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PRELIMINARY GEOLOGICAL REPORT ON THE WEST SLOPE OF THE MOSQUITO RANGE IN THE VICINITY OF LEADVILLE, COLORADO[1]

by C. H. BEHRE, JR.[2]

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ILLUSTRATIONS

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[1]Prepared, in cooperation with the State of Colorado, Colorado Metal Mining Fund, Colorado Mining Association, and Geological Survey Board of Colorado, as an explanation of a geologic map issued in 1939 by the Geological Survey, U. S. Department of the Interior.

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Preliminary Geological Report on the West Slope of the Mosquito Range in the Vicinity of Leadville, Colorado[1]

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The geology of the Leadville mining district has been studied by the United States Geological Survey at intervals since the appearance of Monograph XII.[3] In addition to that publication, the principal contributions have been those of Emmons, Irving, and Loughlin.[4] In 1928 a detailed study of the central part of the Mosquito Range, originally described in Monograph XII, was begun by the U. S. Geological Survey in cooperation with the State of Colorado and the Colorado Metal Mining Fund. The eastern slope, including the Alma and adjacent mining districts, was studied by Singewald and Butler.[5]

The western slope (Fig. 1), including the Leadville and adjacent areas, was studied by the writer under the general direction of G. F. Loughlin. The economic results thus far published are included in the papers shown in the footnote.[6]

These areas, which adjoin the central Leadville district to the north, east, and south, as shown on Plate 13 of Professional Paper 148, include areas in which the bedrock is somewhat better exposed than in the central part of the Leadville district. The earlier work on these outlying areas, as reported in Professional Paper 148, was brief and represented largely reconnaissance information obtained by the first survey under Emmons. The intensive studies briefly outlined in this report were undertaken to work out the geology in more detail and thereby to suggest places in the areas where further exploration for ore is worthy of consideration. The results of the work are expressed in a geologic map of Leadville and vicinity published by the U. S. Geological Survey. This map is a revision of a

[3] Emmons, S. F., The geology and mining industry of Leadville, Colorado, with atlas: U. S. Geol. Survey Mon. XII, 1886.

[4] Emmons, S. F., and Irving, J. D., The Downtown district of Leadville, Colorado: U. S. Geol. Survey Bull. 320, 1907. Loughlin, G. F., The oxidized zinc ores of Leadville, Colorado: U. S. Geol. Survey Bull. 681, 1918. Loughlin, G. F., Guides to ore in the Leadville district, Colorado: U. S. Geol. Survey Bull. 779, 1926. Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colorado: U. S. Geol. Survey Prof. Paper 148, 1927.

[5] See Singewald, Q. D., and Butler, B. S., Preliminary geologic map of the Alma mining district, Colorado: Colorado Sci. Soc. Proc., vol. 12, pp. 296-308, 1930. Preliminary report on the geology of Mount Lincoln and the Russia mine, Park County, Colorado: Colorado Sci. Soc., Proc., vol. 12, pp. 389-406, 1931. Suggestions for prospecting in the Alma district, Colorado: Colorado Sci. Soc., Proc., vol. 13, pp. 89-131, 1933. Geology of mines along the London fault, Alma district, Colorado: U. S. Geol. Survey Bull. in press.

[6] Behre, C. H., Jr., Revision of structure and stratigraphy in the Mosquito Range and the Leadville district, Colorado: Colorado Sci. Soc., Proc., vol. 12, pp. 37-57, 1929. Behre, C. H., Jr., The Weston Pass mining district, Lake and Park Counties, Colorado: Colorado Sci. Soc., Proc., vol. 13, pp. 55-75, 1932. Loughlin, G. F., and Behre, C. H., Jr., Zoning of ore deposits in and adjoining the Leadville district, Colorado: Econ. Geol., vol. 29, pp. 215-254, 1934.

part of the map published in 1886 as Atlas Sheets XIII and XIV and parts of Atlas Sheets VI and VII in Monograph XII, and reprinted with a few changes in 1927 as Plate 11 in Professional Paper 148.

The field work—mainly in the less productive, outlying areas—virtually was completed in 1932, but the region has been revisited since 1932 for study in greater detail. The text of an exhaustive and detailed report of the region is nearing completion. This brief report is presented as an explanatory text to accompany a preliminary edition of the geologic map published by the Geological Survey. The area represented by this new map includes the area represented by the geologic map of the Leadville district published as Plate 13 in Professional Paper 148 and extends it to the north, the east, and the south.

The new map is in some respects more accurate and in other respects less accurate than the map of the central Leadville district, which has been included without revision. In parts of the outlying areas outcrops are numerous, and boundaries can be more accurately traced on the surface, but, as the mines are relatively small and scattered, underground clues to concealed geologic boundaries are scarcer. In contrast, though much of the surface within the Leadville district is covered with glacial deposits, mine workings are so numerous that the bedrock map is based largely on underground data. In the southwest part of the region, moreover, the glacial cover is so continuous and mines and prospects are so scarce that bedrock boundaries must be generalized.

The writer is indebted greatly to Mr. G. F. Loughlin for repeated advice and much helpful criticism in field and office work. He also wishes to acknowledge the efficient assistance of Messrs. E. N. Goddard and A. E. Sandberg, each of whom served as assistant for one field season. Special thanks are also due Mr. C. W. Henderson of the U. S. Bureau of Mines, Denver, for general information, especially regarding operators and mine output. Adequate acknowledgment of indebtedness to all of the mining men of Leadville who have been helpful is impossible, but special mention should be made of Messrs. George Argall, Ezra D. and Edward Dickerman, John Harvey, Frank Kendrick, Jesse F. McDonald, J. B. McDonald, F.

J. McNair, Douglas Platt, and H. H. Wallower; and of the following deceased—W. E. Bowden, C. N. Larson, and Carl Schmidt. Special thanks are due to Messrs. E. P. Chapman, John Cortellini, Marvin Kleff, and R. D. Longyear for the loan of maps and other data, and for valuable suggestions.

LIMITS OF THE AREA; PHYSIOGRAPHIC FEATURES

The area herein described comprises about 40 square miles in Lake County, central Colorado. It includes the high peaks of the Mosquito Range between latitudes 39° 10′ and 39° 17′ 30″ and the west slope as far as the city of Leadville, at about longitude 106° 17′ 30″ west. The highest altitudes along the crest of the range exceed 14,000 feet, and those of the valley floors along the western edge of the district range from 10,000 to 10,400 feet above sea level.

The city of Leadville, the residence of most of the miners and supply point for the mines, is also the site of the Arkansas Valley smelter, to which the main part of the ore from the district is shipped. The town and mines are served by the Denver and Rio Grande Western Railroad and by a line of the Colorado and Southern Railway connecting with Climax, Colorado.

The physiographic features of the area do not merit extended discussion in this report. The remnants of several high-level erosion surfaces have been noted.[7] The detailed topography of the higher reaches is typical of a region carved by mountain glaciers. Glacial moraines and outwash cover much of the lower slopes. The observed features of glacial erosion and deposition are, with negligible exceptions, assignable to the latest glacial stage (Wisconsin?) of the southern Rocky Mountain region.[8] Between the glacial deposits and the bedrock there are thin deposits of silt and clay (generally regarded as late Tertiary[9] in age) that have been penetrated by shafts close by Leadville but have not been found in any of the outlying mines or outcrops examined by the writer.

