SUGGESTIONS FOR PROSPECTING IN THE ALMA DISTRICT, COLORADO[1]

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and
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[1]Published by permission of the Director of the U. S. Geological Survey, the Colorado Geological Survey Board, and the Colorado Mining Association.
[2]Assistant Geologist, U. S. Geol. Survey.
[3]Geologist, U. S. Geol. Survey.

Introduction

The location of the Alma district is shown in Figure 1. Since the summer of 1928 detailed study of the geology of this region has been in progress as a part of the program of the Colorado Metal Mining Association, the State of Colorado, and the United States Geological Survey. As the work progressed papers have been published to make the information available.[4] Papers of more technical nature have also been

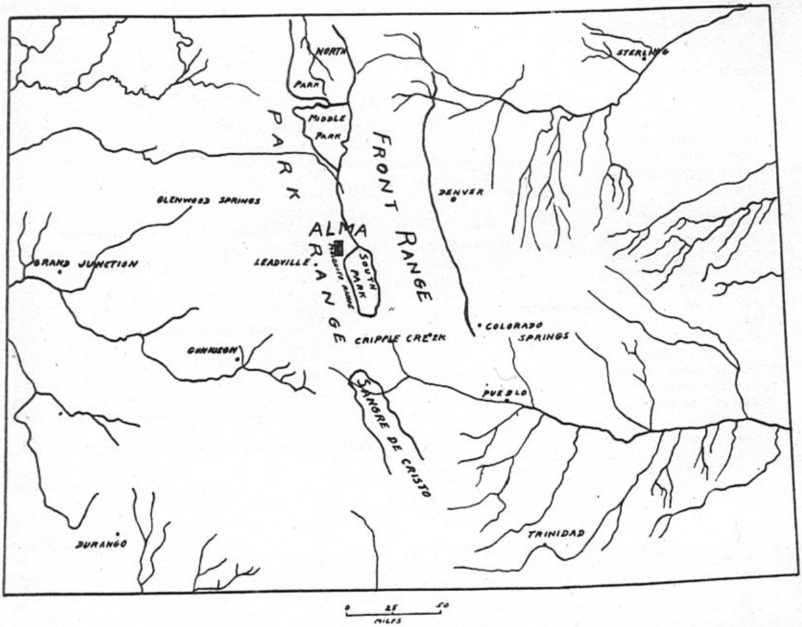


Figure 1.—Index map of Colorado showing location of Alma district.

published.[5] In addition, there are now in preparation for pub-

[4] Singewald, Q. D., and Butler, B. S., Preliminary geologic map of the Alma mining district, Colo.: Colorado Sci. Soc. Proc., vol. 12, no. 9. pp. 295-308, 1930; Preliminary report on the geology of Mount Lincoln and the Russia mine, Park County, Colo.: Idem, no. 12, pp. 389-406, 1931.

[5] Singewald, Q. D., Depositional features of the "Parting" quartzite near Alma, Colo.: Am. Jour. Sci., 5th ser., vol. 22, pp. 404-413, 1931; Alteration as an end phase of igneous intrusion in sills on Loveland Mountain, Park County, Colo.: Jour. Geology, vol. 40, pp. 16-29, 1932; Igneous history of the Buckskin Gulch stock, Colo.: Am. Jour. Sci., 5th ser., vol. 24, pp. 52-67, 1932.

