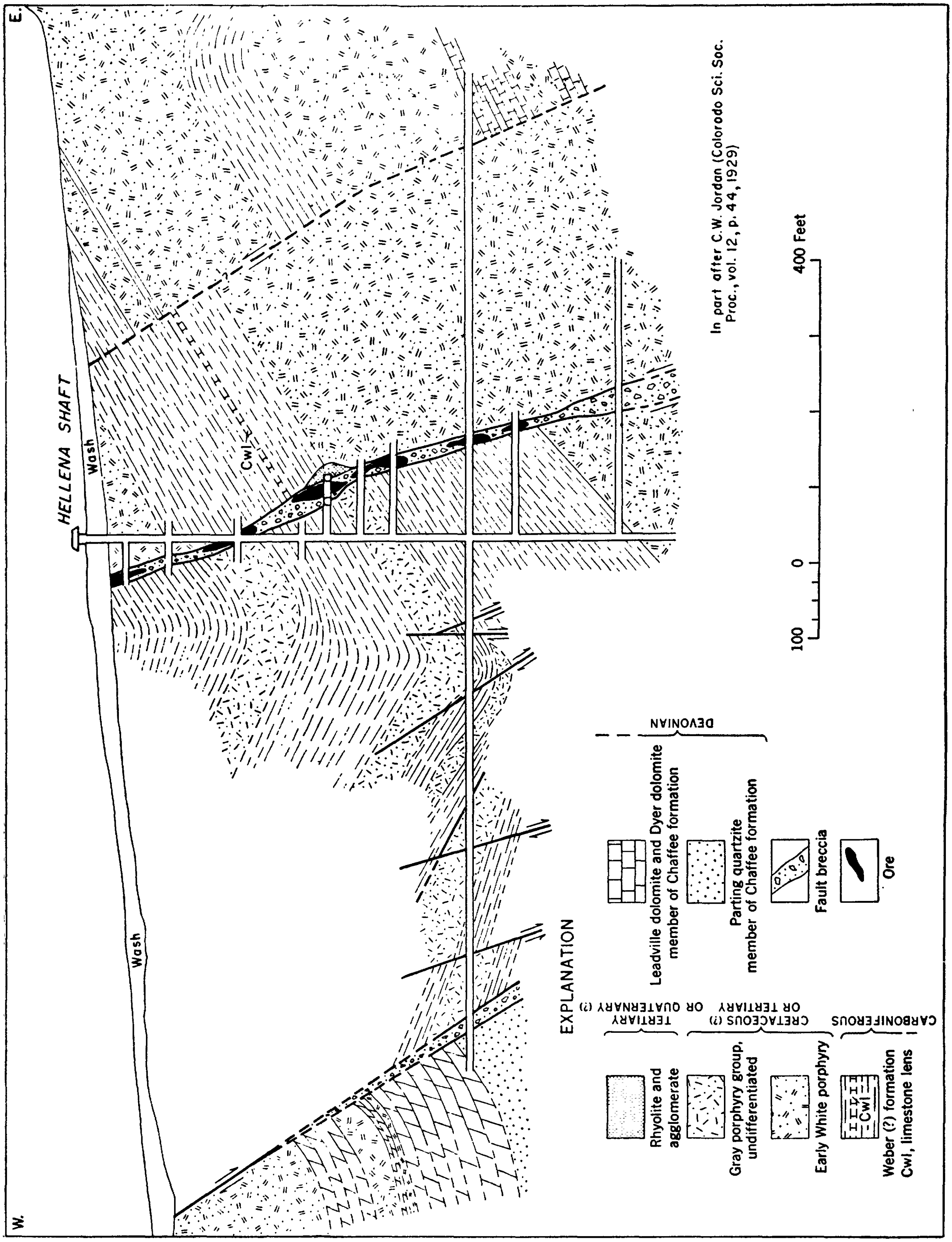

FIGURE 88.—East-west section through the Hellena shaft; in part after C. W. Jordan.

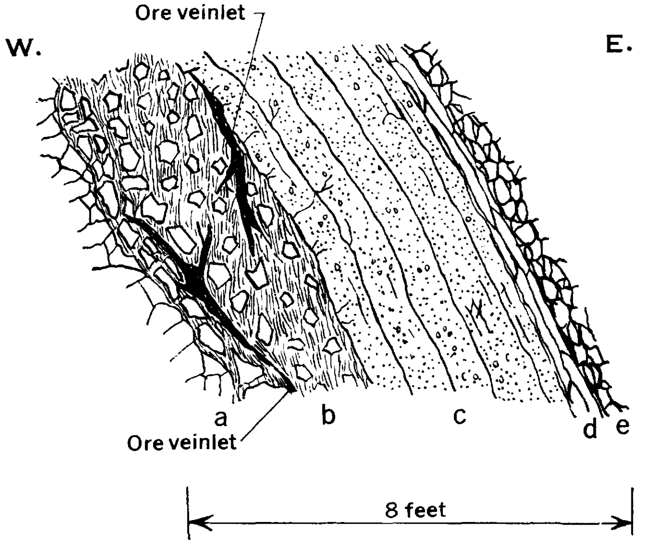

FIGURE 89.—Section across hanging-wall part of Hellena vein, 3d level, Hellena mine, showing sheeting, gouge, and ore. *a*, shattered rock in foot wall; *b*, fault breccia; *c*, sheeted or bedded grit of Weber(?) formation; *d*, rhyolite, sheeted parallel to hanging wall; *e*, rhyolite breccia.

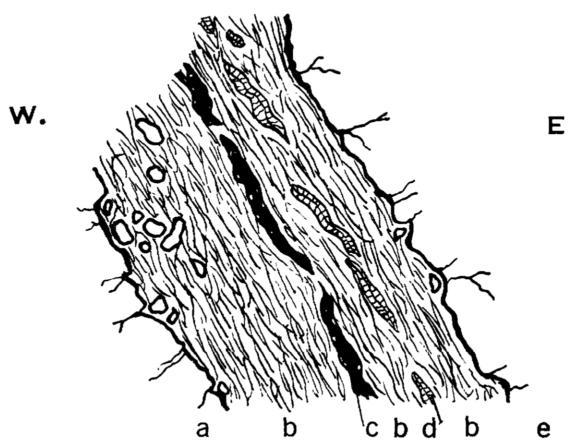

FIGURE 90.—Diagrammatic cross-section of vein, showing rhodochrosite, Hellena mine, 3d level. *a*, shattered rock in footwall; *b*, gouge; *c*, discontinuous vein of sulfide ore; *d*, discontinuous vein of rhodochrosite; *e*, shattered rock in hanging wall.

indicated higher temperatures, nearly all the ore is in openings along the Hellena fault and very little was formed by replacement of the walls. Perhaps this distribution is due largely to the chemically resistant nature of the wallrock so far exposed by the workings. It may also be attributed in part to gouge, which prevented ore-forming elements from spreading into the walls. It may be that at greater depths the limestone is extensively mineralized where the fault crosses the contact between the Leadville dolomite and the widespread sill of early White porphyry above, although the limestone may have been so sealed off by gouge as to escape replacement. The actual depth to that contact here is not known, however, and data on the structural conditions between the Hellena fault and the fault found at the west end of the 501-ft level are not adequate to justify an estimate. A preliminary step in exploring for such a deep ore body would be to drill holes from the 501-ft level or from the surface, on both sides of the Hellena fault. In selecting drilling sites, care should be taken that points east of the fault are started far enough east of the present shaft to avoid crossing the fault before reaching the limestone, and thus failing to explore its eastern or hanging wall.

ONTARIO-LOU DILLON GROUP

The old abandoned workings of the Ontario-Lou Dillon, group (O–20 to O–24, O–27 to O–30, O–42), are in the north wall of Iowa Gulch, north and northwest of the new Hellena shaft and within 1,200 ft of it.

The Lou Dillon (O–22) and New Orleans (O–29) tunnels and shafts are no longer accessible and no ore remains on their dumps. With the exception of the lowest Ontario tunnel, nothing could be learned of

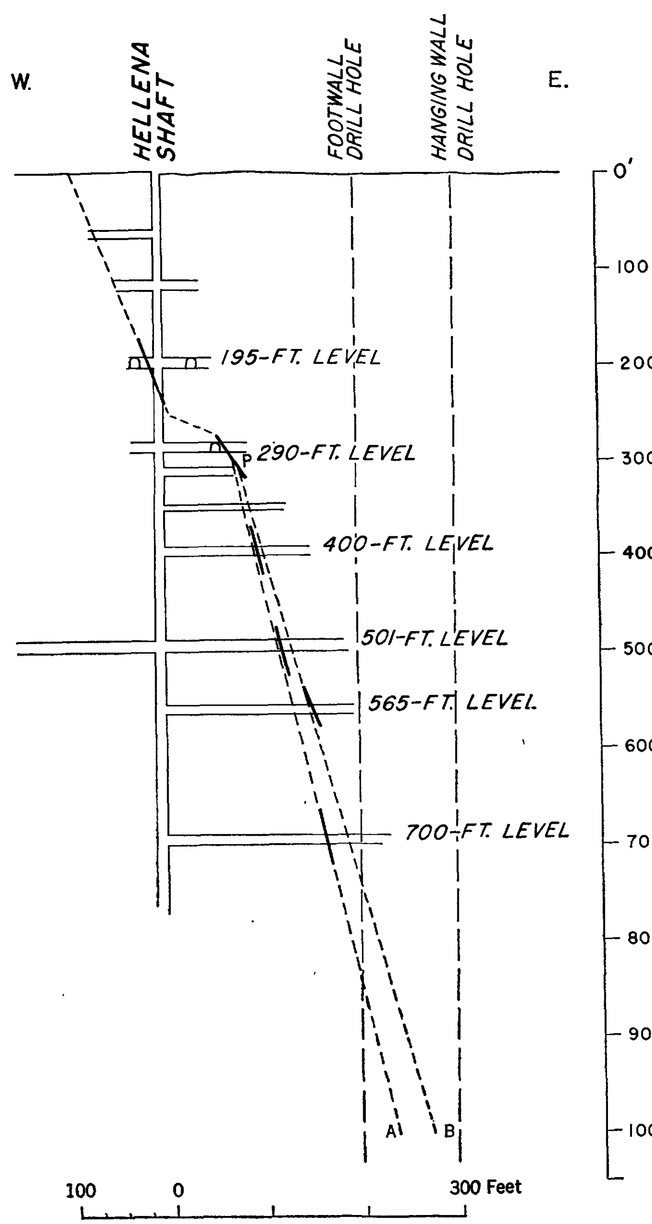

FIGURE 91.—Projection of Hellena fault below shaft.

their past output or of details of their geology. The identity of the rocks penetrated can be inferred from material on the dumps. The northward entension of the Hellena fault was encountered in the east workings connected with an old shaft on the American Continental claim (O–29–a), about half way between the Lou Dillon shaft (O–22) and the portal of the American New Orleans main adit (O–29). A hole drilled in the American Continental workings at their eastern end and just east of the Hellena fault started 110 ft below the surface in early White porphyry, passed through 171 ft of porphyry, 8 ft of fault breccia (or rhyolite agglomerate), and then 103 ft more of porphyry. Here the drill entered grit of Weber(?) formation and penetrated it for a depth of 25 ft, to stop at a depth of 417 ft below the surface of the ground.

The Ontario claim lies about 650 ft northwest of the American New Orleans adits. In it are four adits and a shaft (O–27). They were driven along a fault that in places brings sills of Johnson Gulch porphyry against grit beds of the Weber(?) formation. Only the lowest adit (also called the Midas mine) was accessible from 1929 to 1933 (fig. 92). In it a fissure vein filling a fault lies between walls of Johnson Gulch porphyry. The vein strikes N. 6°–11° E. and dips steeply west, but is joined in its hanging wall by several small fissures which strike about parallel but dip only 30° W.; along them, as also along the main fissure, considerable stoping has been done and indeed the main adit is badly caved in many places under such stopes. In some places the ore-bearing material of the stopes still remains in the walls and consists of a silicified breccia suggesting, in the angular forms and mixed nature of its fragments, some of the rhyolite agglomerate found in various workings in this area. According to Emmons (1886, p. 507) this vein contained coarse-grained galena where the walls were porphyry, but was unproductive where it passed through sandstone. It strikes about parallel to the Hellena vein, but is 700 ft to the west and dips west instead of east. The output of this group of claims is not known but Emmons (p. 608) cites analyses of ore from the Ontario tunnels, rich in galena and pyrite, and containing 20 ounces of silver to the ton. Here also pyrite is a characteristic mineral, as in the Hellena mine and elsewhere in this area.

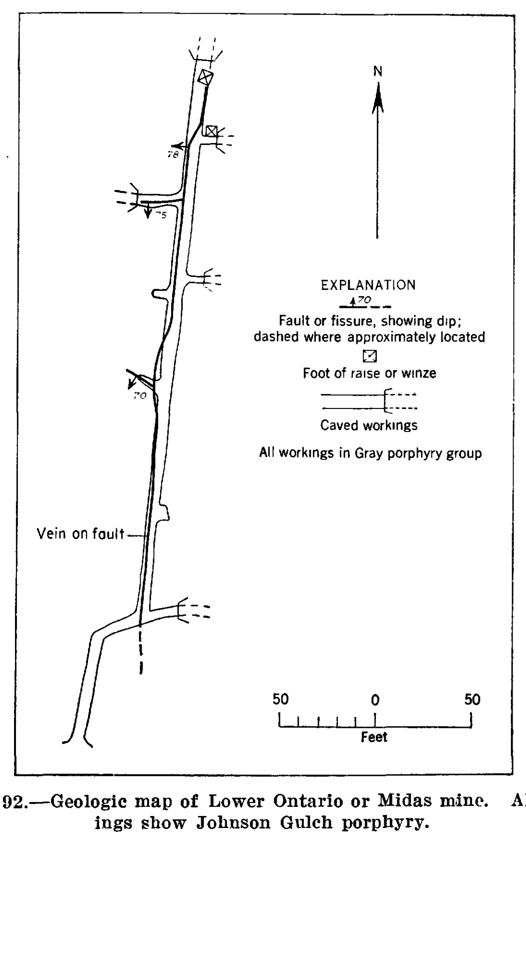

FIGURE 92.—Geologic map of Lower Ontario or Midas mine. All workings show Johnson Gulch porphyry.

North of the Ontario tunnels, and apparently on the same vein, is the Green Mountain shaft. This property once supplied high-grade ore but is no longer accessible. Data regarding two exceptionally rich shipments made about 1884 are recalled by Mr. Ezra Dickerman of Leadville (Oral communication, 1930) as follows: 5 tons averaging 456 ounces of gold, 42 ounces of silver, and 30 percent of lead; and 8 tons averaging 266 ounces of gold, 40 to 42 ounces of silver, and a moderately high percentage of lead.

The two Yale adits (O–6 and O–7) are about 800 ft due west of the lowest and most southern of the Ontario adits. The east adit (O–6) (fig. 93) was driven along northeastward-trending fissures that are not exposed at the surface. The most conspicuous of these fissures strikes N. 32° E. This working is chiefly in Johnson Gulch porphyry. Near the portal, however, the tunnel and a northwest-trending crosscut expose a

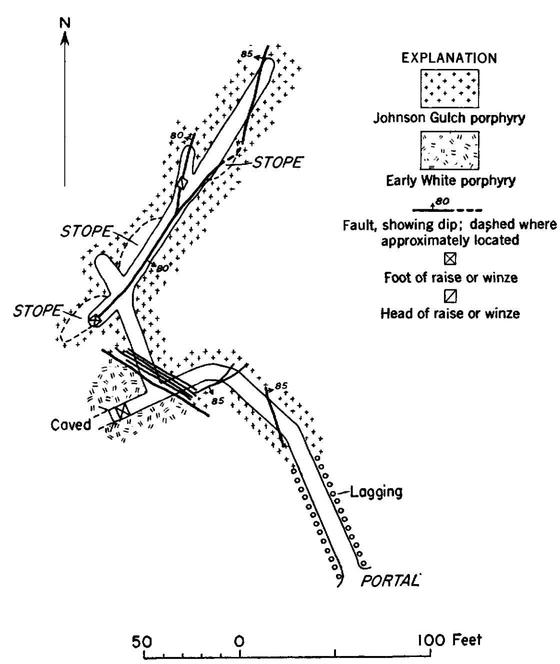

FIGURE 93.—Geologic map of the East Yale tunnel.

broad shear zone, irregular and filled with gouge, which is inferred to represent the main branch of the Weston fault. It brings the Johnson Gulch porphyry on the northeast down against early White porphyry on the southwest. Few signs of ore are seen.