Of late origin are immense piles of rock fragments, due either

[7]Behre, C. H., Jr., Talus behavior above timber in the Rocky Mountains: Jour. Geol., vol. 41, pp. 622-635, 1933. Behre, C. H., Jr., Physiographic history of the upper Arkansas and Eagle Rivers, Colorado: Jour. Geol., vol. 41, pp. 793-803, 1933.

[8]Capps, S. R., Pleistocene geology of the Leadville quadrangle, Colorado: U. S. Geol. Survey Bull. 386, 99 pp., 1909.

[9]Emmons, S. F., Geology and mining industry of Leadville, Colorado: U. S. Geol. Survey Mon. XII, pp. 71-72, 1886. Emmons, S. F., Irving, J. D., and Loughlin, G. F., Op. cit., pp. 17-20, 1927.

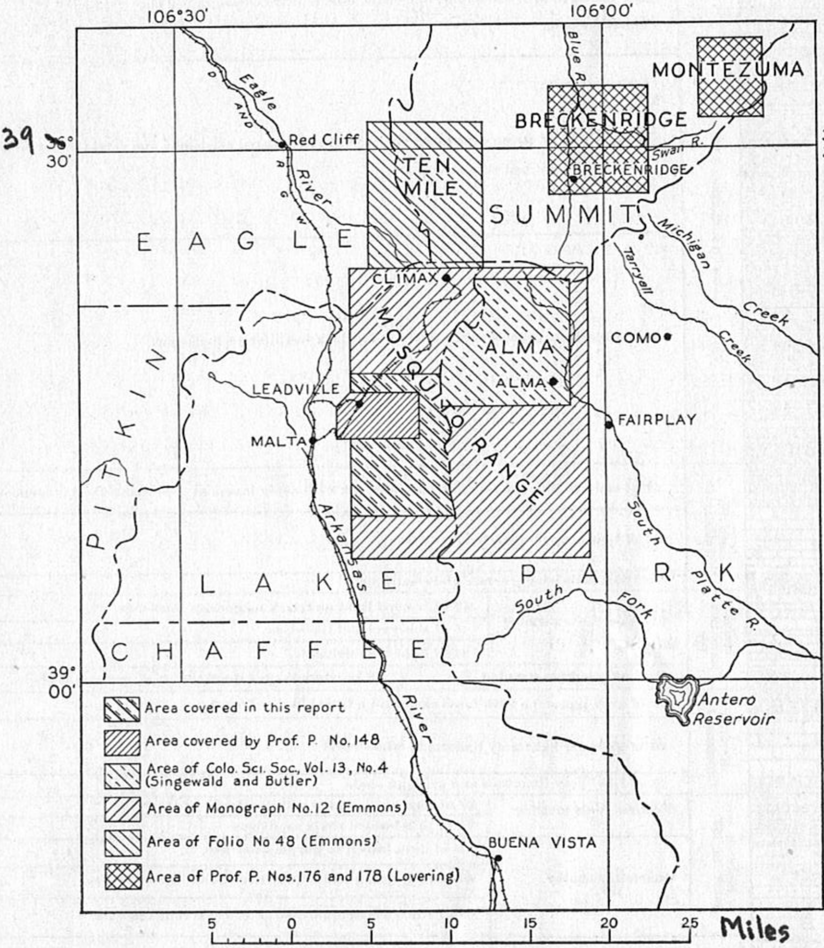
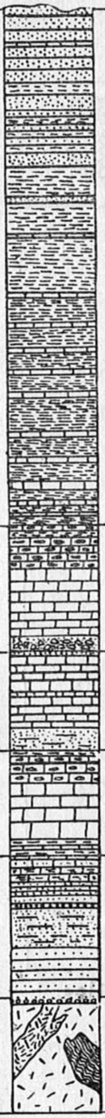


Fig. 1. INDEX MAP SHOWING AREA COVERED AND ITS RELATION TO OTHER MAPPED AREAS.



Pennsylvanian	Weber (?) formation, 2,450'		2,000' or less of grit, sandstone, and shale, dominantly coarse-grained clastics, rarely limestone beds.
			200' of light-gray, green, and black shale, with intercalated sandstone and rarely limestone beds; one prominent bed of white quartzite.
			250' of black carbonaceous shale and dense dark fossiliferous limestone.
Mississippian	Leadville limestone, 140'		44 of massive blue-gray magnesian limestone with shaly layers at top; black chert is common.
			90' of blue-gray magnesian limestone.
			6 of limestone conglomerate and sandstone.
Upper Devonian	Chaffee formation, 107'	Dyer dolomite member 80'	40' of banded light and dark magnesian limestone.
			5' of ocher-colored limestone.
			35' of light-gray dolomite.
		Parting quartzite member, 27'	19' of white sugary quartzite; 8' of variegated shale.
Lower Ordovician	Manitou limestone, 110'		30' of gray limestone with fossil casts and a little chert.
			60' of granular light-gray limestone, white chert
			20' of light-gray limestone and greenish shale.
Upper Cambrian	Sawatch quartzite, 150'	Peerless shale member 45'	20' of impure limestone with "red cast beds."
			25' of thin-bedded shaly sandstone.
		Quartzite member 105'	5' of dark-brown to purple quartzite.
			40' of alternating white quartzite and brown sandstone.
			60' of white glassy quartzite, 2' of basal conglomerate.
Pre Cambrian	Granite, gneiss, schist		Porphyritic to equigranular gray or pink granite and orthogneiss; biotite, sillimanite, and hornblende schist, dike rocks

Fig. 2. COLUMNAR STRATIGRAPHIC SECTION OF WEST SLOPE OF MOSQUITO RANGE NEAR LEADVILLE, COLORADO.

to gradual accumulation at the foot of steep cliffs, as seems to be true in the southerly head of Big Evans Amphitheater, or to landslides, as in Iowa Gulch near the Clear Grit mine.

STRATIGRAPHIC SUCCESSION

The general stratigraphy is shown in Fig. 2, except for subdivisions of pre-Cambrian rocks. The map shows the distribution of all the stratigraphic subdivisions that can be recognized in the field, but complete descriptions are reserved for the more detailed report. Brief descriptions follow:

Pre-Cambrian rocks.—The pre-Cambrian rocks of the area fall into two general groups—an older group of schists and gneisses, and a younger group of intrusive granites. The older group consists mostly of gray or pinkish-gray biotite-hornblende gneiss and finely-laminated, fine-grained quartz-biotite gneiss. It also includes several varieties of schist, among which a dark-gray to black biotite-sillimanite schist is dominant.

The dominant intrusive granites comprise an earlier one of the Pikes Peak type and a later one of the Silver Plume type. Both are pinkish medium- to coarse-grained granites. The Pikes Peak type has somewhat larger crystals of potash feldspar, and contains more biotite than the Silver Plume type, which is not so coarse-grained and has its elongate feldspar crystals in roughly parallel arrangement. The Silver Plume type in general has a lighter color because of the sparseness of coarse biotite flakes. This lighter color, together with the parallel arrangement of feldspar crystals, generally serves to distinguish the Silver Plume from the Pikes Peak type, but contacts between the two are not sharp and in some places the distinction may be very difficult to make without microscopic study.

Besides these granites, a gray, medium-grained quartz-mica diorite is found on East Ball Mountain. Pegmatite and aplite dikes and a few dark-gray basic dikes are present throughout the granite and schist areas.

Areas of pre-Cambrian in which the rocks are not well exposed or not clearly separable have been mapped as undifferentiated pre-Cambrian.