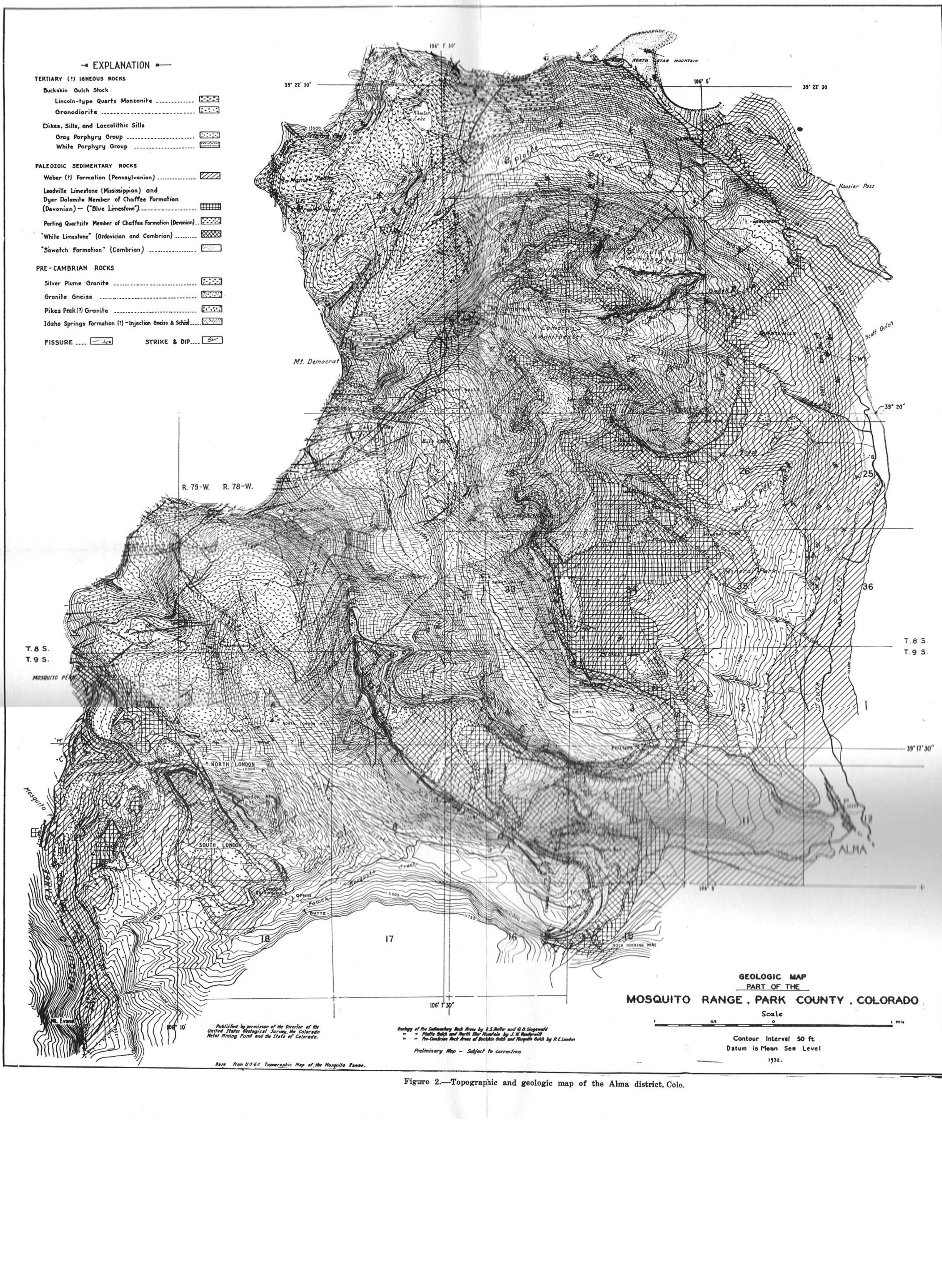
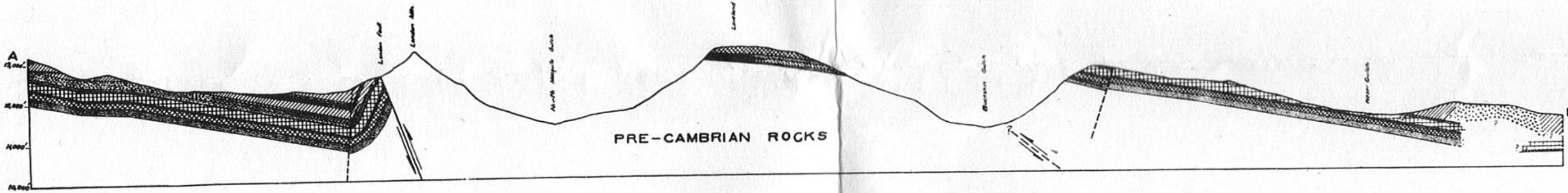


Figure 2.—Topographic and geologic map of the Alma district, Colo.



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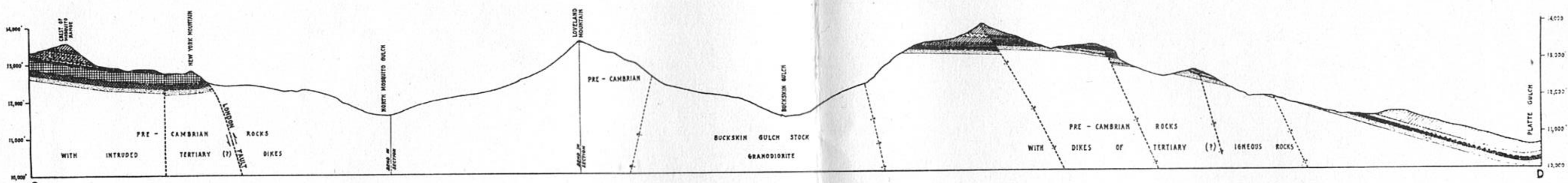