The west tunnel (O–7) lies a hundred feet to the west and at slightly higher altitude (fig. 94) than the east adit. It is chiefly in Johnson Gulch porphyry but there is a small exposure of early White porphyry on the southwest side of a fault at the end of a west crosscut (fig. 94). Many fissures that trend N. 0°–45° E. and dip steeply northwest or southeast, resemble the fissures of the eastern adit and seem to be subsidiary fissures leading off from the main Weston fault, which is exposed in the east adit. The dump contains pyritic ore, partly oxidized, and small quantities of lead and

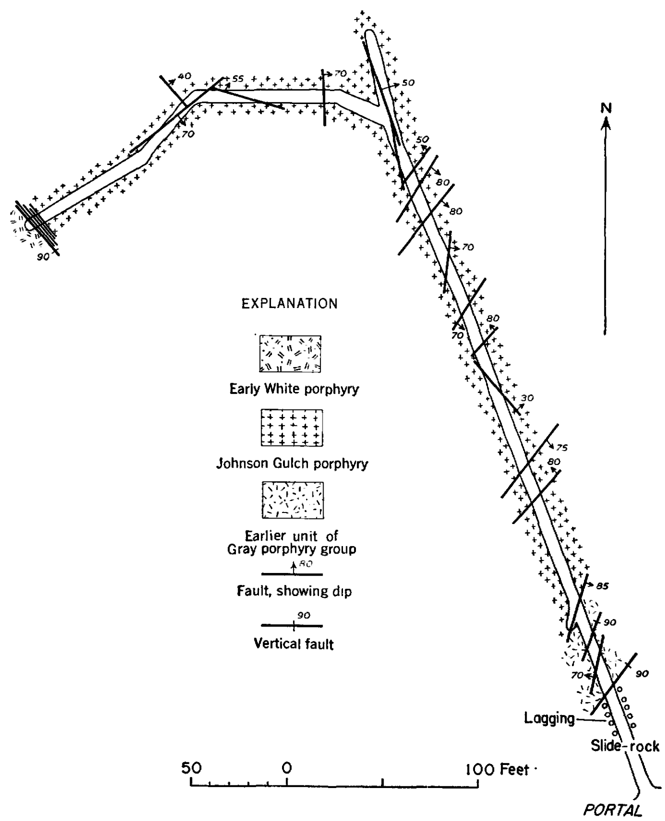

FIGURE 94.—Geologic map of the West Yale tunnel.

zinc sulfides. The mineral composition of the ore is similar to that in the Hellena mine, suggesting that ore deposited in the immediate vicinity of the Hellena and Weston faults in Iowa Gulch was formed at somewhat higher temperatures than that deposited farther east or west.

The shaft of the old North Star mine (O–34) is no longer accessible, but is said to have supplied a small quantity of ore from about 300 ft of workings. Several shallow pits lie northwest of the shaft.

FIRST NATIONAL AND JULIA-FISK GROUP

A group of prospect pits and shafts of the First National and Julia-Fisk mines lies on the northern side of Iowa Gulch, about 3,000 ft due west of the Hellena mine and about 1,400 ft due north of the Doris mine. With one exception, the surface workings are either in Leadville dolomite or in the overlying sill of early White porphyry. A single shaft was opened in limestone of the Weber(?) formation. None of the larger openings are now accessible, so the only sources of information are the material on the dump and data furnished by Mr. E. P. Chapman of Washington (oral communication, 1930), based upon his conversations with former miners.

The Julia-Fisk shaft (P–49) was sunk to a depth of 600 ft, penetrating a sill of early White porphyry, the Leadville dolomite, and the rest of the stratigraphic succession down to the Sawatch quartzite. At a depth of 410 ft the Parting quartzite was reached. On the contact between this quartzite and the Dyer dolomite a small bedding-plane deposit of silver-bearing galena was found; driving northeastward, the operators mined ore valued at $20 per ton. In the Sawatch quartzite near the bottom of the shaft, a gold-bearing fissure was discovered, assaying 1.0 ounce gold and 40 to 50 ounces silver to the ton, but organizational difficulties and heavy pumping costs compelled the company to stop operations. Mining was carried on chiefly between 1900 and 1910, and dewatering today would necessitate considerable initial cost. Ore on the dump contains galena, dark-brown sphalerite, and large quantities of manganosiderite. The presence of manganosiderite indicates that the ore of this mine, like that of other mines nearby, was formed at a relatively high temperature.

The First National shaft (P–52) is situated 400 ft southwest of the Julia-Fisk mine. The surface geology is like that at the Julia-Fisk shaft; the Leadville dolomite was reached at a depth of 198 ft by a shaft, which was dug to a depth of 256 ft. From this shaft four levels were driven—146, 160, 198, and 246 ft below the collar. In 1937 the longest drift extended 375 ft from the shaft. A map of the mine furnished by Mr. G. R. Elder of Leadville in 1934 indicates a small ore body south of the shaft on the 246 level. Later mining (according to E. P. Chapman) led to eastward drifting and developed a large body of zinc carbonate at a shallow depth near the east boundary of the property. Work was resumed in 1937–38, when the 198-ft level was extended along three fractures. Selected samples of ore assayed 0.15 ounce of gold and 7.6 ounces of silver to the ton, 7.5 percent of lead, and 11.2 percent of zinc. Descriptions suggest that there has been some silicification of the Leadville dolomite under the base of the early White porphyry that appears at the shaft collar; the ore body is a discontinuous blanket just beneath this silicified stratum (R. D. Elder, Personal communication, 1938). C. J. Moore (Unpub. rept. 1909) estimated the value of the output at $15,000. The large dump in 1932 yielded many specimens of primary minerals, including galena, dark-brown sphalerite, a little chalcopyrite, and much pyrite, and also some vein quartz and considerable manganosiderite. Most of the manganosiderite occurs as rhombohedrons with curved surfaces, and some as very thin rhombohedrons forming rosettes, under which arsenopyrite commonly appears in short prisms up to 0.05 in. (1.2 mm) in length. Both forms of manganosiderite are mentioned in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 151–152). Much of the ore is banded because it has replaced limestone along the beds. The presence of manganosiderite and arsenopyrite suggests that the temperature during mineralization was slightly higher here than in most of the outlying parts of the Leadville district, and gives reason to hope for extensively mineralized ground in this vicinity.

The same general type of mineralized rock is seen in several small openings (P–45) and on their dumps, about 800 ft west of the Julia-Fisk shaft. The surface rock is Leadville dolomite and a sill of the overlying early White porphyry. It seems that most of the ore occurs at the contact of these two rocks. However, pieces of Parting quartzite found on one dump show incomplete replacement by small groups of galena and light-colored sphalerite crystals.

LILLIAN MINE AND ADJACENT OPENINGS

The term Lillian mine is now applied to two large workings and a group of several small prospects. The eastern of the larger workings is known as the Altoona adit; its portal is at an altitude of 10,673 ft. The other large working is the Brian Boru mine, whose portal is about 400 ft N. 60° W. from that of the Altoona adit.

The Altoona adit (lower tunnel, P–68) was worked as a prospect in 1929 and 1930. It connects with older workings of the Lillian mine, which are now caved and inaccessible. Work in the Altoona tunnel was on two levels. The upper level explored the Sangamon fault, which strikes N. 7°–8° W., dips 70° E., and is marked by down-dip striae. The Sangamon is one of several north-trending faults crossing the southern slope of Printer Boy Hill. Although the Leadville dolomite bordering the fault is considerably bleached and silicified in places, or ore is to be seen on the upper level.

The main level, 132 ft lower (pl. 14), penetrates Manitou dolomite and porphyry of the Johnson Gulch type, which contains the typical scattered pink phenocrysts of potash feldspar. Northward-trending faults are conspicuous in this adit. Several of them are reverse faults, but the Sangamon fault, which is well exposed at two points, is normal.

At the northeastern end of the workings that are now accessible a raise passed through 83 ft of the upper part of the Manitou dolomite, 18 ft of red and green shale of the lower part of the Parting quartzite, 29 ft of typical Parting quartzite, and it entered the Leadville dolomite above.

The contact between the Johnson Gulch porphyry and the Manitou dolomite on the main level is generally a fault along which the Manitou dolomite is dragged down so it would appear that bodies of the dolomite overlie the porphyry and were dropped down against it by faulting. At exposures in the northeastern workings of the main level, however, the porphyry (though overlying some of the dolomite) probably is a thin sill from one of the dikes in this region, intruded between beds of Manitou dolomite.

The Altoona adit (plate 14) was operated on a small scale during the years 1920–30, but the development work was disappointing. From the Nellie S. mine several fair-sized stopes were opened, presumably in the upper part of the Leadville dolomite above the highest level of the Altoona mine. The ore bodies thus exposed were in part veins and in part small blanket deposits containing the lead minerals galena and cerussite and also zinc carbonate and pyrite. The minerals found included lanarkite and schapbachite, both bismuth-bearing minerals. The ore was rich in silver, and some contained visible native gold (Emmons, 1886, p. 510; Emmons, Irving and Loughlin, 1927, p. 295). The blankets are distinctly elongate in a north or northeast direction (Emmons, Irving, and Loughlin, 1927, p. 295, pl. 45) and, according to the published maps, are parallel to the feeding fissures. The orientation of these blankets agrees with that of the Printer Boy vein, as described by Emmons (1886, p. 232)—in fact, the Sangamon fault or the Nellie S. fault may be identical with the vein found in the Lovejoy workings in the northern side of Printer Boy Hill. It is directly on the strike of that vein, and the sequence of rocks in the Lovejoy workings is identical with that described above.

The Brian Boru adit (P–62) is now largely caved, but some 300 ft of workings that can still be examined are in Leadville dolomite (fig. 95). An east drift about 70 ft north of the portal enters early White porphyry that has been brought down against the Leadville dolomite by a normal fault striking N. 10° E. Two small blanket deposits, within 250 ft of the portal, apparently related to other northeast-striking faults, have been mined out. Nothing could be learned as to the nature of these ores.

North and northeast of the Brian Boru and Altoona adits numerous small prospects have been driven in the beds at the top of the Leadville dolomite, just under the early White porphyry, and near faults trending northward or northeastward. At several of them, copper-

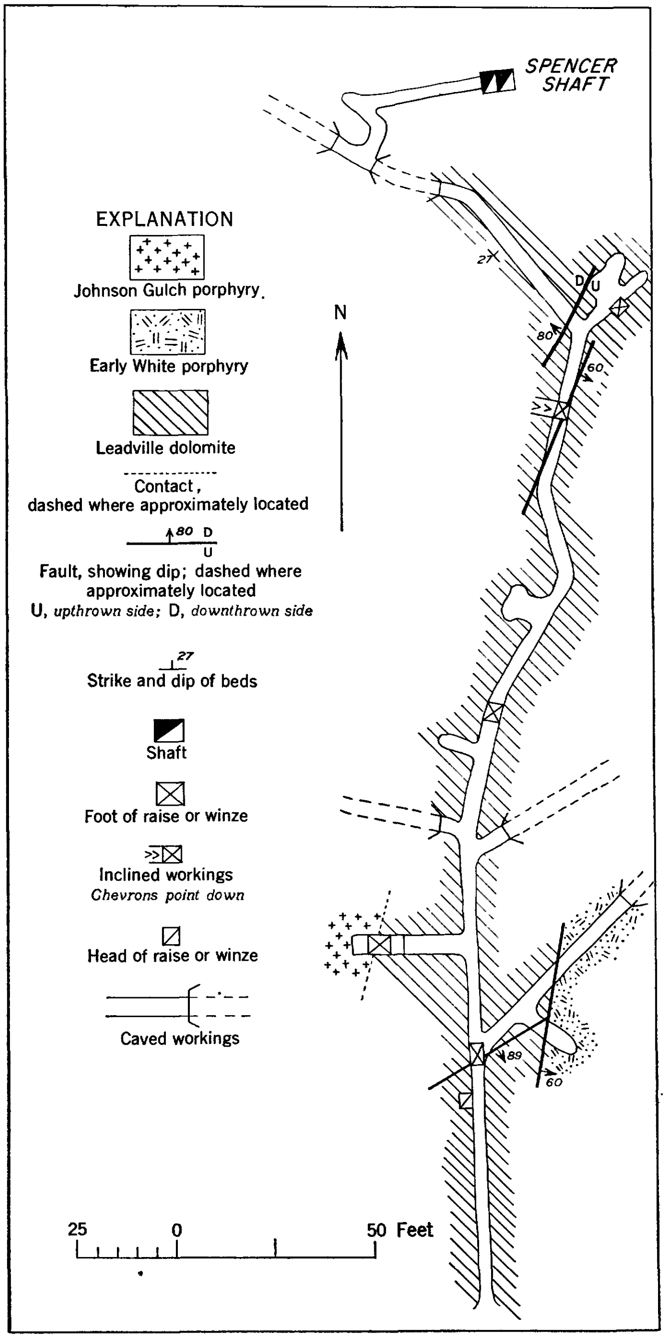

FIGURE 95.—Geologic map of the accessible part of the Brian Boru tunnel.

stained rock is found on the dump, together with silicified Leadville dolomite and extensively sericitized and partly epidotized early White porphyry; such altered rocks have been found associated with ore but are not infallible indicators. Some prospects reached the Dyer dolomite.

West of the Brian Boru and Sangamon adits, at altitudes ranging from 10,750 to 11,100 ft, several small prospects have been opened in beds below the base of the sill of early White porphyry that overlies the Leadville dolomite. Most of them seem to have been driven along dikes of Johnson Gulch porphyry, which locally contain a little finely crystalline, disseminated pyrite. Strongly silicified Leadville dolomite is also found on many of their dumps. However, some of these prospects lie west of the Mike-Pilot fault complex, along which the west side is downthrown, and consequently they are in the upper part of the Leadville dolomite or in the overlying early White porphyry.

The widespread silicification of the limestones, and the magnetite found on some of the dumps, indicate that mineralization in this area, as in the vicinity of the Hellena mine, took place at higher temperatures than those of most of the marginal deposits. This magnetite is partly altered to hematite, and locally the Leadville dolomite contains small cloudy patches of finely disseminated hematite.

MANSFIELD MINE

The Mansfield mine and the prospects within 600 ft of it to the southeast and east were opened for the most part in the outcrop of the sill of early White porphyry overlying the Leadville dolomite. Some of the rock cut by the main shaft may be bleached Johnson Gulch porphyry, though the evidence is inconclusive because of the extreme degree of alteration. The Mansfield is a three-compartment shaft, said to have been sunk to a depth of 800 ft. It is said that some ore was found, but there is no record of production from this shaft. Operations were stopped because cost of pumping became excessive. Bleached, silicified, and conspicuously iron-stained Leadville dolomite was found on the dumps near the main shaft.

REX MINE

The Rex mine is the most extensive in Iowa Gulch, west of the Lillian mine. Mining began in 1893 and a shaft was sunk on what may be regarded as the Mike (?) fault or as its extension southward from its junction with the Pilot fault on the southern slope of Printer Boy Hill. The surface rock is most probably a highly altered member of the Gray porphyry group. A large flow of water, encountered at a depth of about 300 ft where the shaft entered the Manitou dolomite, precluded further deepening of the shaft. A drift was begun, but the flow of water continued to be so large that work was abandoned, despite the reported finding of a good grade of gold ore.

A new firm leased the mine in 1901, the shaft was retimbered, and the contact between the porphyry and the Manitou dolomite was explored; lead carbonate ore was found which was noncommercial at that time (E. P. Chapman, personal communication). However, geological conditions seem to be generally favorable for the occurrence of ore along the contact between the porphyry and limestone or along crosscutting fissures because the shaft is situated on or just east of the premineral Mike (?) fault and only 900 ft southeast of the small pluglike body of Johnson Gulch porphyry that was probably a minor center of mineralization.

Less than 2,500 ft west of the Rex shaft, and also east of the Dome fault, there are several openings in the early White porphyry. Although they are close to the contact between the great sill of early White porphyry and the underlying Leadville dolomite, these prospect pits are far from all known channels of mineralization and would produce but negligible quantities of ore.

DORIS GROUP

The two shafts and one tunnel of the Doris mine (P–114) are located in an old landslide terrain, where bedrock is not exposed. None of the workings are now accessible and local geologic conditions cannot be closely inferred. The shaft is said to be at least 400 ft deep. It is believed that much of the exploratory work was done east of the shaft, along the contact between the Leadville dolomite and the overlying early White porphyry, but some at least was in the Dyer dolomite. On the dump Leadville dolomite and a little quartzose vein matter and limonite are the principal materials; there is, however, a small quantity of specularite indicating, as at the Julia-Fisk group, a relatively high temperature of mineralization.

Mine production records of U. S. Geological Survey and Bureau of Mines, kindly compiled by C. W. Henderson of the U. S. Bureau of Mines, 1934, show that the total output of the Doris mine was about $156,000.

Three prospects (No. P–113) 500 ft west of the Doris mine reveal mineralized rock similar to that in the mine.

About 600 ft north of the Doris mine are three shafts and a tunnel (P–53). The Leadville dolomite is at the surface here and exploratory work was apparently done in the upper part of the subjacent Dyer dolomite. The rocks have been altered in ways that are commonly associated with ore formation, including silicification of some beds, the development of "zebra rock" in the Leadville dolomite, and the pyritic replacement of a sandy bed, presumably that separating the Dyer and Leadville. However, no ore was found by the writer in place, or on the dumps.

About 500 ft east of the last-described group of prospects and 1,000 ft northeast of the Doris mine is a large group (O–55) of shallow pits and shafts and a short tunnel. Leadville dolomite (in part silicified and pyritized) and a little sericitized early White porphyry were encountered.

ELLA BEELER-CLEAR GRIT GROUP

Here many geologic details can only be inferred because much of the valley floor is covered by alluvial and glacial deposits, and most of the workings are no longer accessible. Much of the information assembled in the present report was obtained from reports by mining geologists to whom the workings and older reports were accessible. C. J. Moore, E. P. Chapman, G. M. Schwartz, and R. D. Longyear furnished unpublished reports and personal communications. Special thanks for data from a more recent study of the Clear Grit mine are due the E. J. Longyear Co. of Minneapolis and E. C. Congden of Duluth, Minn.

Thin beds of limestone that are essentially inclusions in the sill of early White porphyry appear above and south of the new Clear Grit shaft. Possibly these beds belong to the lower part of the Weber (?) formation or, more probably, to the uppermost part of the Leadville dolomite, as suggested by their color, texture, and massiveness. If they belong to the upper part of the Leadville dolomite, their position in the sill of early White porphyry, opposite outcrops of basal sandstone of the Weber (?) at the Julia-Fisk shaft, suggests that the porphyry sill was in part transgressive, cutting the Leadville dolomite below its top and lifting its upper beds on the south side of Iowa Gulch, but advancing to a stratigraphically higher position between the Leadville and the basal beds of the Weber (?) north of the gulch near the Julia-Fisk workings.