Cambrian rocks.—The lowest Paleozoic formation is the Sawatch quartzite. It consists of two members, as shown in Fig. 2. The lower member is white, glassy, quartzitic rock, which grades upward into alternating beds of white quartzite and buff-colored sandstone, bearing lower Upper Cambrian fossils. At its base there is generally a conglomerate, about two feet thick, containing rounded quartz pebbles. The upper 45 feet (Peerless shale member) are shaly sandstone overlain by shaly limestone. At a distance, the striped appearance of these beds is striking.

Ordovician rocks.—The Manitou limestone has a distinctive light-buff to light-gray color. It is almost wholly dolomitic and on fractured surfaces is distinctly and rather coarsely crystalline, in contrast with the more fine-grained textures of stratigraphically higher limestones. Its uniform beds, mostly between 2 to 4 feet in thickness, give the outcrops a massive rather than a banded appearance which, together with the light-gray color, serves especially at a distance as a distinguishing characteristic. At close range the presence of lenses and small nodules of white chert, a fine tracery of silica parallel to the bedding, and the sugary texture are typical. The Manitou limestone contains a few fossils of Lower Ordovician age.

A profound but not angular unconformity separates the Manitou limestone from the overlying Devonian beds.

Devonian rocks.—The Devonian Chaffee formation contains two subdivisions—the Parting quartzite member below (in earlier reports referred to the Ordovician), and the Dyer dolomite member above (in earlier reports included with the Mississippian limestone under the term "Blue limestone"). The age of these units has until recent years been in doubt, but the publications of Kirk, Johnson, and the writer in 1931 and 1933 have established that it is Devonian.[10] The Parting quartzite ranges from 19 to 62 feet in thickness and its basal red and green (variegated) shale, noted in Fig. 2, is absent from some places. The base of the formation is sharply marked against the Manitou limestone, but its typical sandy beds grade upward into the overlying Dyer dolomite through layers intermediate in composition between limestone and sandstone.

The Dyer dolomite member consists of light-gray, bluish-gray,

[10]Kirk, Edwin, The Devonian of Colorado: Am. Jour. Sci., 5th ser., vol. 22, pp. 237-239, 1931. Behre, C. H., Jr., and Johnson, J. H., Ordovician and Devonian fish horizons in Colorado: Amer. Jour. Sci., 5th ser., vol. 25, pp. 477-486, 1933.

buff-colored, or pinkish beds that are somewhat sugary in texture and thus resemble the Manitou limestone; but otherwise they differ, especially in their thin-bedded character. Locally the Dyer dolomite bears the distinctive colonial coral, Syringopora.

Mississippian rocks.—The overlying Leadville limestone is apparently not separated from the Dyer dolomite member of the Chaffee by any marked discordance, but its base is marked by a conglomerate averaging six feet in thickness and composed of subangular pebbles and boulders in a calcite matrix. Locally this basal bed is a calcareous sandstone. Above are beds from three to six feet thick of banded blue-gray dolomitic limestone. These are distinctly darker, both on the fresh and weathered surfaces, than the underlying light-gray Manitou or buff or yellowish Dyer strata. The texture is characteristically fine-grained to microgranular and, except where recrystallized near intrusions, contrasts strikingly in this respect also with the older limestones. Chert is present but, in contrast to that in the Manitou limestone, is black where fresh and weathers deep yellowish brown. It forms discontinuous beds, especially near the top of the formation, rather than isolated nodules which are typical of the Manitou limestone. Locally the rock is altered and shows closely-spaced replacement veinlets of secondary, white dolomite—a feature popularly referred to as "zebra rock." Thickness measurements range from 125 to 160 feet. Fossils are rare, but enough have been found to establish the Mississippian age of the formation and to enable correlation with the Madison limestone of the Northern Rocky Mountains and with the Kinderhook or lower Burlington of the Mississippi Valley.[11]

Pennsylvanian rocks.—The basal member of the Weber (?) formation, which overlies the Leadville limestone, is dominantly a black shale. There is no angular discordance between the topmost Leadville limestone and this shale; however, the contrast between them is marked, and the presence of sink-holes in the Leadville limestone partly filled with such shale in other localities near the Mosquito Range and the variations in thickness of the Leadville limestone both suggest that there is an unconformity between the Mississippian and the Pennsylvanian.

[11]Girty, G. H., The Carboniferous formations and faunas of Colorado: U. S. Geol. Survey Prof. Paper 16, pp. 221-223, 1903. Johnson, J. H., Paleozoic formations of the Mosquito Range, Colorado: U. S. Geol. Survey Prof. Paper 185-B, p. 27, 1934.

The line between the Permian and Pennsylvanian has never been drawn with certainty in the Mosquito Range. It seems best, however, to regard all of the Paleozoic rocks above the Leadville limestone in the district here described as of Pennsylvanian age and to apply to them the designation "Weber (?)" as has been done in earlier writings.[12] This name suggests correlation with the Weber quartzite of Utah, but the correlation is in doubt.

Much of the Weber (?) and all of the overlying formations have been stripped from the Leadville district. Despite this fact the Weber (?) locally is very thick—at least 1,300 feet in a measured section on Prospect Mountain. In the Leadville district, it consists of three fairly definitely separable members: (1) the lowest, a black, carbonaceous shale, 250 feet thick, with interbedded black, foetid, fossiliferous limestone and rare beds of fairly pure quartzite; (2) coarse-grained sandstone or "grit," 200 feet thick, in beds as much as 5 feet in thickness separated by beds and partings of light-gray, green, and black shale, a few beds of limestone, and one prominent bed of white quartzite; (3) dominantly beds of coarse-grained "grit," sandstone and shale (with a few limestone beds)—as much as 2,000 feet in total thickness. Invertebrate fossils are largely confined to the calcareous beds, but plant fossils have been found at several sandy and shaly horizons. These collections suggest that the Weber (?) is best regarded as equivalent to the middle and a part of the upper Pottsville of the eastern United States.[13]

LATE CRETACEOUS AND TERTIARY IGNEOUS ROCKS

Virtually all the igneous rocks of the Leadville district are intrusive; however, some facies broke through to the surface. They fall into three general divisions: (1) The White[14] porphyry group, which comprises light-colored, finely-granular, or porphyritic rocks; (2) the Gray[14] porphyry group, which comprises medium- to dark-gray intrusive rocks that range in texture from fine-grained and equigranular to coarse-grained porphyritic; (3) a late group which includes quartz latite porphyry and rhyolite agglomerate, appar-

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[12]Johnson, J. H., Paleozoic formations of the Mosquito Range, Colorado: U. S. Geol. Survey Prof. Paper 185-B, pp. 27-28, 1934.

[13]Johnson, J. H., op. cit., p. 33, 1934.

[14]This descriptive name (White) or (Gray) is used in a titular sense for the convenience of those accustomed to this term in earlier reports on the Leadville district.

ently younger than the rocks of the other two groups. The distinctions between these groups are largely lithologic, in part recognizable in hand specimens and in part only with the aid of the microscope. The distinctions are also partly structural; their relative ages are proved by fragments of the older inclosed in rocks of the younger groups and by dikes or sill-like bodies of younger rocks that cut across older ones.

The exact age of these igneous rocks is not known. In general, it may be said that most of them are of late Cretaceous and early Tertiary age. The late group probably is of middle to late Tertiary age.