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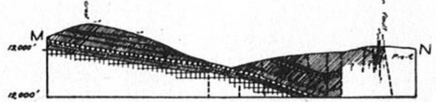

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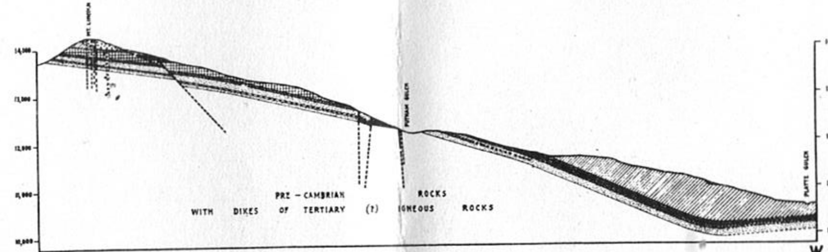

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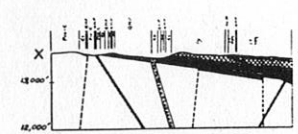
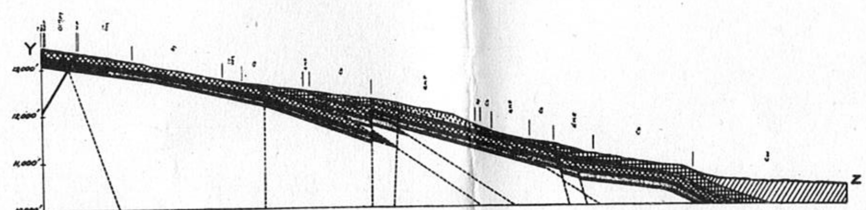


SECTION X-Y
THROUGH LOVELAND
MOUNTAIN



SECTION Y-Z THROUGH LOVELAND MOUNTAIN

lication by the United States Geological Survey a report on the Paleozoic formations of the Mosquito Range, by J. Harlan Johnson, and a detailed report on the ore deposits along the London fault, by the authors of the present paper.

To supplement the present paper, a detailed areal geologic map, on the scale of 1 inch = 1,000 feet, has been published by the Colorado Scientific Society.[6] Figure 2 is a map reduced from the larger, more detailed map. The work on which these maps are based has been confined to the region between Mosquito Gulch and North Star Mountain. John W. Vanderwilt mapped and studied the Platte Gulch area, largely of pre-Cambrian rocks, and Robert E. Landon the pre-Cambrian areas of Buckskin and Mosquito Gulches. Robert D. Butler ably assisted from 1928 to 1930.

The important general reports on the area previous to this study were the monograph on Leadville by Emmons,[7] the revision of that report by Emmons, Irving, and Loughlin,[8] and the report on the Alma district by Patton, Hoskin, and Butler.[9] Numerous less general papers have been published on parts or features of the district.

The writers are deeply indebted to the mining men of the district for much information and for courtesies that aided the work. In this preliminary report this general acknowledgment must take the place of an attempt to list those who have assisted. The writers are likewise indebted to their colleagues in the Colorado work and to Mr. G. F. Loughlin of the Washington office of the U. S. Geological Survey for assistance and suggestions.

The main purpose of this paper is to suggest future possibilities of mining in the district. With this in mind, the salient features of the distribution and occurrence of the known deposits are discussed in a manner to emphasize their

[6]Price $7.50.
[7]Emmons, S. F., Geology and mining industry of Leadville, Colo.: U. S. Geol. Survey Mon. 12, 1886.
[8]Emmons, S. F., Irving, J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colo.: U. S. Geol. Survey Prof. Paper 148, 1927.
[9]Patton, H. B., Hoskin, A. J., and Butler, G. M., Geology and ore deposits of the Alma mining district, Park County, Colo.: Colorado Geol. Survey Bull. 3, 1912.

bearing on the search for new ones. It is not the purpose of this preliminary paper to discuss in detail the origin and mineralogy of the deposits nor to present the complete evidence for all the statements made, if it is of a highly technical nature; these matters will be treated in the final report.

Rocks

The consolidated rocks of the district include pre-Cambrian schists, gneisses, and granites, Paleozoic sedimentary rocks, and Tertiary intrusive rocks.