The mines of this group (pl. 15) are the Clear Grit discovery shaft (O–50), on the western part of the Clear Grit ground, the new Clear Grit shaft and workings, the Constance shaft (O–49) and tunnel, and many other tunnels, including Ella Beeler (O–46, O–47, O–65), Little Troubadour (O–49), Louisa (O–64), Little Julia (O–65, west), and Fortuna (O–46). The workings reached by way of the new Clear Grit and Constance shafts are loosely referred to as the Clear Grit mine. Most of the ore produced from this property in the early days was from shallow workings along the Constance tunnel, reputedly driven on the western branch of the Weston fault. Some ore was also found at greater depth in a "contact" deposit between the Leadville dolomite and a sill of early White porphyry. The chief ore minerals were pyrite and silver-bearing sphalerite. The fissure vein mined was as much as 20 ft in width and locally had a high content of lead. The "contact" body was at least 250 ft long and some assays showed as much as 3,940 ounces of silver to the ton, but the average was 12 ounces. Production of this type of ore began in 1883, but was temporarily discontinued about ten years later. The estimated value of the total output from these operations is, according to an apparently trustworthy unpublished report by C. J. Moore, $14,000 including some $12,000 for 638 short tons mined in 1883–84. This report by Mr. Moore presents sections of these earliest workings with stoping on two levels, one at a depth of 80 ft below the surface.

By 1885 the so-called Clear Grit vein, along the main Weston fault, had been discovered in work east of the Little Troubadour tunnel in the northern part of the Clear Grit claim. The ore was much like that from the Constance workings. Two fissure veins were found, 1 to 4 ft wide with ore shoots containing 30 to 50 ounces of silver to the ton; a third, about 6 in. wide, contained native silver, ruby silver, and enargite in ore assaying as much as 300 ounces of silver to the ton. Figures quoted by Moore show an output for 1885–89 of 84,600 short tons of ore, with a total average assay of 8.4 percent of lead, 0.06 ounce of gold, and 46.2 ounces of silver to the ton. Some doubt, however, attaches to the total tonnage figure quoted.

In 1885 work was directed chiefly still farther east, mainly to the three Ella Beeler tunnels, operating on the southward extension of the Hellena fault (pl. 15). These operations are properly designated the Ella Beeler workings. The only accounts of them available to the writer are those by C. J. Moore (see pl. 16). Most of the ore produced came from the Hellena fault fissure itself (fig. 96), where masses of rhyolite agglomerate were found. George Hartmann (personal

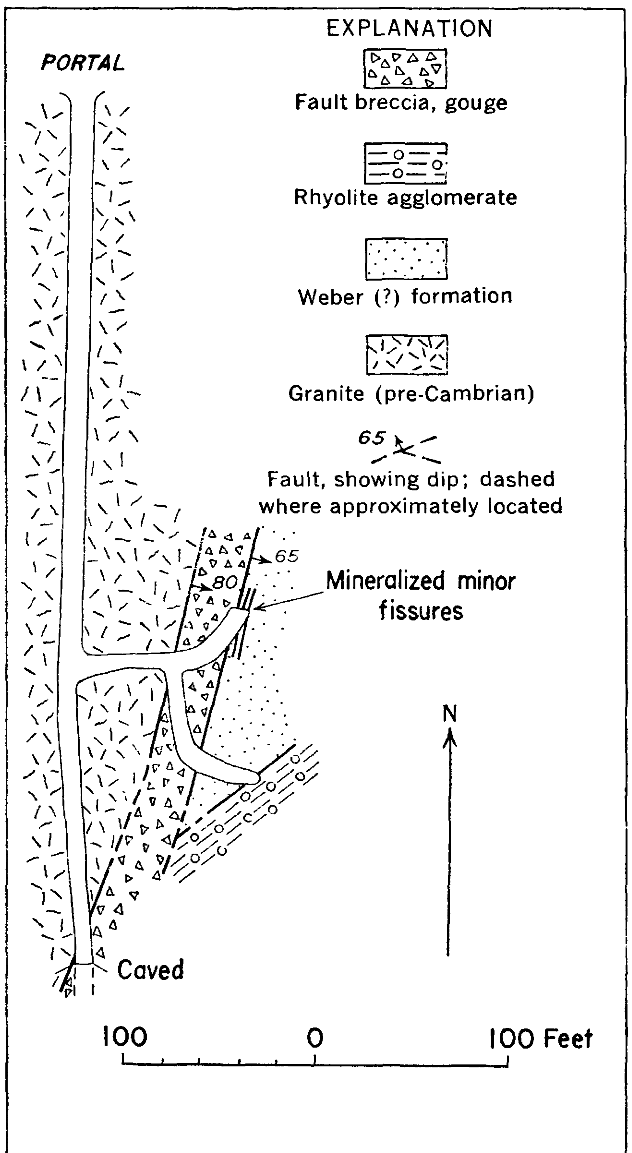

Figure 96.—Geologic map of accessible part of Ella Beeler tunnel.

communication, 1932), reports that one ore shoot, about 100 ft long and 7 ft wide, assayed $100 per ton. Subordinate shoots were found where the fault intersected the contact between the Sawatch quartzite and the underlying pre-Cambrian granite, and fairly large bodies of oxidized ore were developed along the Hellena fault at the contact between shale of the Peerless formation and an overlying sill of early White porphyry. An incomplete record of production given by Moore is as follows:

Output of Ella Beeler workings

	Period	Zinc (percent)	Lead (percent)	Gold (ounces per ton)
Upper tunnel, Hellena vein	1889–91	10. 2	21. 3	0. 47
Lower tunnel, Hellena vein	1903–13	11. 7	14. 4	. 40
Contact workings	1885–90			

	Silver (ounces per ton)	Weight (short tons)	Value
Upper tunnel, Hellena vein	31. 6	138. 151	$4, 789. 71
Lower tunnel, Hellena vein	22. 9	494. 366	9, 852. 62
Contact workings	48. 1	102. 167	2, 307. 00
Total		734. 684	16, 949. 33

The New Clear Grit shaft, located west of the Ella Beeler workings, was last operated in 1930. It penetrated a sill of early White porphyry and reached the Leadville dolomite at a depth of 398 ft. At this point an unusually vigorous flow of water (probably from one of the branches of the Weston fault, for the ground is described as having been heavily shattered) forced abandonment of the work. As in the Hellena mine, pyrite is one of the most conspicuous minerals of the ore in this group of prospects, especially in the smaller openings in the slope of Long and Derry Hill.

The Ready Cash or Two Mile High adit (O–69, west tunnel) is about 1,800 ft southeast of the new Hellena shaft and approximately 1,200 ft east-southeast of the Ella Beeler workings (pl. 15). It is said (W. D. Leonard, personal communication, 1934) to have had a gross output valued at $480,000, chiefly from two small veins in the pre-Cambrian granite. These veins are reported to have strikes of N. 25° E. and N. 45° E., and to dip 50 degrees or more to the southeast, thus trending about like the Union fault; they may be related to the local monocline or, as mentioned on page 74, may be regarded as the diverging branches of the Union fault where it fingers out. The ore was siliceous and galena-bearing with large amounts of gold and silver. Considerable free gold and some secondary silver chloride are reported (Emmons, 1886, p. 508). Some ore was produced from the slightly lower Big Chicago tunnel (O–70, east tunnel), the main body of the deposit occurring as a vein said to trend N. 30° W.

LONG AND DERRY HILL

A thick alluvial cover conceals the bedrock geology almost wholly on the lower, western slopes of Long and Derry Hill from the Musk Ox shaft (S–17) westward. Scattered outcrops and deeper workings, such as the Musk Ox shaft, give just enough evidence to indicate that there are two major faults trending about south-southeast approximately 1,500 to 3,000 ft west of the Musk Ox shaft—probably the Dome and Iron faults respectively.

Evidence of the bedrock geology west of the Musk Ox shaft is too scant to merit further discussion. Exposures to the east also are few, up to the point where the road from Iowa to Empire Gulch crosses the crest of Long and Derry Hill. Still farther east exposures are fair on both slopes of Long and Derry Hill, and tunnels and shafts furnish abundant clues to the geology on the ridge crest where the bedrock is largely concealed by timber and soil. The geology of this part of Long and Derry Hill, east of the road from Iowa Gulch to Empire Gulch, is much like that of Iowa Gulch to the north. The beds dip gently eastward. In the columnar section presented below, the thicknesses of the sills are averages only, since they vary greatly from place to place.

Generalized columnar section of formations exposed on Lower Long and Derry Hill between Mike and Weston faults

	Thickness (feet)
Weston fault	
Sill of early White porphyry	20
Shale and grit of Weber(?) formation	120
Sill of early White porphyry	150
Shale and grit of Weber(?) formation	120
Sill of Gray porphyry group	130
Shale and grit of Weber(?) formation	120
Sill of early White porphyry	460
Leadville dolomite	260
Dyer dolomite member of Chaffee formation	40
Sill of early White porphyry (local)	50
Dyer dolomite member of Chaffee formation	30
Parting quartzite member of Chaffee formation	40
Manitou dolomite (upper part only)	80
Sill of Iowa Gulch porphyry	100±
Mike fault	

This sequence, like the similar one on the southern slope of Long and Derry Hill, is repeatedly broken by faults. The direction and amounts of these displacements vary, but the faulting has generally brought older rocks to the east against younger ones to the west. Like the faults on Printer Boy Hill, several of those on Long and Derry Hill are occupied by dikes of Johnson Gulch porphyry.

Mineralization here was scattered and nowhere intense. A few short tunnels are located on the northern slope of Long and Derry Hill but the largest openings, by far, are the Belcher tunnel (P–105), the Kenosha mine (T–6, T–7, and T–10), the Musk Ox shaft (S–17), and the prospects near the Faint Hope tunnel along the crest of lower Long and Derry Hill (T–12 to T–35). Much placering has been carried on below an altitude of 10,900 ft on the southwestern spur of Long and Derry Hill.

PROSPECTS AND MINES NEAR CREST OF LOWER LONG AND DERRY HILL

The group of prospects near the crest of Lower Long and Derry Hill consists of two shafts, each about 50 ft deep, and a long tunnel, now caved. Much iron-stained limestone, apparently from the uppermost part of the Leadville dolomite, appears on the tunnel dump; it is typical of the "contact" or "vein material" that so commonly occurs just under the sill of early White porphyry that here overlies the Leadville dolomite.

The prospects, long abandoned, are described by Emmons (1886) under the names Faint Hope (T–15), Diana (T–16), Homestake (T–23), Gildersleeve (T–34), Campbell (T–34 and T–35), Porphyry (T–22), and Himalaya (T–21); they seem to have been designed chiefly to explore the upper beds of the Leadville dolomite. In describing the Faint Hope tunnel, Emmons stated that it was connected with the Porphyry shaft, which was sunk through 46 ft of "vein material" composed of low-grade ore. Most of the mines mentioned above were operated in a single ore body or several closely spaced ore bodies. Collectively, they are commonly called the Long and Derry mines. Apparently a large part of the output was from discontinuous masses extending downward irregularly into the limestone. Parts of these bodies cropped out on the surface and were thus among the earliest ores discovered in the Leadville region. Small bodies of pyritic ore were found, but apparently the chief primary ore mineral was galena, with which were associated noteworthy quantities of cerussite and cerargyrite. The most conspicuous outcrops consisted of black rock that is now identified as silicified Leadville dolomite, thoroughly impregnated with oxides of iron and manganese (Emmons, 1886, p. 509).

BELCHER TUNNEL

The main Belcher tunnel (P–105) and the adjacent minor adits are all caved. They are driven in Leadville dolomite, just a little above the top of the Dyer dolomite, which they enter virtually along the strike of the beds, about S. 20° E. Because they are thus directed, the tunnels fail to reach the top of the Leadville dolomite. Some of the dumps, however, contain galena and a little calamine, and one shows considerable chalcopyrite. Each of the openings clearly follows a small fissure or fault, along at least two of which dikes of Johnson Gulch porphyry have been intruded.

Iron-stained, silicified Leadville dolomite of the kind here so common crops out near the portal of the Belcher tunnel. Emmons (1886, p. 229) records also the presence of an ore body in the "lower Blue limestone" which was developed by the main Belcher tunnel. From this group of prospects E. P. Chapman (Personal communication, 1936) reports the mining of several small ore bodies, chiefly by lessees; the ore assayed 30 to 150 ounces of silver to the ton and occurred in pockets along inconspicuous fissures, presumably related to the faults mentioned above.

KENOSHA MINE

Old workings of the Kenosha mine lie on each side of the Mike fault. The two prospects west of the fault are in early White porphyry. Those east of the fault consist of an old caved shaft and several pits; they penetrated Parting quartzite, Dyer dolomite, and dike rock of Johnson Gulch porphyry. Considerable iron-stained limestone came from these workings; some nodules, selected by Emmons (1886, pp. 227, 557, 602) for analysis, contained 21.10 percent insoluble matter, 7.7 percent Fe_2O_3, 65.98 percent MnO, and 0.12 percent silver. There is no evidence that the outcrop here was large.

MUSK OX MINE

The equipment of the Musk Ox mine (S–17) was extensive and included a boiler house, several cabins, and a well-timbered shaft. The shaft is no longer accessible, and nothing could be learned of earlier operations in it. Material found on the dump and evidence in nearby openings such as the two shafts of prospect S–16 reveal that the bedrock nearest the surface here is a sill of early White porphyry; below this the shaft entered the Leadville dolomite and some of the fragments found were from the Dyer dolomite (as indicated by their slightly sandy texture and their pinkish-gray, buff and yellowish colors). No ore could be found on the mine dump, and records or even rumors of ore discoveries are lacking.

The next prospects to the west (S–12 and S–13) have Leadville dolomite on the dump, suggesting that the prospects are separated from the Musk Ox shaft by a small fault, trending due north. The first large fault (the Dome fault) is about 1,200 ft west of the Musk Ox shaft. As this is a post mineral fault (Emmons, S. F., Irving, J. D., and Loughlin, G. F., 1927, pp. 92–93 and pl. 39) there is no reason to believe that the Musk Ox mine holds special promise of ore. However, it does penetrate to the horizon most favorable for mineralization—the top of the Leadville dolomite.

PLACER PROSPECTING

Minor gold placer diggings are found in the gravels and sands spread over the lower southwestern slopes of Long and Derry Hill, and there are numerous prospect pits on both sides of the northeastern head of Thompson Gulch in the terrace material that lies at altitudes below 10,850 ft. Some attempts to reach bedrock are indicated by several timbered shafts that range from 50 to 100 ft in depth. Examples are S–5 (a two-compartment, timbered shaft), S–9 (an 80-ft shaft), and S–49. A few tunnels (such as S–40) have been driven in the same terrace material, presumably in a vain search for bedrock. This extensive prospecting proves that between Iowa and Empire Gulches, at altitudes lower than 10,700 ft, the alluvial cover on pre-Tertiary bedrock is mostly more than 25 ft thick and, very probably averages 50 to 75 ft in thickness. Bedrock mining has virtually been abandoned because of this alluvial cover.

The origin of the unconsolidated deposits covering bedrock in this area has been discussed in detail on pages 16–18. The gravels and sand that make up these prominent terraces are due to alluviation, possibly connected with glaciation but more probably resulting from relatively rapid uplift and the consequent deposition from overloaded streams. Therefore, the deposits are not confined to the bedrock valleys but are spread over the divides between, much as desert wash is distributed over mountain spurs by the merging of the alluvial fans of a piedmont plain. The material observed in prospects and other openings consists of poorly sorted particles of all sizes, among which boulders are conspicuous. Some of the boulders are poorly rounded but none of those found on the higher levels was observed by the writer to be either striated or faceted, except in the great valleys of Iowa and Empire Gulches, where the moraines lap against the sides of the terraces. Some terrace cuts expose sandy beds—sand and gravel in which the boulders are embedded. In other places, as in prospects S–33 to S–35, water stands permanently though the pits are only 10 ft deep and are situated nearly 500 ft above the valley floor—an almost certain sign that a moderately continuous silt layer underlies the immediate locality.

There is no record of gold produced from any of these prospects, and the fact that none of them has been enlarged beyond the prospect size indicates their low potentialities as sources of placer gold. All the larger placers in the Leadville district are in stream valleys; the dredging operations in the valley between Half Moon and Lake Creeks at Hayden, the placering along California Gulch, and earlier placering along Colorado Gulch and in the main Arkansas Valley due west of Leadville are typical examples. In contrast (if the above explanation of the origin of the high terraces is correct) those terraces between Iowa and Empire Gulches are composed of material transported only short distances down the adjacent slopes, partly by short streams, partly by slope wash. The sorting necessary to build up rich placer deposits would have been relatively slight in these alluvial gravels. Furthermore, the adjacent higher bedrock, though locally containing rich gold ores, generally contained lead-zinc-silver ores characteristic of the marginal, gold-poor facies of mineralization; the hope of finding placer gravels rich in gold on the high terraces is therefore still further reduced. The most promising areas are in the valleys of Iowa and Empire Gulches, below the level of the intervening high terrace whose surface along a given meridian is generally 400 to 500 ft above the floors of the two gulches. These gulches contain deposits made by streams that have been flowing over some mineralized bedrock, and the stream sorting is confined to definite channels in which available gold may have been concentrated into small deposits rich enough for exploitation.

UPPER LONG AND DERRY HILL AND WEST SHERIDAN MOUNTAIN

About 2,000 ft west of the 12,040-ft summit of Upper Long and Derry Hill is the plexus of faults here designated the Hellena-Weston-Iowa fault complex. The Union fault breaks into several smaller fractures whose traces are seen on the north slope of Upper Long and Derry Hill. The crest of the hill is composed of Cambrian rocks and evidence of mineralization is negligible. At the east end (about 1,000 ft east of the 12,040-ft summit) the Ball Mountain fault crosses the crest, faulting Manitou dolomite on the east against the Cambrian rocks; what appear to be branches of the same fault repeat the pattern with higher beds for another 1,000 ft eastward. Still farther east (2,000 ft due east of the 12,040-ft summit) the great Mosquito fault crosses the ridge, and the rocks in the east wall of the fault are upthrown 400 to 500 ft, locally bringing pre-Cambrian rocks against a sill of early White porphyry intruded along the top of the Dyer dolomite. Between the Mosquito fault and the northern peak of West Sheridan Mountain are several smaller faults having the same relative throw as the Mosquito fault.