The rocks of the late group are classified easily. However, the earlier rocks including the White porphyry group and the Gray porphyry group have been variously subdivided in previous reports,[15] and similar rocks have been recognized and subdivided in the adjacent Alma district by Singewald and Butler.[16] For most practical purposes the old classification into three groups (White porphyries, Gray porphyries, and agglomerate) may still serve. More attention, however, has been given by the author than by previous writers to the subdivision[17] of these groups, especially the Gray porphyry group. On the preliminary geologic map, only the Johnson Gulch porphyry, latest of the Gray porphyries, has been separated from the other members of the group; the other members are discussed separately in the text. The distinctive features of members of each group to a large extent are microscopic and not always recognizable in specimens. The megascopic descriptions will be given briefly in the belief that the technical reader will find them helpful. The members of the groups recognized by the present writer are named in Fig. 3. The older members of each group

[15]Emmons, S. F., The geology and mining industry of Leadville: U. S. Geol. Survey Mon. XII, pp. 78-86, 1886. Emmons, S. F., Irving, J. D., and Loughlin, G. F., Op. cit., pp. 46-51, 1927. Behre, C. H., Jr., Revision of structure and stratigraphy in the Mosquito Range and the Leadville district, Colorado: Colorado Sci. Soc., Proc., vol. 12, pp. 42-43, 1929.

[16]Singewald, Q. D., and Butler, B. S., Suggestions for prospecting in the Alma district, Colorado: Colorado Sci. Soc., Proc., vol. 13, p. 74, 1933.

[17]In detailed map studies it has been possible to distinguish several subdivisions of Gray and White porphyries, but on the map accompanying this report, all of the Gray porphyries except the Johnson Gulch are grouped together under the general term "Gray porphyry." Since an appreciable age difference separates the earlier White porphyry from the later White porphyry, the two have been distinguished in this manuscript under the terms "early white" and "late white" porphyry. These designations are used here in the interests of simplicity and in place of the usual regional names sanctioned by general geologic usage.

appear at the bottoms of the columns, and the ages of members of one group with respect to those of other groups are shown by their respective positions in the different columns. There are reasons favoring the contemporaneity, as shown in Fig. 3, of the Iowa Gulch and Sacramento porphyries, also of the Lincoln and Evans Gulch porphyries, but the relative ages of these two pairs have not been demonstrated with certainty. Finally, the relative ages of the Little Union quartz latite and the rhyolite agglomerate have not been proved. The reasons for assignment of these relative ages will not be discussed further in this brief report but are based partly on structure and partly on the degree of alteration that each rock type has undergone.

Age Relations of Late Cretaceous and Tertiary Igneous Rocks

White porphyry group	Gray porphyry group	Rhyolite and quartz latite group
		Rhyolite and Rhyolite agglomerate (youngest) Little Union quartz latite
"Late white" porphyry		
	Johnson Gulch porphyry Iowa Gulch and Sacramento porphyries Evans Gulch and Lincoln porphyries Quartz diorite porphyry	
"Early white" porphyry (oldest)		

Fig. 3. AGE RELATIONS OF LATE CRETACEOUS AND TERTIARY IGNEOUS ROCKS.

The rocks will be described below in groups, the White porphyries being considered first, then the Gray porphyries, and finally the quartz latite, the rhyolite and the rhyolite agglomerate.

WHITE PORPHYRY GROUP

Rocks locally called "White porphyry" were intruded at two different times, and are conveniently termed the "*early* white" porphyry (which was intruded before the members of the Gray porphyry group) and the "*late* white" porphyry (which was intruded afterward).

The "early white" porphyry is snowy white to very light-gray. It has a stony to finely-granular groundmass, and locally a sugary texture that is in part the result of alteration. It has relatively few, small phenocrysts of sodic plagioclase, quartz, and biotite,[18] which rarely attain 0.1 inch in diameter. It is essentially a light-colored granodiorite porphyry.

"Early white" porphyry occurs almost entirely in sill-like bodies, the thicker of which have the more granular textures. Two such prominent sills can be traced in the walls of the western slope of the Mosquito Range, from Evans Amphitheater to Peerless Mountain. One of these is in the Cambrian quartzite and averages 100 feet in thickness; the other is at the top of the Leadville limestone and attains a thickness of more than 1,000 feet on Mount Sherman.

The "late white" porphyry is a granodiorite porphyry which strongly resembles the "early white" porphyry but its groundmass generally is more dense and stony, and its phenocrysts are mainly of feldspar accompanied by a few of quartz or biotite. The biotite sometimes is altered and bleached to secondary muscovite. The "late white" porphyry has a greater tendency to break into thin slabs, typically half an inch thick. It occurs everywhere in dikes, with the exception of a single sill-like body that cuts obliquely across a sill of "early white" porphyry on the southwesterly slope of Mount Sheridan. A conspicuous dike of "late white" porphyry about two miles long extends from the western slope of East Ball Mountain northeast and across the entire head of Evans Amphitheater.

[18]See reference to muscovite and sericite, Prof. Paper 148, p. 45.

GRAY PORPHYRY GROUP

All the rocks of the Gray porphyry group are, as the name suggests, darker in color than the "white" porphyries; moreover, very few of them fail to show distinct phenocrysts, and many are very porphyritic. In some the groundmass is visibly granular. The phenocrysts include plagioclase, orthoclase, and quartz as well as biotite and hornblende.

The Gray porphyry group includes six members: quartz diorite porphyry, Lincoln porphyry, Evans Gulch porphyry, Sacramento porphyry, Iowa Gulch porphyry, and Johnson Gulch porphyry. The last five are quartz monzonites. All the Gray porphyries appear to be closely related to one another in time and probably also in mode of origin. Moreover, their intrusion, especially that of the later members of the group, was apparently an immediate precursor of mineralization, to which the Johnson Gulch porphyry seems to have been the most closely related.

Quartz diorite poryhyry occurs as a single dike, about 10 feet thick, that trends N. 20° E. along the southwest slope of East Ball Mountain. It dips steeply southeast and can be traced northward for nearly a mile. It is a greenish-gray rock, very much darker than any of the others described except the Iowa Gulch porphyry. It contains only a few phenocrysts of feldspar and fewer of hornblende. It seems to be the only representative in the Leadville region of the monzonitic diorite porphyry of the Alma district described by Singewald and Butler.[19] It is here classified as a quartz diorite porphyry. The age of the quartz diorite porphyry is uncertain, but similar rock was inferred by Singewald and Butler[20] to be older than the other rocks of the Gray porphyry group. On the other hand, this quartz diorite porphyry dike may be of the same age as the "late white" porphyry, as it occupies fractures parallel to those occupied by the "late white" porphyry and apparently was formed during or just before the intrusion of the latter.

The Lincoln porphyry is the most distinctive member of the Gray porphyry group. It is characterized by numerous large, well-formed orthoclase crystals and even more numerous somewhat

[19]Singewald, Q. D., and Butler, B. S., Preliminary report on the geology of Mount Lincoln and the Russia Mine, Park County, Colorado: Colorado Sci. Soc., Proc., vol. 12, pp. 394-395, 1931.

[20]Singewald, Q. D., and Butler, B. S., Personal communication, 1938.

smaller but still very conspicuous bipyramidal quartz crystals in a light-pinkish-gray groundmass. The orthoclase phenocrysts are generally an inch or two long and those of quartz attain lengths of five-eighths of an inch. Smaller plagioclase, biotite, and hornblende phenocrysts, as well as minor amounts of other minerals, appear in the groundmass. Under the microscope the groundmass is seen to consist of sodic plagioclase (albite-oligoclase) and quartz. The rock is a quartz monzonite in composition.