Pre-Cambrian Rocks

Schists.—The oldest rocks in the district are schists of diverse composition. Quartz-mica schist is by far the most abundant type, but sillimanite and hornblende schists are also present. A few lenses, composed mainly of quartz, are doubtless metamorphosed quartzite. This group of schistose rocks is probably to be correlated with the Idaho Springs formation, of the Georgetown quadrangle, which Ball[10] regarded as derived largely from the metamorphism of sedimentary rocks. As a result of lit-par-lit injection or replacement, the schists almost everywhere are transformed into injection gneiss, with which they are included on the geologic map.

Gneisses.—Injection gneiss, which locally grades into nearly pure schist, is by far the most widespread of the gneissic rocks. A variety of gneiss containing coarse, knotty-looking masses of orthoclase occurs in Platte Gulch in proximity to pre-Cambrian granite. Vanderwilt regards it as a variety of the schist and injection gneiss group, as he has found all gradations from normal schist to rock that is so thoroughly granitized as to be inseparable from normal granite. A very light-colored granite gneiss in Buckskin Gulch is regarded by Landon as an early aplitic facies of the Silver Plume granite.

Granites.—Pre-Cambrian granites in the area are of two types—a coarse-grained porphyritic pink biotite granite,

[10]Spurr, J. E., and Garrey, G. H., Economic geology of the Georgetown quadrangle (together with the Empire district), Colo., with general geology by S. H. Ball: U. S. Geol. Survey Prof. Paper 63, p. 37, 1908.

which has been correlated with the Pikes Peak granite, and a finer-grained porphyritic gray granite, which has been correlated with the Silver Plume granite of the Georgetown area. The former is limited to a few small masses; the latter is exposed over large areas.

Distribution.—Pre-Cambrian formations, as shown in Figure 2, are most extensively exposed along the crest of the range, where erosion has removed the Paleozoic sedimentary rocks, and in the deeply eroded canyons extending eastward from the crest. Gneisses and schists predominate toward the east, and granite toward the crest of the range.

Paleozoic Sedimentary Rocks

The authors, in another paper,[11] have described the Paleozoic sedimentary rocks, and J. Harlan Johnson is publishing a discussion of the stratigraphy of the Mosquito Range. This paper, therefore, presents only a columnar section (fig. 3) and a chart (fig. 4) showing thicknesses at different localities in the district.

The distribution of the sedimentary rocks is shown on the accompanying generalized map (fig. 2). They occupy the tops of the ridges sloping up to the crest of the range. In the northern part of the area they have been eroded from the ridges for a distance of 1 to 2 miles east of the range crest. South of Mosquito Gulch, however, they are present to the crest of the range. Along the east flank of the range the Paleozoic rocks form a continuous band, with the Weber (?) formation cropping out at the surface.

Tertiary Intrusive Rocks

Tertiary intrusive rocks occur in dikes, sills, and a stock. In all these modes of occurrence they range in composition from diorite to granite. The following table gives the chief characteristics by which the different rock units may be distinguished in the field.

---

[11]Singewald, Q. D., and Butler, B. S., Preliminary geologic map of the Alma mining district, Colo.: Colorado Sci. Soc. Proc., vol. 12, no. 9, pp. 295-303, 1930.

Classification of the Tertiary igneous rocks of the Alma district, Colorado:

Buckskin Gulch Stock

Rock units	Characteristic megascopic appearance	Diagnostic features
Quartz monzonite.	Large crystals of pink orthoclase and, in places, quartz in a medium-grained matrix composed of plagioclase, quartz, orthoclase, biotite, and hornblende. Transitional to both Lincoln porphyry and pegmatite. Cut by numerous thin aplite dikes.	Pinkish color and porphyritic texture owing to large pink orthoclase crystals.
Granodiorite.	Light to medium gray, fine-grained to medium-grained, essentially equigranular rock in which plagioclase, quartz, biotite, hornblende, and, in places, orthoclase are readily recognized. Ranges in composition from quartz monzonite to diorite. Cut by numerous thin aplite dikes and, at places, by pegmatite dikes.	Gray color, equigranular texture, and absence of large pink orthoclase crystals.