Aside from these faults, the geology of this area is relatively simple. The sequence is normal and the strata dip uniformly and gently eastward. Several sills of early White porphyry have invaded the Cambrian formations; they are thin west of the Ball Mountain fault but thicken in the downfaulted block between it and the Mosquito fault. The north peak of West Sheridan Mountain is capped by an early White porphyry sill; this sill lies generally above the Manitou dolomite but is slightly transgressive, so that a thin wedge of Parting quartzite lies beneath it on the southern edge of the north peak. Another sill of early White porphyry overlying the Dyer dolomite is exposed on Upper Long and Derry Hill just west of the Mosquito fault and also on the south peak of West Sheridan Mountain. Dikes of Johnson Gulch porphyry occupy faults cutting the block between the main Ball Mountain and the main Mosquito faults. Similar dikes and a prominent, somewhat transgressive, sill occur on the northwestern, northern, and northeastern slopes of the north peak of West Sheridan Mountain. Here also are two sills of Iowa Gulch porphyry, the easternmost exposures of this type of rock. A dike of later White porphyry cuts across the saddle separating West Sheridan Mountain from Mount Sheridan.

There are no large openings or mines in this area. The crest of Upper Long and Derry Hill is pitted with small openings but only a few of them or their dumps are at all promising. Of most interest in this locality are the gold deposits in the Cambrian rocks and lead-zinc-silver deposits in the limestones under the larger sills of early White porphyry. The moderately promising gold prospects include several openings in and near the Latch, Tilton, and Belcher claims, the tunnels at altitudes of 11,500 to 11,750 ft on the north slope of Upper Long and Derry Hill, and the tunnels on the eastern slope of the north peak of West Sheridan Mountain. The most promising example of the lead-zinc-silver deposits comprises the workings on the southern slope of the south peak of West Sheridan Mountain.

LATCH, TILTON, AND ADJACENT CLAIMS

Prospecting on the Latch and Tilton claims is represented by several shafts (N–142, N–143, and O–75), all abandoned long ago and now completely caved. All seem to have been in Cambrian quartzite or shale of the Peerless formation. They are said to have been worked for gold. Although they are located on or near the trace of the main Ball Mountain fault, none seems to have struck large deposits of ore. A little iron-stained rock is exposed.

On the dumps of prospects N–139 to N–141 the dominant rock is Sawatch quartzite, with some fragments from sills of early White porphyry. Here the lowest working (N–139) is a caved tunnel in the lower part of the Sawatch quartzite, in which are many minor fractures, deeply stained with manganese dioxide. About 150 ft higher and 500 ft southwest is a caved shaft (N–140), in a higher zone of deeply iron-stained Cambrian rocks. The tunnel (N–141), in the same type of rock, is no longer accessible. The history of operations on these claims is not available but it is rumored that gold ore was found in small pockets like those on the south side of East Ball Mountain.

PROSPECTS ON EASTERN SLOPE, NORTH PEAK, WEST SHERIDAN MOUNTAIN

An opening (U–13) evidently driven in search for gold in the topmost Sawatch quartzite enters the black top bed of quartzite on the eastern slope of north West Sheridan Mountain. The adit extends 40 ft N. 70° W. from the portal and has a branching drift extending 20 ft southwest along the jointing. Like those of the two preceding groups, this prospect yielded a few pockets of high-grade gold ore from small-scale operations.

TUNNELS ON SOUTHERN SLOPE, WEST SHERIDAN MOUNTAIN

At an altitude of 12,750 ft on the southern slope of West Sheridan Mountain are two tunnels and a shallow pit (U–34) within a radius of approximately 250 ft. They are located just above or below the Parting quartzite. The minerals on their dumps are typical of all local prospects that are in this approximate stratigraphic position. They include bladed barite, which has replaced the Manitou dolomite, and a little galena, which filled fissures and to a small extent replaced the limestone. The history of these small operations is not known. They are very difficult of access and were never highly productive, but indicate that this ground is moderately favorable for ore deposition.

MOUNT SHERIDAN, CREST AND EASTERN SLOPE

The crest of Mount Sheridan is made up of a sill of early White porphyry at least 200 ft thick. Beneath this porphyry in descending stratigraphic sequence occur a dense blue-gray basal quartzite bed of the Weber(?) formation, a thin zone of black carbonaceous shale, and the sequence of beds common in the Leadville and Dyer dolomites. On the southern slope, however, a sill of early White porphyry, 150 ft thick, lies within the Dyer dolomite. On the northern slope a sill of White porphyry separates the Manitou dolomite from the Peerless formation, but this sill thins abruptly, and ends against a fault a short distance to the southwest. A third sill of early White porphyry, about 30 ft thick, occurs within the Sawatch quartzite and is exposed both on the northwest and southwest slopes of Mount Sheridan. Because of the eastward dip of the beds no rocks older than the Dyer dolomite are exposed on the floor of the Fourmile Amphitheater, just east of Mount Sheridan.

This sequence is broken by several faults. Some of those described for the southern part of the Iowa Amphitheater (pp. 69–70) extend southward across the westward-trending ridge that connects Mount Sheridan with West Sheridan Mountain. Along most of these faults the west side is downthrown. One low-angle fault, striking northwest and dipping northeast, displaces the Dyer-Leadville contact on the southern slope of Mount Sheridan and suggests in strike and in flatness of dip the reverse faults (p. 70) associated with ore bodies on the western slope of Mount Sherman. Between Peerless Mountain and Mount Sheridan this fault is displaced locally by small normal faults. Traces of such normal faults are clearly evident along the steep eastern wall of the Empire Amphitheater.

Few of the dikelike intrusives are large bodies. One small dike and sill of later white porphyry, with good columnar jointing, cuts a sill of early White porphyry and the adjacent beds of the Dyer and Leadville on the southerly slope of Mount Sheridan, about 1,800 ft south-southeast of the summit.

The slopes of Mount Sheridan have been explored in many small prospects. Those on the northern side were described on page 138 (see Nos. U–23 and U–33). Mining and prospecting have never been extensive near the crest of the peak, partly because of the poor accessibility. Prospects on the southern slope (U–29, U–31, and U–32), and in the sag between Peerless Mountain and Mount Sheridan (U–30 and U–65) are moderately promising. These prospects are briefly described below. The Hilltop mine, less than a mile northeast of the summit of Mount Sheridan, was very productive. The area surrounding the Hilltop mine is not included in the topographic base of plate 1, but a description of the mine is given below.

PROSPECTS ON SOUTHERN SLOPE OF MOUNT SHERIDAN

Of the three prospects on the southern slope of Mount Sheridan the two northern ones (U–31, U–32) are caved tunnels and the third (U–29) is a shallow shaft. All are on or very near the contact between the Leadville dolomite and the Weber(?) formation, and all, as shown on the map, are along or near faults and have breccia on their dumps. Ore from the middle opening (U–31) is considerably copper-stained. Rock from the other two openings is discolored with limonite. Nothing is known of the history of these long-abandoned openings.

PROSPECTS IN SADDLE BETWEEN MOUNT SHERIDAN AND PEERLESS MOUNTAIN

Prospects U–30 and U–65 are in the saddle between Mount Sheridan and Peerless Mountain, near the contact between the Leadville dolomite and an overlying sill of early White porphyry; they occupy positions in the hanging wall of a very gently dipping fault (p. 71) and just east of its trace. Fault breccia is found on the dumps and the country rock is silicified and iron-stained, but signs of ore are absent.

HILLTOP MINE

The Hilltop mine is just east of the Mosquito Range about 3,000 ft due northeast of Mount Sheridan (fig. 97). Though it is outside the area covered by the base map of the Leadville district, this area was visited in 1931 for five days and the surface geology carefully studied. A topographic base was prepared at the time; subsequently a topographic map on a smaller scale was made by topographers of the U. S. Geological Survey as part of a larger project. The surface geology of this area was examined also by Q. D. Singlewald and R. D. Butler of the Geological Survey, to whom thanks are due for data and helpful suggestions.

The Hilltop mine (fig. 98) consists of two shafts, extensive underground workings, an open-cut, and several small openings. From the mine a trail, plainly marked but not in good repair, extends westward, crosses the Mosquito Range at Hilltop Pass, 13,150 ft

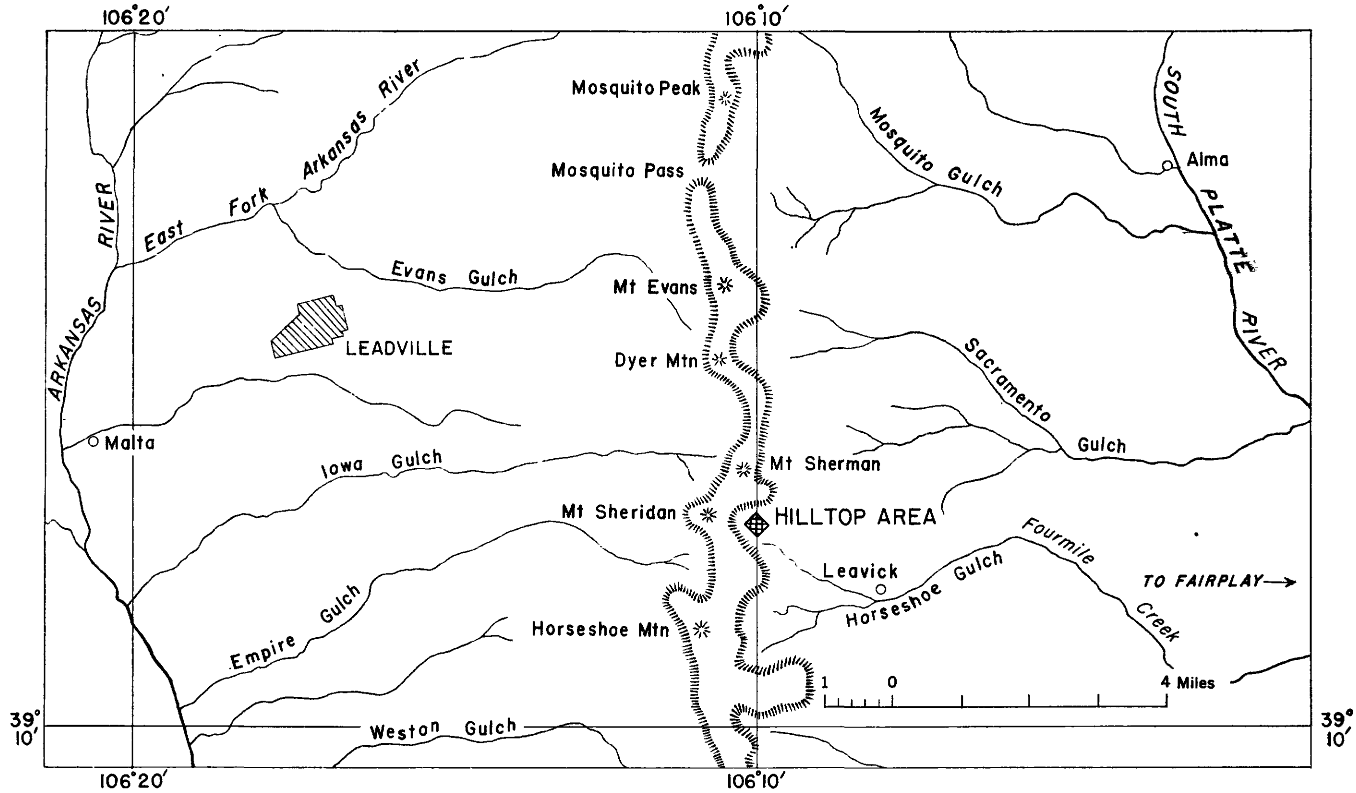

FIGURE 97.—Location of Hilltop area in relation to Leadville and chief physiographic features.

above sea level, and joins the road down Iowa Gulch. A poor wagon road extends two miles eastward from the mine to the mill and cabins at the deserted camp of Leavick. From Leavick a road that can be traveled by automobile extends northeast to Fairplay. The mine is in Fourmile Amphitheater, a typical cirque. The camp is at the lower end of Fourmile Amphitheater, at its junction with a similar amphitheater. The local physiographic features are mainly of glacial origin.

The bedrock geology is much like that along the range to the west (fig. 56). The base of the Weber(?) formation is characterized by a white to blue-gray quartzite approximately 35 ft thick, well exposed about 2,400 ft south of the No. 2 Hilltop shaft. The chief ore-bearing rocks are the Leadville and Dyer dolomites, here mapped together as the "Blue" limestone of Emmons because not clearly distinguishable in the few exposures. The dominant igneous rock is a very thick sill of early White porphyry. The lower 800 ft of this sill is found here but the total thickness is 1,200 ft where exposed on the west slope of Mount Sherman. Lenses of the Weber(?) strata are included in this sill; two of these lenses are exposed on the north wall of the cirque in which the mine is located and a third, about 30 ft thick, crops out 1,000 ft east of the mine. A dike with a maximum width of 46 ft and a strike of N. 20° W., said to be composed of a member of the Gray porphyry group, was found in the northeastern end of the mine; if, as is asserted by the former mine operators, this dike dips 70°–90° W., its projection would bring it to the surface about 150 ft east of the No. 2 shaft, but the bedrock here is covered by talus and no outcrop of the dike could be found.

Structurally the area is a part of the regional homocline typical of this part of the Mosquito Range. Five faults have been inferred or recognized at the surface (fig. 56). The Hilltop fault is of considerable economic importance, for the workings of the Hilltop mine are along it. The fault strikes N. 21° E., and dips 70° NW., offsetting the contact between the Leadville dolomite and the Weber(?) formation in a way (fig. 56) that suggests that along the northern end of the fault the upthrow is to the east, whereas at the southern end it is to the west. A more reasonable interpretation is that the movement is chiefly horizontal, the eastern side having moved relatively northward. The Hilltop fault is evidently of premineral age as the largest ore shoot in the Hilltop mine lies in or alongside it.

Two minor faults trending N. 35° W. are outlined by the Lind and Stewart drifts in the Hilltop workings and by breccia zones on the surface. The dip of the western fault is 70° SW. but that of the eastern fault is not known. The shape of ore bodies developed in the Lind and Stewart stopes (fig. 98) has led miners to infer the presence of a postmineral fault trending about N. 33° E., some 250 ft ESE. of the No. 2 Hilltop shaft, but the evidence at hand does not justify this interpretation.

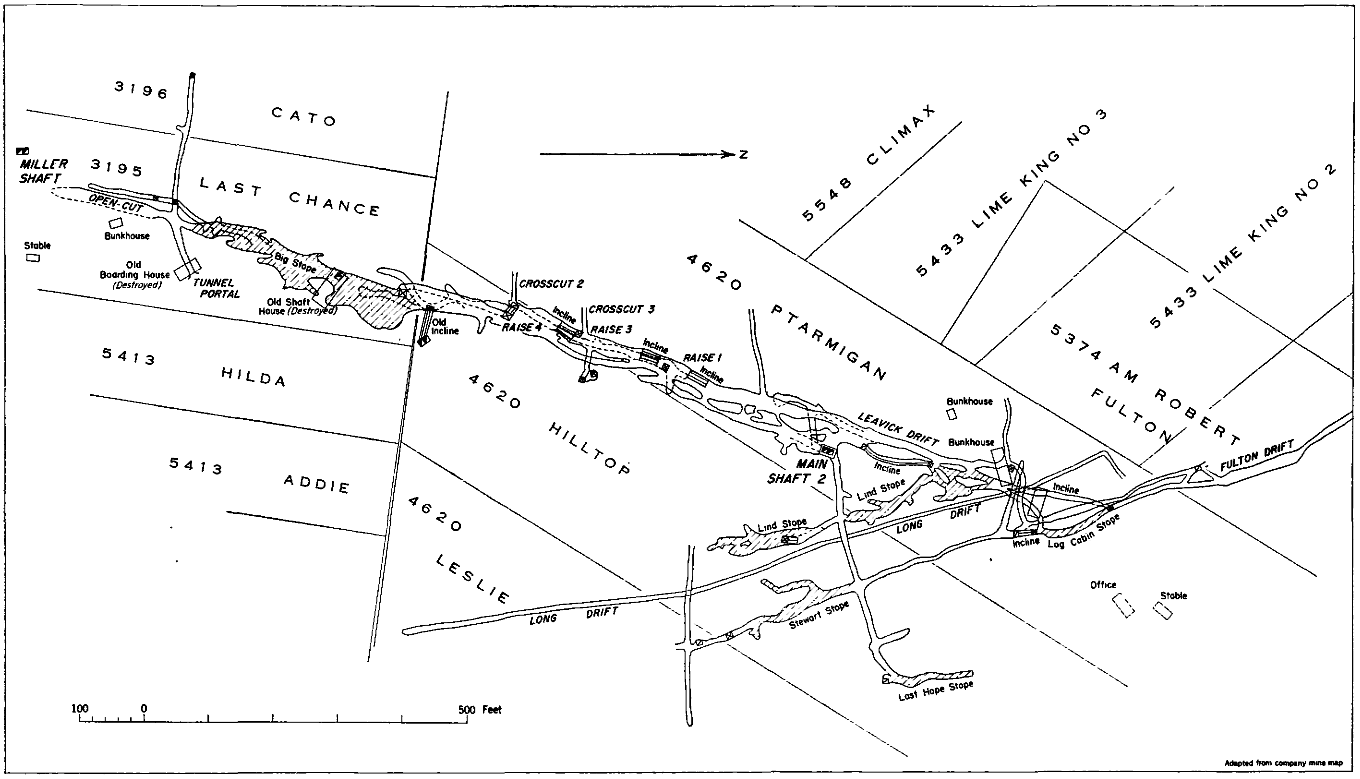

FIGURE 98.—Map of claims and workings of the Hill Top mine.