In the Leadville district this rock forms two conspicuous sills each about 100 feet thick on the slopes of Little Ellen Hill, and thinner sills in the Weber (?) formation on the ridge between Prospect Mountain and Birdseye Gulch.

The Evans Gulch porphyry is light-pinkish-gray to light-greenish-gray, fine-grained, only slightly porphyritic, and of granitoid appearance. Its most distinctive mineral is black (?) hornblende, which forms needle-like crystals 0.2 mm or less in length. Other easily recognizable minerals are brown mica and white plagioclase (oligoclase-andesine). These three minerals, which constitute about 35 percent of the rock, are imbedded in a white, or light-gray, fine-grained groundmass of quartz and alkalic feldspar. This rock is a quartz monzonite.

Outcrops of the Evans Gulch porphyry are confined to the northern part of the district, in the neighborhood of Evans Gulch, Little Ellen Hill, and Prospect Mountain, where the rock occurs solely in the form of sills.

The Sacramento porphyry, like the Evans Gulch porphyry, is light-greenish-gray, but, unlike the Evans Gulch porphyry, conspicuously porphyritic. The principal phenocrysts are white plagioclase, clear quartz, and brown biotite, all about 0.1 inch or less in diameter, accompanied in places by small needles of dark-green hornblende and very thinly scattered large crystals of orthoclase. All these minerals are set in a gray-green, stony groundmass. The greenish tint of the rock is especially characteristic and is caused by secondary epidote and chlorite. Like the other Gray porphyries, the Sacramento porphyry is best classed as a quartz monzonite.

This rock was first distinguished by Emmons, who indicated Gemini Peaks, between Mounts Dyer and Sherman, as the type locality.[21] It is also well exposed on the eastern cliffs of Evans Amphitheater, where it forms a sill 500 feet thick.

The Iowa Gulch porphyry appears in two facies—one a typical porphyry, the other a breccia. The porphyry is the more common; it is a light-gray to brownish-gray non-clastic porphyry, distinguished by conspicuous well-crystallized phenocrysts of white feldspar and brown biotite in a dark-gray, stony groundmass, frequently characterized by flow structure.

The breccia or clastic facies, highly localized, shows a matrix of finely fragmental material containing sharp-edged rock fragments of the same composition as the porphyry and very rarely small blocks of the sedimentary rocks cut by the breccia. It has features similar to the "clastic dikes" of the Ouray district.[22] Though suggesting in some respects the rhyolite agglomerate previously described at Leadville,[23] it is clearly different, for the rock is more basic and petrographically most closely related to the quartz monzonites of the Gray porphyry group, as shown by the rather calcic variety of the plagioclase, the complete absence of orthoclase, the rarity of quartz, and the nearly parallel arrangement of feldspar needles in the groundmass. The clastic variety can be distinguished megascopically from the similar rhyolite agglomerate only by the predominating fragments of its own non-clastic facies. It is obviously slightly later than the denser variety, but is continuous with it and genetically closely related, and therefore is described here for convenience.

As its name implies, the Iowa Gulch porphyry is best exposed in Iowa Gulch. Here the type occurrence is a thick sill that lies under the Manitou limestone, about a mile west of the Hellena mine. The unusual clastic facies is well shown where the wagon road connecting Iowa and Empire amphitheaters crosses the 11,000-foot contour on the northern slope of Long and Derry Hill.

The Johnson Gulch porphyry shows many textural varieties, the differences being largely in the number and sizes of phenocrysts

[21] Emmons, S. F., Geology and mining industry of Leadville, Colorado: U. S. Geol. Survey Mon. XII, pp. 81-82, 1886.

[22] Burbank, W. S., Revision of geologic structure and stratigraphy in the Ouray district of Colorado, and its bearing on ore deposition: Colorado Sci. Soc., Proc., vol. 12, pp. 195-200, 1930.

[23] Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colorado: U. S. Geol. Survey Prof. Paper 148, pp. 55-59, 1927.

and the texture of the groundmass. Typically the rock is medium-gray and, next to the Iowa Gulch porphyry, is the darkest of the more common rocks of the Gray porphyry group. By contrast, its phenocrysts are chiefly light in color and consist of quartz crystals up to one-fourth of an inch in diameter, slightly smaller and more numerous white plagioclase crystals, and a few pink orthoclase crystals as much as as inch long. The feldspar crystals are unusually well formed. Some biotite and hornblende phenocrysts also occur; varieties differ in their content of these two minerals. The dense groundmass consists of very fine-grained quartz and plagioclase. Like most members of the Gray porphyry group, this rock is a quartz monzonite porphyry.

The Johnson Gulch porphyry is the most widespread variety of Gray porphyry in the Leadville district. It forms numerous dikes in Iowa Gulch and on Printer Boy Hill. These dikes are known to cut the "early white" porphyry and the Iowa Gulch porphyry, as well as a sill of Sacramento (?) porphyry on Long and Derry Hill, and are thus younger than those rocks. According to Emmons, Irving, and Loughlin,[24] large masses of closely similar Gray porphyry are cut by the Yak tunnel beneath Breece Hill, where they constitute at least a part of the obscure Breece Hill plug, which has never been mapped on the surface because of the high degree of alteration that has rendered its component rocks indistinguishable from adjacent altered porphyries. In the work of Emmons, Irving and Loughlin,[25] much of the Gray porphyry on Printer Boy Hill was referred to the Lincoln porphyry, but, though highly altered, this rock now seems best classed with the Johnson Gulch porphyry; no typical Lincoln porphyry containing well-formed quartz phenocrysts has been found on Printer Boy Hill.

Attention should be directed that Lovering and Goddard, in studies in the Front Range, concluded that a rock somewhat similar to the Lincoln porphyry of this paper is the youngest of the Gray porphyry group.[26] It is the opinion of this writer that Lovering

[24] Op. cit., p. 48, 1927.
[25] Op. cit., p. 48, 1927.
[26] Lovering, T. S., Geology and ore deposits of the Breckenridge mining district, Colorado: U. S. Geol. Survey Prof. Paper 176, pp. 15-16, 1934. Goddard, E. N., The influence of Tertiary intrusive structural features on mineral deposits at Jamestown, Colorado: Econ. Geol., vol. 30, pp. 372-373, 1935.

and Goddard's "Lincoln porphyry" corresponds more properly to the Johnson Gulch porphyry of this paper. The evidence for this contention cannot be presented in detail in this short paper.

RHYOLITE AND QUARTZ LATITE GROUP

The late group includes two members—the Little Union quartz latite and a rhyolite that occurs mainly as agglomerate. The Little Union quartz latite crops out near the head of Little Union Gulch, not far from the southern edge of the area mapped. There it forms two plugs of irregularly elliptical ground plan. In contrast with most of the other igneous rocks of the Leadville area, which are white or gray, the Little Union quartz latite has a brownish color, weathering to a darker rusty hue. The groundmass is stony to finely granular, has faintly visible flow lines, and is locally slightly vesicular; indeed, the texture suggests a flow, but the field relations show that both masses are intrusive. The rock contains conspicuous crystals of brown mica and less prominent crystals of white feldspar (poorly striated plagioclase) in moderate abundance.

The Little Union quartz latite contains inclusions of "early white" porphyry. It is believed to have risen along the Union or a related normal fault, which is known to cut Gray and White porphyries farther north. Moreover, it is fresher than the other porphyries, excepting the "late white" porphyry. It is thus younger than the "early white" porphyry and probably also younger than the Gray porphyries.

The rhyolite and rhyolite agglomerate were first described in Professional Paper 148.[27] In the study of the outlying parts of the Leadville region no outcrops of these rocks were found, but in several of the mine workings in Iowa Gulch agglomerate and rhyolitic tuff were seen. One exposure is in an old tunnel of the Ella Beeler group on the south side of Iowa Gulch due south of the new Hellena shaft, and other is in an abandoned tunnel whose portal is on the south slope of Printer Boy Hill, beside the "upper road," 800 feet northeast of the "Lilian" mine. In both places the agglomerate follows a fault and strongly resembles fault breccia, but flow lines can be seen in some places and prove the partly pyroclastic origin. Where flow lines are absent the fact that a great majority of the

[27]Op. cit., p. 55, 1927.

fragments are of rocks not adjacent to the exposed parts of the fissure but of rocks known to exist at considerable depth, is a strong indication of agglomerate.

This agglomerate appears to have been derived from explosions, largely gaseous under shallow cover, similar to those described by Burbank.[28] The agglomerate evidently is of late Tertiary age, for it contains fragments of definitely recognizable ore minerals which are believed to be of Miocene age. As ore deposition seems to have followed all other igneous rocks mentioned in the preceding description, except possibly the "late white" porphyry and the Little Union quartz latite, it is believed that the rhyolite and rhyolite agglomerate are the latest igneous rocks of the region.

STRUCTURE

A brief description of the outstanding structural features of the region is given below. Details are reserved for the final report.

REGIONAL STRUCTURE

The central part of the Mosquito Range, which includes the area here described, is part of the faulted eastern limb of the Sawatch anticlinorium whose axis trends northward along the crest of the Sawatch Mountains, the range west of the Leadville district. Along this axis pre-Cambrian rocks attain altitudes of more than 14,000 feet. The overlying Paleozoic sedimentary rocks have been eroded from the crest and east slope of the Sawatch Mountains, but are present throughout the width of the Mosquito Range. The west slope of the Mosquito Range is faulted into a number of blocks in each of which the prevailing dip of the sedimentary rocks is easterly.

Most of the faults are normal and trend nearly parallel with the regional strike of the beds. Though the dips and displacements of the faults vary, both as to amount and direction, their prevailing dips are westerly and generally their east walls relatively have been raised. Faulting has thus so largely compensated for the easterly dip of the sedimentary rocks that much of the high crest of the Mosquito Range, comparable in altitude to the Sawatch Range,

[28] Burbank, W. S., Revision of geologic structure and stratigraphy in the Ouray district, Colorado: Colorado Sci. Soc., Proc., vol. 12, pp. 195-200, 1930.

shows either pre-Cambrian granite or the lower Paleozoic rocks that immediately overlie it.

FOLDS

The faulted east limb of the great anticlinorium is modified by local folds. Some of these, for example the Weston, Tucson, and Colorado Prince, are anticlines with steep west limbs and moderately dipping east limbs and have been broken by steeply to moderately dipping reverse faults. Others are either shallow synclines that represent drag along the downthrow sides of normal faults or corresponding gentle anticlines on the upthrow sides. Folding is also suggested by the outcrop pattern, but this pattern has resulted from topographic irregularities of uniformly dipping, irregularly faulted beds.

FAULTS

The general fault pattern has been well described in Professional Paper 148.[29] There it was shown that the faults could be classified into four general groups: (1) faults related to Tertiary intrusions; (2) reverse faults and auxiliary faults accompanying regional folding; (3) normal faults subsequent to folding but preceding ore deposition; and (4) post-mineral normal faults. Besides actual faults there are many fissures of similar strike and dip along which no measurable movement has taken place. The larger of these fissures as well as the faults are shown on the geologic map. Finally, there are bedding plane faults, some of which represent minor movements supplementary to normal faulting, but others of which are the upward extensions of steeply dipping reverse faults, notably the Tucson Maid fault and a fault in the deeper workings of the Ibex mine. The amount of movement along these bedding-plane faults cannot be estimated unless their relations to related normal faults or to the cross-cutting parts of reverse faults are clearly defined.

In the discussion that follows, the major faults or fault complexes will be described very briefly—progressively from east to west. Incidental mention of mineralization along the faults is made in these descriptions, but the extent and significance of mineralization is more fully considered under "Suggestions for prospecting" (pages 73-79).

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[29]Op. cit., p. 62-106, esp., p. 63.

No new data were acquired on the following important faults recognized in the central part of the Leadville district: Colorado Prince,[30] Silent Friend, Adelaide, Emmet, and Valentine-Cloud City. For information regarding these faults the reader is referred to detailed descriptions given in Professional Paper 148.

The Sherman-Sheridan faults constitute a group of nearly horizontal thrusts that crop out along the west slope of Mount Sherman from the Continental Chief mine southward. They virtually coincide with bedding planes and are therefore not easily recognized. They are cut by more steeply dipping normal faults and parallel fissures.

The Liddia fault is best shown in the workings of the Liddia mine and on the south slope of Dyer Mountain where the base of the Leadville limestone is lifted relatively about 500 feet on the east side of the fault. It is a steeply dipping fault that branches in both directions and dies out southward on the western slope of Mount Sheridan.

The South Dyer fault, a reverse fault similar in strike and displacement to several of the thrusts in the central Leadville district, strikes N. 40° to 45° W. and dips 55° to 60° or less N. E. It has been traced from the Mosquito fault southeast to Mount Sherman where it appears to pass into a fold. It may be the equivalent of the Colorado Prince or some deeper reverse fault west of the Mosquito fault.

Several smaller faults are well exposed on the north and south slopes of East Ball Mountain. They show no pronounced effects of mineralization, but subparallel fissures near them have contained small bodies of gold ore.

The Mosquito fault is one of the outstanding geologic faults of the Mosquito Range and of the State. Through much of its extensive length it brings pre-Cambrian rocks on the east against Mississippian and Pennsylvanian rocks to the west. From Empire Gulch south it appears either to cut off or follow the same course as the Weston fault. From the saddle south of Little Ellen Hill northward it forms occasional branches which reunite farther on. The most

[30]See, however, Behre, C. H., Jr., Revision of structure and stratigraphy in the Mosquito Range and the Leadville mining district, Colorado: Colorado Sci. Soc., Proc., vol. 12, pp. 53-57, 1929.

westerly of these branches retains the greatest displacement and extends along the western front of the Mosquito Range to Climax,[31] 13 miles north of Leadville, and beyond. The result of the splitting is especially conspicuous in the northern head of Evans Amphitheater, where at least four faults can be recognized, the shortest having a length of 1.25 miles. All except the easternmost of them have the effect of lifting the east side and near or along each there is some evidence of mineralization. Between these branches are several minor faults, which are well exposed in the cliffs near the Daisy mine, south of the steepest part of the Mosquito Pass road.

In the area herein described the main Mosquito fault is, at least locally, mineralized; it may possibly also have undergone some postmineral movement, as has already been suggested.[32] There are three good exposures of the beds on either side of the fault—(1) where the fault crosses the Mosquito Pass highway, (2) on the south side of the saddle between Little Ellen Hill and West Dyer Mountain, and (3) on the southeastern slope of Empire Hill. In all three places the west side shows close compression and upturning of the beds, and the crumpling of these beds is strongly suggestive of a reverse fault. The actual dip of the fault plane is seen in one place only, the southeastern slope of Empire Hill, where the dip is clearly to the east. The statement that this is a normal fault, as expressed in Professional Paper 148,[33] is therefore no longer tenable.