The abrupt discontinuity of lenses of the Weber(?) formation in the northern part of the area mapped is attributed to a fault trending N. 45° W. that is believed to be continuous with one that was exposed in the Last Hope drift of the Hilltop mine. It is here called the Fulton fault because of its presence on the Fulton claim. This fault probably unites with the three faults mapped about 600 ft north of the Hilltop No. 2 shaft.

A small fault trending N. 5° W., with an apparent downthrow on the east side, is seen in the southern part of the area. Probably the chief component of movement along this fault is horizontal, the east side moving relatively southward to set Leadville dolomite in the east wall against quartzite of the Weber(?) formation in the west wall; this may account for a sharp steepening in dip of the quartzite to 55° on the west side of the fault (fig. 56). Evidence has been cited of important horizontal movement parallel to the planes of several of these steeply dipping faults, as on the Hilltop fault and the small southern fault. In addition, the Lind fault is said to have been marked by horizontal striae. These strong evidences of horizontal movement are like those seen in the Continental Chief mine, about 1¼ miles north of the Hilltop mine (p. 133).

On the dumps of the Hilltop mine and in several of the neighboring prospects the ore consists of a highly leached and oxidized limestone, partly replaced by rosettes of barite and by irregular, spongy-textured areas of grayish or dull olive-green smithsonite. Locally, quartz, straw-colored siderite, and recrystallized calcite are present. Small amounts of aurichalcite, and of light-blue smithsonite, resembling the well-known specimens from Laurion, Greece, were found on the dump of the Hilltop mine.

In addition to the ores described above, considerable bodies of galena, with small quantities of pyrite and chalcopyrite, were mined, mostly in the deeper workings. The sulfide ore had a high silver content.

Oxidation evidently extended to the deepest parts of the mine. A typical ore shoot is said to be composed of a central mass of galena with very small quantities of sphalerite, bordered by a thick sheathing of smithsonite. A little gold (0.01 to 0.02 ounce to the ton) is reported in a few ore bodies. The known tenor of the ore, like that of the Continental Chief mine, averaged about 25 ounces of silver to the ton and 20 percent of lead. These figures, which probably refer to ore produced before 1901 are from a manuscript by M. F. Crosette, dated 1919. The report was made available through the courtesy of Mr. W. W. Price of Denver, Colo. In later years the ore mined was chiefly in the form of oxidized zinc minerals, especially carbonates, which contained more than 40 percent of zinc but included also two carloads assaying 0.06 ounce of gold and 15 ounces of silver to the ton, and 45 percent of lead (J. B. McDonald, personal communication, 1932). In general, these oxidized ores strongly resemble those described by Emmons, Irving, and Loughlin (1927,

p. 240, fig. 65–C) from the central Leadville district, and also the ores of the Continental Chief and other mines nearby (p. 136). This type of mineralization is characterized in the primary ore by large proportions of galena and light-colored sphalerite and a moderate to fairly high content of silver in unknown forms, by a relatively large proportion of zinc carbonate in the oxidized ore, by small unevenly scattered quantities of gold and by the conspicuousness of barite as a gangue mineral.

The Hilltop mine is the only mine in the immediate area with a record of large output; the other openings are shallow shafts or short tunnels. The mine is no longer accessible and the following account is based on the maps still available and on descriptions furnished by former operators, especially Messrs. J. B. McDonald of Leadville and S. P. Doran of Denver. The map (fig. 98) shows the principal features of the mine. The main ore body was in the Hilltop stope along the Hilltop fault. This ore body had a length of 1,450 ft, a maximum width of 70 ft, and was said to reach a maximum vertical height of 70 ft; it had a cylindrical form the long axis of which extended northeast and inclined gently in that direction. Access was by the No. 1 shaft (70 ft deep) and by the main or No. 2 shaft (540 ft deep); the latter passed through 400 ft of early White porphyry and presumably 35 ft of quartzite at the base of the basal Weber(?) formation before reaching the Leadville dolomite. The ore shoot came to the surface up the dip, ending on the Last Chance claim in an open-cut that marked the southern limit of the ore. Northward the ore body terminated where the Hilltop fault was cut by the Lind fault. In the Hilltop fault the ore extended farther northeast on the upper than on the lower levels.

The Lind and Stewart stopes were in similar ore bodies. The former was 440 ft long and had a maximum width of 40 ft; the latter yielded ore discontinuously for a distance of 840 ft and, according to report, had a width of 10 to 20 ft and a vertical height of 15 to 40 ft. Apparently the two stopes were separated by the nearly vertical dike of a member of the Gray porphyry group, which in one place was in contact with the Lind stope and was there marked by horizontal striae. An eastward cross cut from the Stewart stope developed two small ore bodies shown on the map.

The Lind and Stewart ore shoots die out southward, but no cross fault is known that could account for this fact. Perhaps it may be due to gradual weakening of the solutions as they moved southeastward, away from the main channel of circulation and away from the base of the early White porphyry sill below which the ore is commonly concentrated.

Individual ore shoots of the Hilltop mine strikingly resemble those of the Continental Chief mine (Loughlin and Behre, 1934, pp. 231–232, 242–243); they are replacements near solution channels and not great "blankets" or "contact" deposits like those in the more intensely mineralized areas nearer Leadville (Emmons, Irving, and Loughlin, 1927, pp. 117, 138). In this respect they also resemble most of the ore shoots at Alma, Colo. (Singewald and Butler, 1933, pp. 103–107), and also those at Aspen (Vanderwilt, 1935, pp. 240–241). Apparently the ponding agent at the Hilltop mine was in part the sill of early White porphyry, in part the dense basal quartzite of the Weber(?) formation. A shale, like that forming the roof of the ore in the Continental Chief mine, was exposed in the Last Hope stope, but lay above the ore and quartzite, and was separated from the latter by a sill of White porphyry.

The Hilltop claims were located about 1875, but early work, up to 1883, was confined to the outcrop of the ore body on the Last Chance claim. From there the work was carried northward, at increasing depth. The large stope at the northern end of the Last Chance claim was worked in 1892. In the deeper workings a drift was extended still farther north, partly through the open-cut work, partly through the No. 1 shaft (destroyed by fire in 1910). A few exploratory crosscuts northwest and southeast of the main Hilltop stope disclosed no ore and all work was stopped in 1913.

Fairly accurate estimates of the output of the Hilltop Mine are available for certain periods of operation. Henderson (1926, p. 194) gives the value of production for part of the early period as follows:

	Silver	Lead	Total for year
1888	$323, 225	$352, 000	$675, 225
1889	153, 858	148, 960	302, 818
1890	82, 272	67, 947	150, 219
Total, 1888–90	559, 355	568, 907	1, 128, 262

According to the records of the U. S. Geological Survey and Bureau of Mines, the total production from the Hilltop and Last Chance claims from 1901 to 1923 was:

Tons, dry, of ore	31, 682
Gold, troy ounces	1, 842
Silver, troy ounces	410, 438
Lead, pounds	7, 842, 672
Zinc, pounds	2, 530, 935
Copper, pounds	106, 700
Total value, dollars	850, 000

Approximately a quarter of this production was from the years 1920–1923; it amounted to $212,000. For less than half of the year 1910 an almost complete assemblage of settlement sheets shows a production value of $81,556 (J. M. Redman, oral communication, 1950). The latest episode in the history of production from these claims was one of open-cut operations beginning with shallow stripping on the Last Chance claim. This had yielded to January 1, 1950, eight shipments with an average assay of 6.5 troy ounces of silver, 0.02 troy ounce of gold, and lead contents of 12.0 percent, and zinc values ranging from 0.3 to 2.057 percent (Redman, J. M., oral communication, 1950). In 1952 work was resumed at the Hilltop and Last Chance properties by the owner, the Leadville Land Corp. (Redman, J. M., personal communication, 1952).

PEERLESS AND HORSESHOE MOUNTAINS

Southward from Mount Sheridan, the geologic sequence resembles that of the range crest farther north. The most striking difference is the decrease in the number and thickness of the intrusives toward the south. On the western slope of Horseshoe Mountain the sequence from pre-Cambrian to Leadville dolomite is well exposed, but there are no sills. Midway between Horseshoe and Peerless Mountains there is a thin sill in the Cambrian quartzite. Still farther north, on the crest of Peerless Mountain, early White porphyry forms a thick sill, and sills of the same rock become conspicuous on the slope to the west, occupying positions within Mississippian, Devonian, and Cambrian formations.

Faults in this area comprise chiefly two sorts—low-angle normal faults dipping east, and normal faults of steeper dip striking east. One low-angle reverse fault is on the eastern slope of Horseshoe Mountain. One conspicuous normal fault trace, locally mineralized, is exposed at an altitude of about 13,150 ft on the western slope of Peerless Mountain (p. 71); southward in the saddle between Peerless and Horseshoe Mountains it splits into two branches. Several normal faults striking at about right angles to the crest of the range (fig. 99) are economically unimportant; along them the northern side is generally downthrown.

Considerable prospecting has been done on the crest and western slope of the range, and the bleached walls of a prospector's cabin, only 50 ft below the highest point of Horseshoe Mountain, are visible for miles. However, only two groups of prospect openings hold much promise. One group is on the ridge crest, approximately 2,000 ft northeast of the highest (13,903-ft) point of Horseshoe Mountain (U–69 to U–71). The other is the Peerless (or Peerless Maude) mine and the adjacent prospects.

FIGURE 99.—Normal faulting on east wall, Empire Amphitheater, especially well marked in Cambrian beds. Pre-Cambrian (*p€*), Cambrian (€), Ordovician-Devonian (*O–D*), sill of early White porphyry (*Tew*), and Leadville dolomite (*L*).

PEERLESS (PEERLESS MAUDE) MINE AND ADJACENT PROSPECTS

The openings of the Peerless group (U–66 to U–68) consist of a short tunnel, five prospect pits, and seven shafts, all shallow. The shafts and tunnel are partly caved and partly filled with water or ice. All are in silicified Leadville dolomite or in the overlying sill of early White porphyry. The silicified limestone is considerably iron-stained and mineralized.

Detailed structural study of the prospects was impossible because they are caved or flooded and rubble conceals much of the bedrock immediately surrounding them. Most of the openings lie along and east of the eastern branch of a split normal fault (pl. 1). The four northeasterly shafts in the Peerless group penetrated the sill of early White porphyry and entered the Leadville dolomite, to a depth of 75 ft in the easternmost shaft. The other openings were in Leadville dolomite near its contact with the porphyry.

Mineral deposits here, as on the western slope of Mount Sherman, seem to have been localized at the contact between the sill of early White porphyry and the Leadville dolomite; as in the Continental Chief and Hilltop mines, the ore-forming solutions probably rose along small fractures leading to this contact. The most promising ground is therefore northeast of the openings, under Peerless Mountain, where the uneroded remnant of porphyry rests on the productive limestone zone.

The ore on the dumps consists of galena and a little pyrite, in a gangue made up chiefly of bladed barite, vuggy quartz, and densely crystalline or cryptocrystalline silica. Silica and, to a lesser extent, barite have fairly extensively replaced limestone. In addition, oxidation has produced the common assemblage of much limonite, malachite and azurite, anglesite, cerussite, and a small quantity of grayish "dry-bone" (smithsonite). Copper minerals are conspicuous. It has been said that the ore contains appreciable quantities of silver and gold. The chief output, however, was of lead and silver ore; a little of the ore contains as much as 50 percent of lead and 50 to 200 ounces of silver to the ton. No zinc was recovered, probably because the thorough oxidation had removed most of it. Fourteen samples collected from the dumps yielded the following assays:

Assays of samples from dumps of Peerless mine

[Bloomfield, A. L., Unpublished report, made available through the courtesy of W. W. Price, Colorado Springs]

	Average	Minimum	Maximum
Gold, ounces per ton	0.015	Trace	0.04
Silver, ounces per ton	20.10	0.5	55.9
Copper, percent	3.15	Trace	18.0
Lead, percent	8.6	.5	36.4
Zinc, percent	3.8	Trace	25.7

Maps of the Peerless and adjacent prospects are no longer available. The deepest shaft was only 165 ft deep. From the main shaft ore was stoped north and south of the shaft, some stopes coming within 50 ft of the surface. Most of the ore shoots, according to a personal communication from Mr. John Cortellini, were elongate north and south as though along fissues parallel to the faults shown on plate 1, but other than the faults shown west of the main stopes, no fissures are evident at the surface.

Most of the work in the Peerless mine was carried on in the years 1884–91. From 1891 to 1898 the property was operated by lessees, and for this period incomplete smelter returns show a total output valued at $36,276, most of which was derived from lead and silver (W. W. Price, personal communication, 1932). Mining was simple and inexpensive, because the frozen ground required little support, but living conditions were not good, especially at so high an altitude, and this seems to have been a major difficulty in maintaining operations. Recently it has been suggested that this difficulty might be overcome by establishing a modern camp at an altitude of about 12,000 ft in Empire Amphitheater, and driving a tunnel eastward at an altitude of 12,200 ft. The tunnel length necessary would be about 2,000 ft. This plan involves raising in steps a total of 1,200 ft; transportation could be down Empire Gulch by road or by aerial tramway to the Denver & Rio Grande Western Railroad on the eastern side of the range. Such a plan presumably would be contingent on the proving of adequate ore reserves.

PROSPECTS ON NORTHERN SLOPE OF HORSESHOE MOUNTAIN

A group of prospects (U–69 to U–71) is situated on the northern slope of Horseshoe Mountain. The southern ones (U–71) comprise a caved and ice-filled adit and a shaft estimated to be 40 ft deep. The adit is driven in Leadville dolomite containing typical black chert lenses. The beds dip 18° NE. and are irregularly folded and shattered but not visibly faulted. Ore deposition occurred after all clearly recognizable deformation. Rock on the dump contains ore that has replaced limestone and filled fissures in it; the limestone is partly silicified and partly recrystallized to "zebra" rock. The primary ore minerals are galena, a little sphalerite, quartz, and barite. Oxidation has produced much aurichalcite, malachite, azurite, cerussite, calamine (in vugs), and a little smithsonite.

Prospect U–70 consists of a shallow shaft and a 40-ft tunnel. They are on opposite sides of a branch of the fault trace observed at an altitude of 13,150 ft (p. 71). Shattered and somewhat folded rocks are exposed, but they are not visibly fissured and are only slightly mineralized. Prospect U–69 is a group of shallow pits in silicified Leadville limestone between the southern branches of the same fault. A small amount of malachite is the only evidence of mineralization.

As far as can be determined, mineralization at each of these prospects was related either to low-angle faults like those on the western slope of Mount Sherman, as in the case of U–69 and U–70, or to bedding-plane faults of similar origin.

EMPIRE AMPHITHEATER AND FINNBACK KNOB

Finnback Knob, the 13,405-ft peak, is the center of an area in which a few porphyry dikes are the only country rocks younger than the pre-Cambrian (pl. 1).

Throughout the area the geology is relatively simple insofar as it has an economic bearing. Granite predominates; most of it is Silver Plume(?), but some is Pikes Peak(?) granite. The largest exposures of Pikes Peak(?) granite form a triangular area whose base is north of Empire Gulch and whose center is about 5,000 ft northwest of Finnback Knob. There are also small areas of schist that are xenoliths in the granite; prominent examples are on the cliffs of the northern slope of Finnback Knob. Two lamprophyric dikes, believed to be of pre-Cambrian age, crop out in the head of Empire Amphitheater, 1,000 ft east of Finnback Knob. Pegmatite dikes are common in the granites.

Two long dikes of later white porphyry are exposed on the western slope, and one on the eastern slope of Finnback Knob. They are probably continuous, and though in places talus covers them each has a length in excess of 4,000 ft. They trend northeastward, generally parallel to most of the smaller, postmineral faults of this immediate area. The easternmost of these dikes is exposed on the floor of Empire Amphitheater near Finnback mine, and is connected with an irregularly elliptical ring of dark-gray igneous rock, about 500 ft long and 100 ft wide, that has been intruded into the Silver Plume(?) granite. The rock of this ring has a stony groundmass, conspicuous flow lines, and scattered plagioclase phenocrysts. It may represent the central facies of a pluglike mass of later white porphyry. Although the more central part of the plug is darker than normal later white porphyry, its margin is typical of that rock, and gradation between the two varieties clearly shows that both are facies of later white porphyry.

The predominant north-northeasterly faults are inconspicuous in the rather uniform pre-Cambrian rocks.

Erosion along these faults appears to be the cause of some of the narrow ravines on the northwestern slope of Finnback Knob. Some faults are recognized by the lines of breccia or zones of exceptionally prevalent iron-staining. Dikes of later white porphyry occupy several faults.

There is no record of production from any prospect in this area. Several pits have been dug along the later white porphyry dikes (for example, U–74 to U–76), and others along typical pegmatite veins and thin veinlets of pegmatitic quartz.

The old Finnback tunnel (U–61) that extends S. 80° W. into the hillside is caved about 50 ft from the portal. Nothing is known of its history. It was driven in granite, biotite schist, and later white porphyry. Neither the tunnel wall nor the dump materials are mineralized.

Several shallow pits (U–56 and U–81) are in pre-Cambrian rocks along a subsidiary fault about 300 ft east of the Mosquito-Weston fault zone and 4,500 ft west-southwest of Finnback Knob. The only ore mineral found was malachite, although the fault fissure is filled with quartz and the adjacent granite is silicified. These openings are not promising, but they do indicate that some mineralization has taken place along the fault zone in this vicinity.