The Ball Mountain fault, which should be designated more properly the "Ball Mountain complex," extends from a junction with the Mosquito fault on Long and Derry Hill northward across the summit of Ball Mountain, where adjacent masses of porphyry have been highly silicified. Its northern end is related confusedly to a group of reverse and normal faults near South Evans Gulch.

The Winnie-Luema and associated faults, which lie between the Ball Mountain and Weston faults in the neighborhood of Evansville, contain veins that have been very productive. To the north a few faults of small throw have been mapped on the south slopes of

[31]Butler, B. S., Vanderwilt, J. W., and Henderson, C. W., The Climax molybdenum deposit, Colorado: U. S. Geol. Survey Bull. 846-c, p. 218, 1933. Butler, B. S., and Vanderwilt, J. W., The Climax molybdenum deposit of Colorado, with section on history, production, metallurgy, and development by C. W. Henderson: Colorado Sci. Soc., Proc., vol. 12, p. 332, 1931.

[32]Emmons, S. F., Irving, J. D., and Loughlin, G. F., Op. cit., plate 39 and p. 80, 1927. Butler, B. S., Vanderwilt, J. W., and Henderson, C. W., Op. cit., p. 219, 1933.

[33]Op. cit., p. 80.

Prospect Mountain near Lake Isabelle. The southwesternmost of these, 0.4 miles west of the Great Eastern mine, is probably the northerly continuation of the Winnie-Luema fault.

The Weston, Union, and Hellena faults form a structural complex in the vicinity of Iowa Gulch. For purposes of this preliminary discussion it is best to consider the Weston fault as continuing southward to unite with the Mosquito fault about a mile south of the crest of Upper Long and Derry Hill. The ground east of the Union fault is considerably broken in Iowa Gulch and on Upper Long and Derry Hill and, as exposures there are obscure, the mapping in this critical region is rather uncertain. An eastern branch of the Weston fault, here designated the Hellena fault, trends northward through the Hellena mine, where it dips steeply east and brings pre-Cambrian on the east against Weber (?) and related rocks on the west. Its northward continuation may be the Sunday vein.[34] In the westerly workings of the Hellena mine a fault, inferred to be the main Weston fault, also dips east and brings Weber (?) on the east against Paleozoic rocks on the west. The net displacement along this fault is normal, but the drag along it suggests a reverse movement.

Briefly, the writer's interpretation of this fault complex is as follows: The Union fault, readily followed from the head of Little Union Gulch northeastward to Empire Gulch, breaks into several branches which cross and offset the Weston fault on the southwestern slope of Upper Long and Derry Hill. These branches of the Union fault then end about a mile farther northeast, as can be seen on the northern slope of Upper Long and Derry Hill. The Weston fault, on the other hand, extends northward from its junction with the Mosquito fault in Empire Gulch, is slightly offset by the Union fault as just mentioned, and then splits into two branches, the eastern of which, the Hellena fault, continues about due north. The western or main Weston fault takes a northwestward course. It splits again near the bottom of Iowa Gulch, about 0.4 mile southwest of the Hellena mine, but the two parts reunite some 3,500 feet farther north. Thence the main Weston fault crosses Printer Boy Hill and continues northward as mapped in Professional Paper 148. A mile south of the northern edge of the area it is offset by a north-

[34]Behre, C. H., Jr., Revision of structure and stratigraphy in the Mosquito Range and the Leadville district, Colorado: Colorado Sci. Soc., Proc., vol. 12, pp. 43-45, 1929.

eastern branch of the Iron fault, and is lost still farther north on the southwestern slope of Prospect Mountain.

The Iowa or Iowa Gulch fault, though not exposed, is indicated by the observation that Weber (?) formation and Johnson Gulch porphyry crop out east of the Hellena fault a short distance north of the Iowa Gulch road, whereas pre-Cambrian and Cambrian rocks are exposed in openings 0.2 mile south of the road. It has been described in Professional Paper 148,[35] as well as elsewhere[35] and in respect to this fault the present map differs only slightly from earlier maps. It is probable that the great relative drop northeast of the Iowa fault is the cause of the apparent reversal of displacement along the Weston fault north of Iowa Gulch.

The Mike and Pilot faults were shown as joining virtually at the southern edge of the region mapped in detail in Professional Paper 148. This relationship is confirmed in the work here described. As the fault that continues south from the junction dips east and has a relatively raised east wall, it is correlated with the Mike fault. This interpretation is in agreement with that given in Professional Paper 148.[36] In Iowa Gulch and thence southward many lesser faults lie just east of the Mike fault and trend parallel with it. The Mike fault ends against the Union fault on the northwestern slope of Empire Hill.

The Dome and Iron faults, two major faults whose extent in the immediate environs of Leadville had previously been mapped, have been followed southward by the writer. Exposures are poor, so their trends are uncertain, but suggestions of the Iron fault have been found as far south as the northeastern branch of Thompson Gulch, and the probable position of the Dome fault is indicated by offsets in Cambrian quartzite on the northern slope of Empire Gulch about a mile northeast of the Hatch Ranch. In this southern part of the mapped area, these two faults are indicated by dashed lines to show the uncertainties in their mapping. At its northern end the Iron fault seems to break into several branches, the chief of which trends strongly northeast, offsetting the Weston fault, as previously mentioned.

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[35]Op. cit., pp. 78 and 95 and Pl. 11. Behre, C. H., Jr., op. cit., pp. 39 and 45, 1929.
[36]Op. cit., plate 39.

The Mikado and Pendery faults were mapped on Plate 13 of Professional Paper 148 in great detail.[37] North of the area there shown the Mikado fault is still recognizable near the Chicago Boy mine, but cannot be traced farther because of till cover and the appearance of a sill of Johnson Gulch porphyry on both sides of its projected position. Despite suggestions to the contrary, it cannot well extend into the Canterbury tunnel as it lies parallel with the tunnel and too far to the southwest.

The main Pendery fault appears to extend north of the area shown on Plate 13 of Professional Paper 148 at least as far as the southeastern slope of Prospect Mountain. Subparallel to this fault are several lesser ones, northwest of the Chicago Boy, which displace in varying amounts sills of "early white" porphyry and the Leadville limestone; their exact position and extent are uncertain. The most northwesterly of this group of faults is found in the Canterbury tunnel.

SUGGESTIONS FOR PROSPECTING

In addition to Professional Paper 148,[38] two recent publications, arising from the cooperative geologic work in the Leadville district and vicinity, have dealt especially with prospecting near Leadville.[39] The purpose of the following brief statement is to indicate additional parts of the Leadville mining district where further search for ore seems worthy of consideration. The recommendations are based on geologic relations and upon exploration already carried out. For purposes of this discussion, the region shown in detail on Plate 13 of Professional Paper 148 is here designated the "central Leadville district." With regard to that part of the district, nothing can be added here. What follows deals strictly with the surrounding or outlying part of the Leadville district.

In general, the principal centers of mineralization and the largest ore bodies are in the central Leadville district, but there are minor centers in the outlying parts of the area, which hold considerable promise for the presence of somewhat smaller ore bodies.