EMPIRE HILL

The body of pre-Cambrian rocks forming Finnback Knob and its western slope is terminated on the west by the Mosquito-Weston fault zone, which crosses the ridge between Finnback Knob and the crest of Empire Hill. For some distance west of this fault zone the surface rock is Weber(?) formation; northward it is early White porphyry, Leadville dolomite, or, in the bottom of Empire Gulch, still older formations. On Empire Hill the Mosquito-Weston fault zone is itself largely bounded by two faults between which other branches appear, uniting and diverging irregularly. Parallel to the zone but outside it are minor faults, notably on the hanging-wall side. Due east of the crest of Empire Hill, the Leadville dolomite, Parting quartzite, and slivers of the Manitou dolomite lie between the two bounding faults.

West of the summit of Empire Hill the eastward dip of the beds and the decrease in altitude bring to the surface rocks stratigraphically below the Weber(?) formation (section D–D′, pl. 2). Pre-Cambrian Silver Plume(?) granite crops out at an altitude of approximately 11,650 ft and below, but the top of the pre-Cambrian ranges considerably in altitude; Rocky Point (altitude 12,078 ft), near the south edge of the area, is made up of granite.

Many faults introduce minor irregularities into the orderly succession of rocks below the outcrops of Weber(?) strata on Empire Hill. Although a few faults are oblique to the strike or parallel to the bedding, most of them are essentially at right angles to the strike and offset the beds, resulting in an irregular outcrop pattern.

Despite the many small prospects on Empire Hill, the effective mining has been slight. Prospect pits, shallow shafts, and short adits are especially numerous on the western slope of Empire Hill between the 12,000-ft contour and the top of the pre-Cambrian rocks. Almost all of these openings are near transverse faults but are situated stratigraphically below the contact of the Leadville dolomite and the overlying sill of early White porphyry, or the thin band of Weber(?) strata which in most places separates these two. It is noteworthy that no northward-trending faults, with which most ore bodies in the marginal Leadville district are associated, have been recognized in this area. Prospects that merit brief descriptions are treated in the following paragraphs.

PROSPECTS ALONG MOSQUITO-WESTON FAULT ZONE

The northern group of prospects (U–47 to U–53) along the Mosquito-Weston fault zone, whether in the Weber(?) formation west of the fault or dolomite within the fault zone, are for the most part in shattered country rock. The dolomite is silicified or recrystallized; some quartz has been deposited in veinlets, but no ore minerals.

Near the southern group of prospects (U–78 to U–84) mineralization was more intense than farther north. The northernmost pit of the U–84 group and the tunnel of the U–83 group is in closely sheared granite slightly stained by malachite. Farther south the prospects of the U–82 group are in sheared Leadville dolomite and sheared, greatly silicified pre-Cambrian granite. Similar shearing and alterations are seen in the hanging wall of pre-Cambrian rock all along the fault zone, but the block of Leadville dolomite exposed between the eastern and western faults of the zone is not strongly mineralized, despite extensive bedding-plane faulting and shattering of the beds, accompanied by dragging along the fault so severe that the shale beds of the Weber(?) formation west of the zone are overturned and dip 75° E.

It is striking that in this locality the hanging wall of granite is more mineralized than the dolomite within the fault zone. This difference is similar to that in other mining districts where shattering and mineralization have been generally more effective in the hanging walls of great reverse faults than in the footwalls, partly because the hanging walls have undergone less vertical compression and partly because the "chattering" nature of fault movements has produced more fracturing and comminution.

PROSPECTS SOUTH AND SOUTHWEST OF EMPIRE RESERVOIR

Search for ore in prospects south and southwest of Empire Reservoir has been intense, but has revealed too little mineralization to encourage further exploration. This group of prospects includes one shaft (T–232) estimated to be at least 200 ft deep. Material on the dump shows that the shaft was sunk through grit and shale of the Weber(?) formation, the sill of early White porphyry, and the thin black basal shale bed of the Weber(?) before entering the topmost Leadville dolomite. The eastern of the two shafts in group T–231 is 30 ft deep. Its dump contains altered, pyritized early White porphyry. The two T–231 shafts are located along a fault.

PROSPECTS ON THE NORTHERN SPUR OF EMPIRE HILL

Prospects T–150 on the northern spur of Empire Hill, 4,500 ft north-northwest of the summit are in the upper part of the Leadville dolomite, stratigraphically about 60 ft below the base of a thin black shale bed of the Weber(?) formation. A sill of early White porphyry overlies the Leadville dolomite. The beds generally strike N. 20° E. and dip 20° SE. The two largest openings here are a shaft and tunnel, both caved. In the tunnel a fissure that strikes N. 75° E. and dips 75° NW. is associated with limonite stains and with tiny vugs coated with a little malachite.

A more promising prospect is the tunnel, beyond the first 40 ft, on the Eclipse claim (T–151). The beds have the same attitude as at prospects T–150; however, no fissuring is visible on the surface or in the accessible part of the tunnel. The prospect has a loading chute, and a large dump contains rock considerably stained by iron and manganese oxides and by copper carbonate. The mine is said (J. W. Mitchell, personal communication, 1930) to have yielded sacking ore containing as much as 45 ounces of silver to the ton; nothing more is known of its history.

Several prospects (T–163) about 600 ft northeast of the Eclipse tunnel have revealed mineral-bearing rock of the type just described but only slightly mineralized.

The dump of a caved tunnel (T–152) 2,000 ft northwest of the Empire Reservoir contains barite and calcite. About 200 ft to the north is another largely caved tunnel—the northern of two marked T–152. The cement between the sand grains of the Cambrian quartzite is extensively oxidized. Cubical casts in the cementing material indicate replacement of the quartzite by pyrite, but the mineralized ground is not extensive and shows nothing of value.

HEAD OF UNION GULCH

The Union fault extends southwestward from Empire Gulch toward the head of Union Gulch, from which it derives its name. Southeast of it lies pre-Cambrian granite. The rocks along the northwest side of the fault range from the Weber(?) formation to the pre-Cambrian granite, the latter appearing northwest of the fault at the southern border of the area mapped. Rocks bordering the fault to the northwest include also a sill of early White porphyry in the Weber(?) formation, sills of Iowa Gulch porphyry in the Dyer and Manitou dolomites, and several dikes of Johnson Gulch porphyry.

There are several eastward-trending faults that, with the Union fault, break the rocks into a series of highly irregular blocks. These faults have the dropped side to the south at some places, but elsewhere to the north. Commonly, the dips of the fault planes cannot be measured but they are steep wherever discernible. These faults are most conspicuous in an area whose center is about 3,500 ft south-southeast of Mitchell Ranch and an equal distance north-northeast of the junction between the northern forks of Union Gulch. Here the geology is especially complicated because the faults cross the axis of a sharp syncline almost at right angles.

The most striking structural details are the reverse faults, and they are also closely connected with mineralization. Some reverse faults almost parallel the bedding and cannot be traced with sufficient accuracy to warrant representation on plate 1. Two small reverse faults that cut the Leadville dolomite, strike almost due north, and dip east at low angles; they are exposed about 4,500 ft south of the Mitchell Ranch near prospects T–209 and T–210. Two greater faults lie farther east and are most clearly exposed about 4,000 ft east-southeast of the Mitchell Ranch. These last two faults may be normal or reverse, and the western of the two may be the Mike fault (pl. 1). No ore was seen along the traces of these two larger faults, though silicified and iron-stained rock is conspicuous in the outcrops. The two small reverse faults are not only similarly silicified but both seem to have been the sites of ore deposition.

PROSPECTS NEAR HEAD OF GULCH

Only two groups of prospects merit description, and both are within a mile of the Mitchell Ranch.

The openings at prospect T–219 consist of a short, partly caved tunnel, two shallow prospect pits, and two shallow caved shafts. All the workings are in the middle to upper part of the Leadville dolomite; the rocks are much shattered and conspicuously silicified, but no ore is exposed. Despite its relative inaccessibility, this area merits careful prospecting to shallow depths because the silicification of the rocks is indicative of movement of mineralizing solutions, and the shattered ground may have provided a favorable site for ore deposition.

Prospects T–209, T–272, and T–273 are all in the Leadville dolomite or upper part of the Dyer dolomite, near the southern end of one of the two small reverse faults mentioned above. At T–209 bedding-plane faults with conspicuous slickensides are exposed, and the rocks adjacent to the planes of movement are considerably silicified and iron-stained. Farther south, at T–272 and T–273 where the same conditions prevail, some galena is present.

The openings include a 50-ft vertical shaft, an incline and a vertical shaft southwest of the first, and a caved shaft between. Grouped around these shafts are several shallow prospect pits. The rocks near the northernmost shaft are shattered, silicified, and iron-stained. Specimens on the dump contain disseminated galena and a little sphalerite; considerable cerussite and anglesite have formed around the galena. The absence of barite is striking in an ore of this kind. The mineral assemblage and structural relations are much like those at Weston Pass, 10 miles south of Leadville (Behre, 1932, pp. 61–71).

The incline at the southern end of this group descends N. 85° E. at an angle of about 35° but is caved at slight depth. The vertical shaft at its mouth is also inaccessible. Both openings are in the Leadville dolomite but, because of the eastward dip of the beds, the vertical shaft doubtless penetrated the Dyer dolomite at shallow depth, whereas the entire incline, essentially parallel to the bedding, probably was dug in the Leadville dolomite. A little of the ore on the dump consists of cubes of galena, which was disseminated largely along certain thin beds that seem to have been more permeable or more soluble than the others. Each galena mass is surrounded by a halo of anglesite and cerussite. As in ore from the shaft to the north, sphalerite is rare and barite is absent. The rock is crisscrossed by calcite veinlets and has been extensively leached during oxidation.

These striking effects of mineralization are little known. The area is far from any settlement, and the only road near these prospects is very poor. The minor reverse faults are of special interest because elsewhere in the Leadville district such faults are closely related to ore deposition.

EMPIRE GULCH

A line from West Sheridan Mountain to Finnback Knob makes a convenient boundary between Empire Amphitheater and Empire Gulch. The geology of the area east of the Mosquito-Weston fault complex was described in the section on the Empire Amphitheater.

The rocks in Empire Gulch east of the faults are almost wholly pre-Cambrian granites. The Mosquito-Weston fault extends northward from Empire Hill into Empire Gulch where it joins the Union fault. The fault complex farther north on Upper Long and Derry Hill has four recognizable parts which are, from west to east: the Weston, Hellena, Ball Mountain, and Mosquito faults. Because the fault complex is in Empire Gulch where the faults are not exposed in mine workings and are deeply covered by glacial material, relationships of these faults are not known in detail. It is clear from study of the area north of Empire Gulch that all the faults except the Ball Mountain fault are of one type: they dip eastward rather steeply, they are upthrown on the eastern side, and for most of their courses the beds have been dragged upward to a steep westward dip at the footwall.

The beds in Empire Gulch west of the fault complex are in normal succession as far west as the Union fault, which crosses Empire Gulch approximately 2,500 ft southwest of the 12,040-ft summit of Upper Long and Derry Hill. The Union fault, which trends northeast, is upthrown on the southeastern side and has pre-Cambrian rocks on the east against the sill of early White porphyry, which here is separated from the Leadville dolomite by as much as 75 ft of quartzite and shale of the Weber(?) formation. Downstream to a point one-half mile due east of the Mitchell Ranch, the succession is normal. Still farther downstream other faults are encountered, as shown on the geologic map, plate 1, but the bedrock is not close enough to the surface to excite interest in mining.

Few mines or prospects in the bottom of Empire Gulch and on the slope overlooking it merit detailed description. Openings in the valley itself are numerous but the depth through the glacial deposits to bedrock has been an obstacle to exploration. Furthermore, the rocks prospected on the valley flanks are but scantily mineralized. For example, the closely clustered prospects about 5,000 ft southwest of the Mitchell Ranch, several of which are on or near the Union fault, have no ore exposed on the tunnel walls or on the dumps, and the inference seems justified that the Union fault is of postmineral age. A single prospect pit or caved tunnel (the north pit of T–77) has exposed a small quantity of bladed barite that has replaced Leadville dolomite.

The lower slopes of Upper Long and Derry Hill, facing toward Empire Gulch, are not mineralized to any noteworthy extent. Geological considerations might lead to expectation of ore along the trace of the Mosquito-Weston fault zone where it traverses the south slope of Upper Long and Derry Hill, but rocks in the prospects examined there (T–60 to T–66 and U–5, U–40, and U–41) are not mineralized.

A large dump (T–29) and several small openings high up on the slope of Long and Derry Hill at an altitude of 11,350 ft are in altered early White porphyry, the sill that so generally rests directly upon the Leadville dolomite or is separated from it by a few feet of quartizite or black shale of the Weber(?) formation. The dump indicates an operation of considerable size. Its partly filled ore bin contains a gossan consisting of highly ferruginous and manganiferous cement around blocks of iron-stained, altered limestone(?). No other mineralogical information is available but presumably, like the other prospects on Lower Long and Derry Hill to the west and north, this pit yielded an oxidized lead ore, rich in silver.

PLACER PROSPECTS IN UNION AND EMPIRE GULCHES

Union and Empire Gulches below an altitude of 10,500 ft are almost entirely covered by glacial moraines or outwash. Presumably the country rock is all of pre-Cambrian age and mostly if not all granite. There is no evidence of mineralization, and no known placer gravel. The unconsolidated deposits no doubt resemble those that cover the slopes of Lower Long and Derry Hill west of the 10,750-ft contour (p. 150). Placer gravel may exist in the wide valley bottoms of Iowa, Thompson, and Empire Gulches, between the bordering terraces but there has been no careful placer prospecting in these areas.

MINES OF THE CENTRAL LEADVILLE DISTRICT

During the course of the study of the marginal part of the greater Leadville region, some time was devoted to underground studies in certain properties in the central part of the Leadville district, partly to clarify various features of the geology that might have been revealed since the publication of Professional Paper 148, partly to aid in the development of these or adjoining mines. The results of these studies, which include items of considerable economic importance, are briefly recorded below. No changes have been necessary in the geologic mapping of the central area, as shown in plate 13 of Professional Paper 148, except in the neighborhood of the Eclipse and Nevada mines (M–36 and M–24) on the northwestern slope of Ball Mountain.

DESCRIPTIONS

NEVADA TUNNEL

With the assistance of the late Paul Schmidt of Leadville, the writer studied the geology of the Nevada tunnel (M–24). The structure is highly complicated. The rocks seen in the workings comprise rhyolite agglomerate, early White porphyry, a member of the Gray porphyry group resembling the Johnson Gulch porphyry, both members of the Sawatch quartzite, and pre-Cambrian granite. For data beyond the caved areas (fig. 58) reliance was placed on information furnished by Mr. Schmidt. The two eastward crosscuts have intersected and partly exposed two major faults striking north-northeast; the western of these two faults apparently splits and appears as two faults in the southern crosscut. The three faults thus recognized are correlated with the Silent Friend fault as described in Professional Paper 148 (Emmons, Irving, and Loughlin, 1927, pp. 82–83). Apparently a block of early White porphyry has dropped between the eastern and western faults of this group. East of this block is pre-Cambrian granite and west of it are a member of the Gray porphyry group, the Peerless formation, rhyolite agglomerate, and irregular sills of early White porphyry. These two north-northeastward-trending faults might be interpreted as branches of the Ball Mountain fault, but their displacement would seem to be less than the 2,000 ft typical of the Ball Mountain fault in this area (Emmons, Irving, and Loughlin, 1927, p. 76).

Crossing the workings in a west-northwest direction are several offset faults that may represent the Colorado Prince fault. The Colorado Prince is a reverse fault with the northeastern side upthrown (Emmons, Irving, and Loughlin, 1927, p. 75); it should be offset by the faults striking north-northeast, but the relations are nowhere exposed. The position of the reverse fault in the main tunnel is indicated by an ill-defined shattered zone; between the two branches of the Silent Friend fault its position can only be inferred.

Studies in the Nevada tunnel do not reveal the position of the Ball Mountain fault. According to Plate 13 of Professional Paper 148, it must lie a short distance southwest of the southernmost point of the main Nevada tunnel.

In addition to these two major fault systems, there are several minor, practically vertical, faults striking approximately due north. Most of the main tunnel is driven so as to develop faults of this system. These faults, in contrast to the Silent Friend fault, are either offset by or end against the Colorado Prince fault (fig. 58). One such fault, mineralized and well exposed in the main tunnel north of the Colorado Prince fault, seems to have an exact counterpart, interpretable as its offset segment, exposed in the main tunnel south of the Colorado Prince fault. The other north-south faults are believed to be tensional and compensating fractures that developed simultaneously with the compressional movement of the Colorado Prince fault, or immediately afterwards.

Of special interest are conspicuous bodies of rhyolite agglomerate associated with several of the northward-trending faults, and also along the westernmost branch of the Silent Friend fault (Emmons, Irving, and Loughlin, 1927, p. 82, pl. 13).

Ore is exposed along the north-south faults in two small stopes along the main tunnel, 30 and 85 ft south of the point where the northern crosscut turns east off the main tunnel. In the northern stope the ore is an oxidized, iron-stained, low-grade zinc carbonate, and lies along one of the lesser north-south fissures. The southern occurrence lies in a finely comminuted gouge and consists of disseminated pyrite that is unusually free from oxidation. This shoot lies in the footwall of another north-south fault, almost parallel to the tunnel. Locally, the ore here yields a little gold on careful panning.

At the eastern end, in the face of the southernmost east crosscut, is a gouge zone, here as much as 15 ft wide and made up of decayed granite, heavily limonitized. This zone is believed to be in the east branch of the Silent Friend fault. Gold, silver, and a little lead have been recovered from it. Through the kindness of Mr. Paul Schmidt, in 1928, samples from the early White porphyry of the hanging wall were assayed and found to contain 3 to 4 percent lead. Samples from the footwall commonly contain as much as 2 or 3 ounces of gold to the ton but the metal is finely divided and difficult to extract. Between the footwall and hanging wall two parallel zones of shattered granite contain patches of very high grade gold ore in which gold is locally visible. Iron stains in the gouge suggest that it has been enriched by oxidation. However, it is reported that there was much less gold farther north where the fault is intersected by the northern crosscut.