[37]Op. cit., See also pp. 87 and 89-90.
[38]See especially pp. 177-219.
[39]Loughlin, G. F., Guides to ore in the Leadville district, Colorado: U. S. Geol. Survey Bull. 779, 1926. Behre, C. H., Jr., Revision of structure and stratigraphy in the Mosquito Range and the Leadville district, Colorado: Colorado Sci. Soc., Proc., vol. 12, pp. 37-57, 1929.

These bodies are likely to be rich in lead, zinc, and silver and, probably to a lesser extent, in gold; and should either fill fissures or replace limestone. Early exploration has indicated that the outlying ore bodies are most prominent near the major pre-mineral faults and are most likely to pass from fissure fillings into replacement bodies at the contacts between the Leadville limestone and the overlying sills or between the Leadville limestone and the Weber (?) formation. Such ore bodies are well typified by the Continental Chief[40] and Hilltop mines. They are characterized by silver in association with galena, sphalerite, and pyrite, and by such gangue minerals as barite and carbonates.

Northern area.—North of the central Leadville district, the principal rocks exposed are sandstone and shale beds of the Weber (?) formation and sills of Gray porphyry. Exploration from the surface is difficult as exposures are poor and no strata that indicate any distinctive horizons have been recognized. Geologic structure, therefore, cannot be deciphered at the surface and drilling will be necessary to determine the positions of any productive beds, especially the Leadville limestone and Dyer dolomite member of the Chaffee formation. It is nevertheless possible that exploration northward and eastward from the Yak tunnel in the neighborhood of the Diamond and Resurrection mines may open favorable territory.

Mosquito Pass and Evans Amphitheater.—The Mosquito fault and its subsidiaries in this area are at least locally mineralized. Careful search along them is merited, especially where, 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, Leadville limestone lies close to the main Mosquito fault or between any two minor faults of the Mosquito fault zone.

The southerly head of Evans Amphitheater also seems to merit some study, though showings there in the past have not been highly encouraging. As indicated by several small workings in this locality, the most favorable conditions are at the contact between the Leadville limestone and the overlying thin band of Weber (?) formation or the sills of porphyry.

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[40]Behre, C. H., Jr., op. cit., pp. 51-52.

Iowa Amphitheater.—This area is more promising than those mentioned above. It is characterized by much shattering. The Dyer, Liddia, and South Dyer faults are all major fractures and the last two show large displacements. Reverse faults on the east wall of the northern head of Iowa Amphitheater are also noteworthy; they are here called the Sherman faults; throughout most of their extents they are nearly parallel with the bedding planes. The Sherman and South Dyer faults contain silver-lead-zinc ore with a large content of barite. High-grade ore has been produced in the Continental Chief mine which lies near a minor gently-dipping thrust. Here as elsewhere exploratory mining should first seek one of the northeast-trending mineralized fissures, and then raise or sink along it to the top of the Leadville limestone.

The Hilltop mine, three-quarters of a mile northeast of Mount Sheridan and thus just a little outside the area here described, contained a highly productive body of zinc carbonate and galena-sphalerite-silver ore. The ore lay along fissures parallel in strike with those on the west slope of Mount Sherman. Structural control of this ore body was essentially the same as that of ore bodies in Iowa Amphitheater.

Locally, as on the northern slope of North West Sheridan Peak and on the southern slope of East Ball Mountain, small bodies of gold ore have been mined. They lay along fissures in pre-Cambrian and Cambrian rocks. Search may well reveal similar ore bodies.

Peerless and Horseshoe Mountains.—Along the crest of the range from Mount Sheridan south to Horseshoe Mountain, ore has been found in small but productive deposits, chiefly at the contact between the Leadville limestone and either the "early white" porphyry or the base of the Weber (?) formation, here a quartzitized sandstone. The most promising places for search are along the fractures that cut across the beds, such as those near the Peerless mine, at the prospects midway between Mount Sheridan and Peerless Mountain, and at the pits half a mile north of Horseshoe Mountain along the range crest. This is an area that merits careful exploration.

Head of Empire Amphitheater.—This territory, on the whole, is less likely to contain ore, 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, but evidently have not encouraged further prospecting.

Empire Gulch between Mitchell Ranch and Empire Hill.—There has been extensive prospecting in this area, especially along the Mike fault, north of its junction with the Union fault. Despite its relative inaccessibility, this is one of the most promising parts of the area surrounding the central Leadville area. Especially interesting are the prospects about 1½ miles due west of the crest of Empire Hill, where, with an "early white" porphyry sill above, the Leadville limestone is considerably shattered, not only by faults transverse to the strike, but also by others, unquestionably of pre-mineral age, that parallel the strike and almost parallel the bedding planes. The structural situation is thus analogous to that on the northeast wall of Iowa Amphitheater. Here are several showings of silver-bearing galena, relatively rich, as indicated by assays, but lacking continuity, at least as exposed in shallow workings or at the outcrop.

Iowa Gulch south of Printer Boy Hill.—This area contains the "Lilian," Rex, and Mansfield workings. Of special promise is the region east of the Mike fault, as this fault is known to be of pre-mineral age and shattered ground along it may have served as a channel for ore-forming solutions; moreover, the ground between it and the Doris shaft, three-fourths of a mile east, is heavily shattered and cut by dikes of the Johnson Gulch porphyry, the variety of Gray porphyry that is here closely associated with ore. Apparently a small plug of Johnson Gulch porphyry, similar to the Breece Hill stock to the north, cuts the "early white" porphyry sill exposed west of the Mike fault. By analogy, fissures in or close by such a plug should favor mineralization. A short distance north are the once highly productive workings of the "Lilian" and Steel Spring mines. Finally the exposures are generally fair and exploration at definite horizons is thus not difficult.

For these reasons the numerous fractures and the dikes that fill many of the fractures on both sides of Iowa Gulch deserve careful search for more ore. The arsenopyrite found on the dumps or shafts near the First National mine strongly suggests mineral deposition at a temperature higher than usual for this area and suggests a center of mineralization nearby.

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 formerly extensively worked. Several of these, especially the Hellena, have yielded rich ore. This area is a favorable place for search north of the Iowa fault and at depth below the Leadville limestone; another favorable place is west of the Weston fault in the Leadville limestone below the thick "early white" porphyry sill which here is the bedrock that underlies the gravel floor of Iowa Gulch. Preliminary drilling is favored. In this area, heavy flows of underground water make dewatering and sinking costly.

General suggestions.—A few generalizations may be made to guide in prospecting; however, each has noteworthy exceptions.

First, the most favorable horizon is the top of the Leadville limestone, especially where it is capped by a relatively impervious rock. This horizon is preferable to deeper horizons in the Leadville formation and in the Dyer and Manitou, partly because the more massive Leadville is more brittle than the slightly more shaly lower limestones. More important, however, as a factor favoring the upper Leadville limestone, is the effect of impervious rocks (basal shale of the Weber (?) formation or thick sills of "early white" porphyry) immediately above the topmost Leadville strata.

Even in the more richly mineralized central Leadville district these lower limestone horizons have been well mineralized only locally, generally near major faults or fissures that served as conduits and under local thick sills. Until recently the most promising condition was believed to be a capping of one of the porphyries. As suggested above, it is now recognized that the lowest shaly horizon of the Weber (?), in many places highly carbonaceous, is equally favorable, and much the same may be said of a basal quartzitized sandstone which, in places, as on the upper western slope of the Mosquito Range south of Mount Sheridan, seems to represent the basal facies of the Weber (?) formation.