The ore found in the eastern branch of the Silent Friend fault and in the subparallel lesser faults suggest that here the north-south faults are premineral and that they should be explored. An especially favorable direction for prospecting would be southward along the east branch of the Silent Friend fault.

VENIR MINE

The shaft of the Venir, or South Ibex, mine is on the western slope of Ball Mountain, near the crest of Breece Hill. The shaft (L–59) is about 400 ft S. 50° E. from the Antioch quarry, 2,850 ft S. 25° W. from the Ibex no. 2 shaft, and 2,300 ft N. 15° W. from the portal of the Garibaldi tunnel.

The collar of the shaft, which is the only working connection with the surface, is at an altitude of 11,697 ft. Four levels and several intervening stopes have been developed (see table below, and pls. 17, 18).

Levels of the Venir mine (1935)

Level	Altitude at shaft (feet)	Approximate length of tunnel (feet)
First	11, 560. 3	3, 180
Second	11, 502. 0	1, 740
Third (or intermediate)	11, 460. 0	430
Fourth	11, 410. 0	6, 210

Grit of the Weber(?) formation and a member of the Gray porphyry group appear on the surface (Emmons, Irving, and Loughlin, 1927, pl. 13). Underground, most of the work was done in rock that is clearly a member of the Gray porphyry group, but the rock has been sericitized and silicified so that it cannot be identified with any member of that group; however, its relations to the areas north and south, where alteration is less intense, indicate it to be Johnson Gulch porphyry. On the fourth level (pl. 18) the country rock in the long northeast drift is in a porphyry less conspicuously altered than elsewhere, but even here more exact identification is impossible. On the first level a small amount of much-altered shale of the Weber(?) formation appears in the roof about 360 ft northeast of the shaft; similar inclusions appear in the southeastern workings of the fourth level. A sample from the third level, apparently identical with altered, silicified rock of the Gray porphyry group, proved on very detailed microscopic examination to be a greatly sericitized grit of the Weber(?) formation. This extreme effect of alteration means that even careful microscopic study of specimens from other parts of the mine does not exclude the possibility that a part of the rock exposed is a silicified and partly sericitized early White porphyry. This uncertainty is increased by the strong bleaching that has affected the country rocks.

The Venir mine is just east of the Weston fault and southwest of the South Ibex stockwork (Emmons, Irving, and Loughlin, 1927, pp. 301–302, pl. 13). It lies west of the Garbutt and No. 4 Ibex fissure lodes, two subparallel veins which here strike about N. 15° E. The workings reveal a series of fractures approximately parallel to the No. 4 Ibex and the Garbutt veins. The fissures in the Venir workings generally trend about due north in the extreme southern and southwestern parts of the mine, but curve to northeast in the northern parts of the workings. The greatest fissures trend northeast. A mere azimuth plotting of the fractures would not be significant, as it would not indicate the changes in direction of single fissures, nor could it show the strong contrast in direction between the major and the minor fissures. A study of the mine maps (pls. 17, 18), and especially of the very extensive fourth level, is most instructive. The veins in the Garbutt and Negro Infant workings in and south of the South Ibex stockwork behave very similarly (Prof. Paper 148, pl. 57).

On the first level (pl. 17) two important vein systems were exploited—one at the shaft station and one about 250 ft east of the shaft. In addition, a small and relatively unproductive simple fissure (the "Little vein") was found 45 ft west of the shaft in the southwest workings. The West vein system trends N. 5°–10° E. near the shaft, but at its northernmost end the strike is N. 25°–30° E.; generally it dips 60°–90° NW., averaging about 75°. About 280 ft north of the shaft the vein is broken by a transverse fault, north of which it is shifted about 20 ft to the west. There is considerable branching and reuniting of several subparallel fractures, causing difficulty in development work. The stopes follow the vein up the dip to the southeast, in places reaching the surface.

The East vein or system maintains a more northerly course, and virtually unites with the West system where the two connect with those of the Negro Infant mine. The separate branches of the East vein dip mostly westward; locally they are broken by small transverse faults.

Both veins have conspicuous local shear zones, such as those that lie parallel to the East vein in the southeastern part of the workings on this level. Further, in several places smaller fissures enter the main fissures at acute angles. Examples are clearly visible along the western wall of the East vein, near the 40-ft raise shown on the map, and also at the three strong fissures, each somewhat mineralized, exposed in the main crosscut. A breccia zone is developed where the two principal veins converge in the northeastern part of the workings. Breccia is characteristic of such junctions, as demonstrated by the South Ibex stockwork where the No. 4 Ibex vein and the Garbutt vein approach each other most closely.

Most of the fissures are faced with gouge and are filled with clay and limonite, indicating the former presence of pyrite, now oxidized. Where cleaned by mining, the walls show steeply dipping or vertical striae, which strongly suggest that the movements were not prominently or generally horizontal, as they were farther south in mines of the marginal parts of the Leadville district. (See, for comparison, the Continental Chief and Hilltop mines, pp. 133–134 and 153–154.)

Mineralization produced chiefly fissure fillings of quartz and of pyrite and silicification of the country rock near the vein. Such veins are narrow, averaging 2 inches in width and very rarely exceeding a foot; they are frequently so rich in gold that the ore mined from them is sacked. Much of the ore mined ranged in value from $2 to $41 per ton at a time when the base price of gold was at $20.67 per ounce. The minable rock usually extended no more than six inches into the wall. Some mineralized material along the shear zones formed stockworks, in which the veinlets were so closely spaced that the country rock containing them was mined. Locally the pyrite is slightly cupriferous, and the enclosing rock is stained by malachite; this is especially true along the East vein, notably at the southeastern end of the east drift, where some fracture surfaces are coated with thin films of sooty chalcocite.

As a consequence of the narrowness of the veins and of their steep dips, the stoping typically yields very narrow, steeply inclined openings, just wide enough to be worked by one man, who uses planking as a floor. Such ore bodies may be more than 100 ft high, yet less than a foot wide, though the stope is generally widened somewhat beyond that amount to provide working space.

The lower levels are essentially like the first, except that oxidation is less conspicuous on the second level (pl. 17); only the Little vein and the West vein have been developed. Actually, the West "vein" near the shaft consists of three fissures, trending north-northeast. The two marginal fissures are not over 30 ft apart. All the fissures are mineralized, and all end at the south against a northwestward-trending mineralized fissure that is the southernmost feature exposed along the West vein. West of the shaft are at least two fissures trending generally northward and developed by drifts. Of them the westernmost resembles, and corresponds to, the Little vein of the first level. On this and the next lower level, the vein was very rich, some assays showing as high as 7 ounces of gold per ton.

The third (also called "Intermediate") level (pl. 17) is the least extensive. Here also the West vein system was explored and the several westward-dipping branches were stoped. In a westward crosscut located about 150 ft south of the shaft the Little vein was intersected and some stoping followed it, but the ore here was not rich. On the other hand, the eastern branch of the West vein was intersected about 25 ft east of the shaft and contained very rich ore, some assays of oxidized ore indicating as much as 9 ounces of gold to the ton. This rich ore was in a small fissure striking northwest and intersecting the main eastern branch of the West vein at an angle of 40°. The eastern branch itself contained some pockets of unoxidized ore assaying 1 ounce of gold and 9 ounces of silver to the ton. Along what is probably the northward continuation of the Little vein (as developed in the large stope trending north-northeast and situated west of the shaft), assays showed ore that ranged in tenor from traces to 7 ounces of gold per ton; one small shipment yielded 15 ounces to the ton. These richer ores were all highly oxidized. Oxidation and high gold contents like those just cited were most pronounced in the area south of the shaft where, because of confluence of fissures, the ground was more open and shattered. North of the shaft the gold content on this level, as on the others, declined markedly.

On the fourth level (pl. 18) a long crosscut from the shaft trends east-southeast, intersecting one well-defined vein which strikes about due north and along which there has been some stoping. In the neighborhood of the shaft a series of north-northeasterly fissures, the equivalent of the West vein of higher levels, is conspicuous. Several veins of this series were mined profitably. The Little vein seems to be represented by two shear zones about 50 ft west of the shaft and 15 ft apart that contain some pyrite, but too little gold to justify stoping. The main West fissure extends northward, curving eastward as on higher levels. The drift developing this fissure unites to the northeast with another drift, now caved and inaccessible, which apparently developed the East fissure; therefore the two fissures are inferred to join northward, much as on the first level. On the long east crosscut in the southeastern workings of the fourth level, the southern part of the East fissure was also developed and here actually trended northwest, the strike swinging to a due-north course about 200 ft north of the latitude of the main Venir shaft. Much breccia occurs at the intersection of these two principal fissure systems.

About 150 ft north of the main shaft two long crosscuts have been driven across the north drift. The eastern crosscut reveals little that is new, whereas the western one penetrates new ground in which another important vein trending north-northeasterly was found and stoped. Near its western end this crosscut passes into a well-defined breccia zone—a part of the South Ibex stockwork. The breccia consists of somewhat rounded fragments of an altered porphyry of the Gray porphyry group, bleached, pyritized, and largely oxidized after pyritization. The contact between this breccia and the less shattered but otherwise similar country rock is irregular but as far as exposed, follows an irregular course that partly outlines a polygon, directed first northeast, then in turn north, southwest, and west. The zone may be part of an explosion vent like those of Cripple Creek and the Bassick mine, (Loughlin and Koschman, 1935, p. 273; Emmons, 1896, pt. 2, pp. 430–447) or a collapse breccia (Locke, 1926, pp. 431–458). The ore in this mass has been mined through other workings. It is a pyritic gold ore, richest where oxidized, and averaging about 0.6 ounce of gold to the ton; no other products of value are derived from this ore.

Oxidation is least extensive on the fourth level but, despite the fresher condition of the sulfides, almost no primary ore minerals except pyrite can be seen. Gold, the incentive to mining, seems to be concentrated in the pyrite or in its oxidized residue. Neither galena nor sphalerite was found. Films of chalcocite are common along fracture walls and on pyrite crystals; the quantity is small. However, widespread occurrence of these sulfide minerals and the scarcity of oxidized materials such as is found on the higher levels show clearly that below the fourth level the rock has been saturated with ground water most of the time since primary mineralization.

Pyrite is abundant, especially near shear zones or brecciated areas; it occurs mostly in veins as on the first level. The pyrite of crustified veins is central, and crystalline quartz, the only gangue mineral, is marginal. However, several veins that pinch out along their strikes contain quartz far beyond the last traces of pyrite. These relations suggest that quartz entered the crevices, but failed to fill them completely, commonly occupying only certain lenticular openings—then the pyrite was deposited in the open parts of the vein.

The Venir was operated at intervals between 1920 and 1935 as a small but profitable mine. Careful sampling of the underground workings has proved the presence of low-grade pyritic bodies containing approximately 0.15 to 0.25 ounce of gold to the ton. This content is typical of the larger bodies in or near shear or breccia zones. The richest ore is in the fissures or their small accessory fractures. Experience indicates that generally the veins are leaner to the south, so prospecting southward has been discouraged. As the veins have been prospected northeastward as far as the Negro Infant workings, there is little hope for rich ore beyond, even at depth, because oxidation and enrichment are reduced with increase in depth. The best direction for exploration is eastward, as the fissures developed on the fourth level in the long southeastern crosscut show.

Of great interest for the future, in view of increased gold prices, is the fact that much of the surface area has been sampled and proved to contain low-grade ore bodies. Mr. John Cortellini of Leadville reported (as quoted by E. P. Chapman, personal communication, 1929) that in the rock underlying the area near the Venir shaft, which is now mapped as Gray porphyry, samples reveal the following metal content: gold, 0.20 ounce to the ton; silver, 8.0 ounces; lead, 1.0 percent; copper, 1.2 percent; iron 25.0 percent. His estimate of the total quantity of such ore is 50,000 tons, and this known reserve might be very greatly increased by similar examination of the ground east of the collar of the Venir shaft. Such low-grade ore bodies are well situated for treatment at mills in California Gulch.

The general geology and economic development of the bordering region, in particular the area to the north along the Negro Infant and Garbutt workings, have been described by Emmons, Irving, and Loughlin (1927, pp. 300–306). Fissures in the Venir mine strikingly resemble and are parallel to those of the Forest Queen vein, of the Antioch stockwork, and of several smaller north-south veins west of the Garbutt vein, as described by Emmons, Irving, and Loughlin. Moreover, those veins and the nearby South Ibex stockwork have other features much like those in the Venir mine, especially the occurrence of the stockworks at intersections of major faults.

GARIBALDI TUNNEL AND SUNDAY VEIN

The Garibaldi tunnel (P–12), whose main haulageway is about 2,400 ft long and extends in a N. 58° E. direction, was studied by G. F. Loughlin in 1934. His map has been slightly modified as the result of a brief study in 1942 by the author of the present report, aided by Mr. E. D. Dickerman of Denver (see pl. 19). The portal is at the head of California Gulch. The tunnel was driven northeastward, toward Ball Mountain, to explore the Weston fault and the Sunday vein (originally opened through the Sunday shafts on the western slope of Ball Mountain).

For 550 ft the tunnel goes through porphyry, presumably of the Johnson Gulch type but too highly altered for positive identification. About 550 ft from the portal a shattered zone is intersected, with shale of the Weber(?) formation appearing just beyond, on the northeast side, but the displacement along it is slight. The shattered zone contains streaks, as much as an inch in width, of sulfides (including pyrite, sphalerite, and galena), and a little gold. The Dickerman drift was driven in this zone along a weakly mineralized streak.

The northeastward extension of the adit beyond the Dickerman drift is in shale for a distance of 350 ft. Part of the shale is dark and bituminous, locally containing disseminated pyrite, and part is light-gray and siliceous. It is cut by several subparallel fissures and shear zones that trend about due north and dip generally eastward, and by one irregular body of a variety of the Gray(?) porphyry group. Where the veins cross the shale, the drag of the beds indicates that the eastern side was raised along several, if not all, of the fissures. Most of these fissures are occupied by lean veins. The Cooper drift is along a vein similar to the others, but larger; it strikes due north and dips 50° to 58° E. Where the country rock along it is an altered member of the Gray porphyry group, the vein was rich enough to justify stoping, but south of the tunnel, where the vein passes into shale, it was not productive. Northeast of the Cooper drift several similar veins were found, but they were all in shale and were barren.

Beyond a point 1,050 ft from the portal a series of veins striking about N. 50° W. and dipping 55° NE. borders a broad gouge-filled fault zone. All the veins contain pyrite that yields a little gold. Across one of them, 1,000 ft from the portal, an abrupt change takes place from porphyry to a width of 60 ft of rhyolite agglomerate, followed by highly contorted shale, which apparently represents a bed that was dragged up along the fault from beneath the porphyry sill. Beyond this is a timbered shattered zone, 20 ft wide, and farther northeast the porphyry reappears abruptly along what is interpreted as the northern side of the fault. As the projection of this fault zone with a dip of 55° E. brings it to the surface only about 200 ft northeast of the Weston fault as shown on Plate 13 of Professional Paper 148, it is believed to be the Weston fault. The fault is clearly premineral: on both sides of the fault zone the rock has been extensively replaced by chalcopyrite and pyrite. Strongly replaced rock extends far into the porphyry and locally masks the structure.

Two minor fissures, respectively 1,025 and 1,185 ft from the portal, strike northeastward and dip 50° to 85° SE.; some stoping and raising has been done along them. The northeastern of the two fissures is called Vein No. 6. Beyond it there is little of importance except at a point about 1,875 ft from the portal, where the tunnel passes through a large, gouge-filled, unmineralized fissure, trending N. 5° W. and dipping 50° E.

The main tunnel ends where it intersects the Sunday vein near the northeastern end line of the Greater New York claim. From a point south of the breast of the main tunnel an oblique crosscut eastward from the tunnel intersects the same vein. The Sunday vein has been stoped for about 360 ft north of its intersection with the main tunnel and at intervals for 430 ft to the south. Some of this work was done during the years 1930 to 1935, but most of it was done at an earlier period. The vein is said to have been entirely in a Gray porphyry and grits of the Weber(?) formation on the tunnel level. Too little is known of the rocks in the east wall to determine the amount of faulting along the vein. Local shattering within the Sunday vein suggests that some postmineral movement took place. The vein trends N. 17° to 18° E., dipping 82° to 88° NW. (Emmons, Irving, and Loughlin, 1927, p. 322; Ramboz, unpublished report, 1912, made available through the courtesy of E. D. Dickerman, Leadville Colo.). Its strike and dip are somewhat different, and its direction of dip opposite, from those of the Hellena vein, which is regarded by many as the southern extension of the Sunday vein. Moreover, the Sunday vein here appears 100 to 200 ft west of the northward projection of the Hellena vein if the latter maintains the average strike observed in the Hellena mine. Nevertheless, these two may well be parts of one mineralized zone or even one fissure.

The vein has been far more productive south of the Garibaldi tunnel than north of it, where it is largely composed of gangue. Emmons, Irving, and Loughlin (1927, p. 322) state that it ranged in width from 1½ to 8 ft, averaging 3 to 4 ft, and contained chiefly pyrite, galena, sphalerite, and chalcopyrite. Sphalerite and chalcopyrite were scarce, except locally. The ore was well oxidized at levels above an altitude of 11,600 ft and showed sulfide enrichment to depths of at least 600 ft from the surface.

The output from 1901 to 1912 (Dickerman, personal communication) amounted to a total of 18,558 short tons of ore; individual shipments ranged in content as follows: gold, 0.05 to 0.97 ounce to the ton; silver, 1.90 to 24.90 ounces to the ton; lead, 0.70 to 66.50 percent; copper, 0.10 to 2.57 percent; zinc, 0.20 to 11.80 percent. The ore was hoisted through the Sunday shafts. Operations were suspended from June 1912 until October 1917, continuing thereafter until March 1920. During the second period 1,323 short tons of ore were shipped. This ore ranged in content as follows: gold, 0.07 to 0.49 ounce to the ton; silver, 2.75 to 14.05 ounces to the ton; lead, 5.05 to 33.10 percent; copper, 0.105 to 0.15 percent; zinc, 4.20 to 9.50 percent.

Careful sampling (Ramboz, unpublished report, 1912) of the vein in 1912 led to an estimated average content of 0.14 ounce gold to the ton, 2.35 ounces silver to the ton, and 3 percent lead. According to smelter returns, the total output for the entire period, 1901–20, was valued at $190,116.

RESURRECTION MINE

In 1935 the writer studied the new work carried on by the Zenda Mining Co. along the Yak level from the

Resurrection No. 1 (main) shaft (D–40). According to Emmons, Irving, and Loughlin (1927, pp. 320–322) the Resurrection group developed nine veins that lie generally north of the No. 1 shaft. They state in part:

> Four of them—Nos. 1, 2, 7, and 8 have a roughly cresentic form with large radii of curvature * * * The veins were all accidentally discovered by underground workings driven for the purpose of developing the blanket ores * * * All the veins belong to the north-northeast system * * * 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 large tonnage of siliceous gold ore, much of which contained galena and zinc blende with subordinate silver.

Along this fissure there has been a displacement of 40 ft, which has brought Cambrian quartzite in the east wall up against eastward dipping shale of the Peerless formation.

The writer was able to study the work on the Yak tunnel level only, which was being actively carried on at the time (pl. 20). Here the No. 7 fault vein just west of the main shaft strikes about N. 15° E. and dips 75° to 80° W. The No. 7 fault fissure is 20 ft wide with distinct boundaries. The ore in part replaces country rock, in part fills in between rock fragments, forming a mineralized fault zone much wider than the four feet mentioned above by Emmons, Irving, and Loughlin. The hanging wall of the vein is an altered member of the Gray porphyry group, broken still farther west by other faults.

This conspicuous fissure vein is not recognized with certainty in the first lateral (also called the Bryant lateral) south of the Main (No. 1) shaft. Two faults on this lateral situated 190 ft east of the Yak tunnel may represent the walls of the No. 7 vein, as they are about the same distance apart and have the same general strike; but the faults dip 65° E. and are not appreciably mineralized. It is equally probable, however, that the vein joins a fissure, also mineralized, that strikes S. 40° W. near the Resurrection No. 1 shaft and is exposed 165 ft east of the Yak tunnel in the Bryant lateral.

Farther east, where the Bryant lateral turns from an east-southeast to an east-northeast course to explore the Christmas claim, it enters Cambrian quartzite. About 120 ft east of the turn two conspicuous fault fissures striking N. 20° E. and N. 50° E., with associated shear zones, repeat the Gray porphyry and are somewhat mineralized; another mineralized shear zone (the Christmas fissures) is cut 300 ft farther east. Approximately 525 ft east of the turn a raise was put up at the end of a blind drift on a mineralized fissure striking N. 10° E. in the Peerless formation. At a point 855 ft east of the Yak tunnel the main lateral was turned east-southeastward, cutting through the N. 10° E. fissure and another, striking about N. 30° E.; both of these veins are in shale of the Peerless formation. Farther southeastward this crosscut passes through Manitou dolomite, an overlying sill of the Gray porphyry group, another mineralized fault (not shown or plate 20), more shale, and entered another mass of the Gray porphyry group. The rocks west of this fault dip eastward whereas those east of it dip northward. The lateral was stopped because it neared the side lines of the Christmas claim.

Of the several fissures cut by the Bryant lateral the Weil fissure is the most conspicuous, as it borders a shear zone 8 ft wide. The Weil raise along this fissure found nothing of interest but merits being extended into higher, more favorable rocks. The N. 10° E. fissure that crosses the Bryant lateral about 90 ft east of the fork 930 ft east of the tunnel, also should be explored where it cuts more favorable rocks.

IBEX MINE

The Ibex mine, one of the oldest near Leadville, is known mostly for its output of gold in the early days of mining in the district. The general features of its ore deposits were well described by Emmons, Irving, and Loughlin (1927, pp. 295–300). In 1932 a part of the output came from higher levels in the ground north of the No. 2 shaft, where rich gold ore in small quantities was being mined. Most of the interest, however, centered on the seventh and lower levels, and especially on the possibility of finding blanket deposits and rich gold-bearing veins like those of the Golden Eagle workings and elsewhere. Chief interest lay in the possibility of finding replacement deposits in the Manitou dolomite and shale of the Peerless formation and in veins in these formations and the Cambrian quartzite. Intercalated at various horizons in this part of the sequence are sills of early White porphyry. As the search for blankets at the lower horizons must largely be confined to the Manitou dolomite or to calcareous layers in the Peerless formation, the problems of further exploration were mainly structural; hence the writer spent a part of the summer of 1928 in studying the geology to revise the maps already published in Professional Paper 148, in particular of areas north of the No. 2 Shaft. The new maps are presented in Plates 6–8. A brief discussion of the northern part of the mine at the seventh level and below is given in the following pages. The altitudes of the various levels are as follows:

	Altitude (feet)
Seventh level	10, 915
Fourth level from Kyle winze	10, 760
Tenth level	10, 687
Bott level, above twelfth level	10, 569
Twelfth level	10, 508

The main north haulageway of the seventh level north of the No. 2 shaft (Emmons, Irving, and Loughlin, 1927, p. 300) is driven essentially across a syncline having Parting quartzite downfolded to this level between limbs of Manitou dolomite (pl. 6). About 430 ft north of the shaft and a little west of the main haulage drift, the axis is crossed obliquely by a fault fissure striking north-northwest and having a displacement essentially parallel to the strike of the fault plane, the east side having moved south. This is one of the larger faults of the mine. To the north its course curves northeastward and its displacement decreases until apparently (in Block 44, about 800 ft north of the No. 2 shaft) it is reduced to two fissures which strike north-northeast and have almost no displacement (see pl. 6). Most of the country rock is the unfavorable early White porphyry and the fissures are mineralized only in a narrow band of shale of the Peerless formation along which considerable stoping has been done. These two fissures are recognizable on a sublevel 70 ft above the seventh level at the northeastern end of the workings, where Parting quartzite is faulted against early White porphyry; mineralized ground on this sublevel is negligible.

Along the northeastern part of its course, the seventh level crosses numerous small faults with strikes ranging from due north to about N. 50° W.; none of them is markedly mineralized. A raise in Block 300 connects the seventh level with the previously mentioned level, 70 ft higher. This sublevel splits northward into two branches, of which the western one follows a northwestern fissure in early White porphyry, and the eastern one follows a north-northeasterly fissure east of which Manitou dolomite, Parting quartzite, and volcanic agglomerate appear in a complex relationship, as shown on the map, Plate 6. At least two northwest-trending faults are mineralized in this end of the mine.

The fourth level from the Kyle winze (pl. 8) developed little of interest except a fault contact between a sill of early White porphyry to the northeast and the Manitou dolomite to the southwest. This fault strikes N. 45°–70° W., parallel to the strike of the beds, and dips 30°–60° NE., but it curves irregularly in ground plan and is offset by several lesser faults of northeast strike. Especially disappointing here is the failure to find any important ore shoots in the Manitou dolomite, which is generally productive though not as favorable to mineralization as the Leadville dolomite.

The tenth and closely adjoining levels (pl. 7), north of the No. 2 shaft, cut two sills of altered early White porphyry between which is a thickness of 50 ft of shale of the Peerless formation that contains some thin beds of almost pure limestone. Most of the mineralized fissures trend north or northeast, but the vein matter is not rich. The contrast between the mineralized northeast-trending fissures and the postmineral fissures of north to northwest trend is most striking, especially in the northern part of the workings, where the barren northwesterly fissures intersect and offset the veins of northeasterly strike. Of most economic interest is the ore in the Peerless formation near Swanson's incline. Ore shoots of this group lie along mineralized fissures that trend east-northeast and beneath shaly beds or the overlying sill of early White porphyry. A group of such shoots is exposed south of Swanson's incline. At the southern end of this mineralized area the Peerless formation was so intensely mineralized above the tenth level and west of it (that is, up the dip) that a continuous blanket ore-body could be mined; but farther north, and down-dip from the level, replacement was less continuous between the neighboring feeding fissures. Here the elongate form of the stopes defines the fissures; they average 10 to 50 ft in width. The ore shoot has been opened by Swanson's stope and Swanson's incline for a distance of 270 ft. The main mineralized fissures in this ground trend N. 30°–50° E., and generally dip 75°–90° E., but some curve so as to produce a reversal of dip. An abundance of small feather fractures meet these major fractures at small angles and strike N. 10°–20° E.; an especially good example is in the short exploratory drift extending S. 20° W. about 20 ft from the lower (northeast) end of Bowden's stope; the drift itself is driven along the minor fissures, which are vertical, gaping, and partly filled with crusts of sphalerite and pyrite.

Variously dipping faults that strike parallel to the beds and are distinctly though not abundantly mineralized, occur locally and perhaps more generally than is recognized. Such faults are common in the northern end of this level, but the best example is that at the northeastern end of Swanson's incline (figs. 100 and 101). Here the shale of the Peerless formation, containing much shaly limestone, has been largely replaced by ore and a fault brings the sill of early White porphyry (normally above the shale) against it. The fault dips about 50° NE.; the dip of the beds is similar in direction but only 25°. Up the dip of the beds, the dip of the fault gradually flattens so that the two planes are parallel. In the hanging wall the porphyry is greatly shattered. Though the main fissures of Swanson's stope cannot be traced into the fault, mineral-bearing accessory fractures extend into the fault breccia and cross it, dying out in the solid porphyry northeast of the stope. It is not clear from these relations whether the fault is normal or reverse; less displacement would be required to bring the early White porphyry against the upper part of the shale if the porphyry were assumed to be the sill above the shale rather than one below it. This fault may therefore be assumed to be normal, but the structural features are more like the "zigzag" fissures associated with reverse faulting (Behre, 1937, pp. 525–527).

In the upper end of Swanson's stope the relation between the positions of fissures and the local thick-

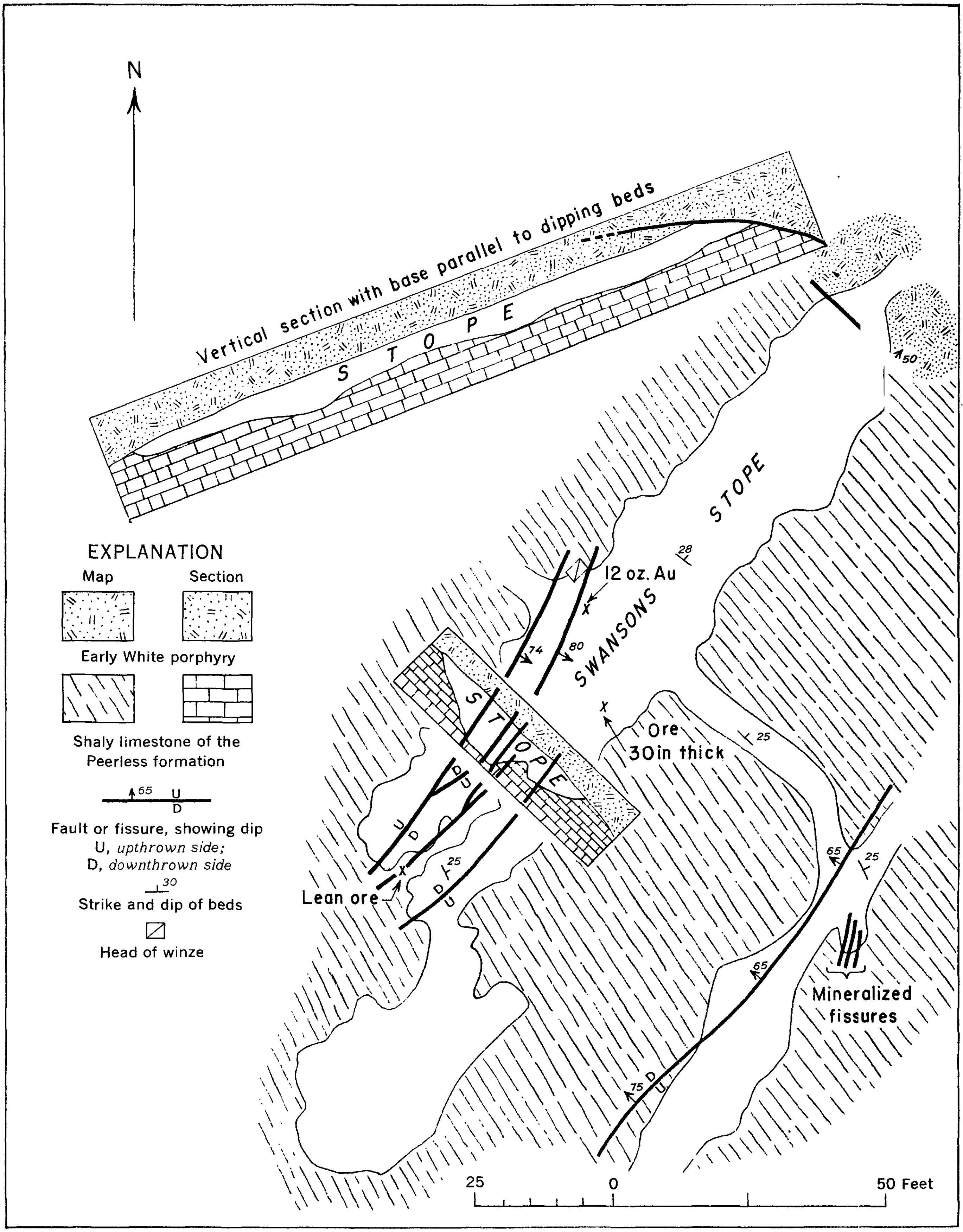

FIGURE 100.—Detailed map of Swanson's stope, Ibex mine, and vertical sections parallel and transverse to its length. Note relations of faults to mineralization.

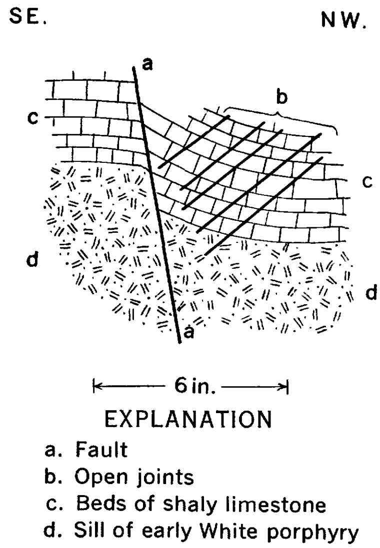

FIGURE 101.—Details of fractures in limestone bed at head of Swanson's stope, Ibex mine. Note open joints, locally mineralized, apparently related to main fault.

nesses of replacement bodies is especially conspicuous. The richer, thicker parts of the ore shoots along fissures are 30 in. or more thick; between the fissures, within distances of no more than 20 ft, the thicknesses decrease to 6 in. or less, and the grade of ore becomes poor. The southwestern edge of the stope is thus lobate, consisting of alternate fingers of rich ore following fissures and intervening prongs of lean or barren country rock. Most of this ore was cupriferous pyrite that had extensively replaced the calcareous beds of the Peerless formation; in addition to the copper, as much as 1 ounce of gold to the ton was recovered. But along certain fissures, such as the eastern fissure in Swanson's stope, the gold content was as much as 12 ounces to the ton. The richness of the ore in and immediately adjacent to places where a vein crosses the sulfide blanket body suggests that the gold was deposited later than the sulfides and was precipitated through interaction of the solutions with the sulfide ores. Along several of the fissures replacement has been so extensive that the original feeding fissure is completely hidden; this probably accounts for the absence of a distinct fissure in Swanson's incline, despite the local intensity of mineralization. Directly beneath the blanket deposits the calcareous shale in places is largely silicified.

At the northern end of the workings winzes have been sunk to connect the tenth level with drifts 54 and 74 ft below the main level, and in this lower work some northeast-trending mineralized fissures have been found cutting the sill of early White porphyry that overlies the Peerless formation. The mineralized ground was not rich enough here to merit further exploration; nevertheless, sinking along such fissures to search for ore in calcareous beds of the underlying Peerless formation offers a reasonable hope of success. Some of these fissures are cut and offset by postmineral faults of northwest trend.

The Bott level (pl. 8) crossed three mineralized fissures trending northward and dipping moderately to steeply eastward; however, the country rock at this level is almost wholly in a zone of little promise—the early White porphyry of the sill below the Peerless formation. At the southern end of the workings a raise of 25 ft broke into a small but rich body of ore in the overlying calcareous beds of the Peerless formation. A fault of northwesterly trend exposed in the northern part of the workings is interpreted by some as the Colorado Prince fault but it proves to be a deeper fault, nowhere recognized at the surface; the writer has named it the Bowden fault (Behre, 1929, pp. 54–55) after its discoverer, W. E. Bowden, one of the men most active in deeper explorations in the Ibex mine.

On the twelfth level (pl. 8) little encouraging evidence was found. Stoping at the southeastern end of this level in the Peerless formation above the main level revealed a lower part of the ore body mentioned in the description of the Bott level. Complex faulting has cut out the Cambrian quartzite at the northern end of the mine, and pre-Cambrian granite has been brought up on the north against early White porphyry on the south. The main fault here is the Bowden fault. The ground is locally shattered and slightly mineralized along a fissure of north-northeasterly trend that was seen as a highly mineralized fissure on the Bott and the tenth levels. The part of the Ibex mine north of No. 2 shaft and below the seventh level has proved disappointing, except where northeasterly fissures cross the calcareous beds of the Peerless formation.

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[Complete list of mines and prospects, and their locations, on plate 1]