Dikes, Sills, and Laccolithic Sills

Rock units		Characteristic megascopic appearance	Diagnostic features
Late white porphyry.		In places has sheeted structure; soft and compact whitish-gray groundmass; rare to fairly numerous phenocrysts of feldspar, quartz, and dark muscovite.	Some varieties distinguishable from early white porphyry by means of feldspar phenocrysts; other varieties indistinguishable.
Gray porphyry group.	Granite porphyry.	Light-gray fine-grained rock that appears almost equigranular to the naked eye; quartz, feldspar, and biotite usually recognizable. Most occurrences have chilled margins that resemble the late white porphyry. Occurs only in a few dikes in Platte Gulch.	Light color and small size of phenocrysts.
	Lincoln porphyry.	Medium-gray groundmass; numerous medium-sized phenocrysts of plagioclase, quartz, and biotite, and scattered pink euhedral orthoclase crystals, half an inch to several inches in length.	Large pink orthoclase crystals.
	Quartz monzonite porphyry.	Most occurrences are considerably altered; medium greenish-gray groundmass; numerous phenocrysts of plagioclase, biotite, quartz, and hornblende.	Altered appearance, medium color, abundance of visible quartz, scarcity of hornblende.
	Monzonitic diorite porphyry.	Fresh appearance; dark-gray groundmass; numerous phenocrysts of plagioclase, hornblende, biotite, and quartz.	Fresh appearance, dark color, abundance of hornblende, rare visible quartz.
Early white porphyry.		Soft and compact whitish-gray groundmass; extremely rare phenocrysts of quartz and dark muscovite.	White color, scarcity of phenocrysts.

GENERAL STRATIGRAPHIC COLUMN OF THE ALMA DISTRICT, COLORADO

UNITS USED IN FIELD MAPPING	LITHOLOGIC ZONES	THICKNESS FEET	DESCRIPTION	DIAGRAMMATIC COLUMN	UNITS AS ADOPTED BY THE COMMITTEE ON GEOLOGIC NAMES		AGE
WEBER (?) FORMATION		1800 ±	Interbedded quartzite, conglomerate, grit, arkose shale, and occasional limestone, all micaceous. Some shale highly carbonaceous. Shale predominates near base, arenaceous beds in upper part.		WEBER (?) FORMATION		PENNSYLVANIAN
					Hiatus		
"BLUE LIMESTONE"	Upper limestone zone	0-160	Blue to black, mostly dense-textured, massive-bedded dolomitic limestone. Shatters easily. Weathers with pitted surfaces and breaks into blocky fragments. "Zebra-rock", chert, and limestone-breccia are common.		LEADVILLE LIMESTONE		MISSISSIPPIAN
	Quartzite zone	0-8	Fine-grained to dense "cherty looking" white quartzite. Extremely lenticular.				
					Hiatus		
	Lower limestone zone	40-78	Fairly thin-bedded, mostly dense, white and blue dolomitic limestone. White beds weather cream-colored. Exposed surfaces generally smooth.		DYER DOLOMITE MEMBER	CHAFFEE FORMATION	DEVONIAN
PARTING QUARTZITE		0-55	Cross-bedded and conglomeratic quartzite and sandy limestone. Quartz pebbles subangular. Locally, slightly shaly. Weathers light to dark brownish gray.		PARTING QUARTZITE MEMBER		
					Hiatus		
"WHITE LIMESTONE"	Upper limestone zone	0-130	Thin-bedded white and medium blue, mostly "crystalline" dolomitic limestone. Weathers light gray, developing siliceous ribbing. Breaks to slabby fragments. Locally, slightly shaly at top.		MANITOU LIMESTONE		ORDOVICIAN
	Shaly zone	12-27	Interbedded dolomitic limestone, shaly limestone, and limy shale. Limestone weathers brown, shale green.		PEERLESS SHALE MEMBER	SAWATCH QUARTZITE	CAMBRIAN
	Lower limestone zone	15-30	Drab to brownish weathering limestone, dolomitic and somewhat sandy, with numerous limy shale partings.				
So-called SAWATCH FORMATION	Shaly zone	18-30	Thin-bedded, almost flaggy dolomitic limestone and shale. Upper limestones contain "red casts". Limestone weathers brown, shale green.				
	Upper limy zone	15-30	Brownish-weathering dolomitic limestone with numerous shale partings.				
	Purple quartzite zone	2-15	Purple to nearly black quartzite. Slightly cross-bedded. Contains tiny angular quartz pebbles.				
					Hiatus (?)		
	Upper white quartzite zone	6-14	Fairly thick bedded, white fine-grained quartzite.				
	Lower limy zone	9-13	Thin-bedded series of quartzite, limy quartzite, sandy limestone, shale, and, rarely, limestone. Weather brownish and "sandy-looking".				
	Lower white quartzite zone	45-90	Fairly thick bedded, white, fine-grained quartzite. A few beds have small quantities of carbonate cement. At base is a white quartzite conglomerate with pebbles less than 1" in diameter.				
PRE-CAMBRIAN			Schist, injection gneiss, granite, and pegmatite.				PRE-CAMBRIAN

Figure 3.—General stratigraphic column of the Alma district, Colorado.

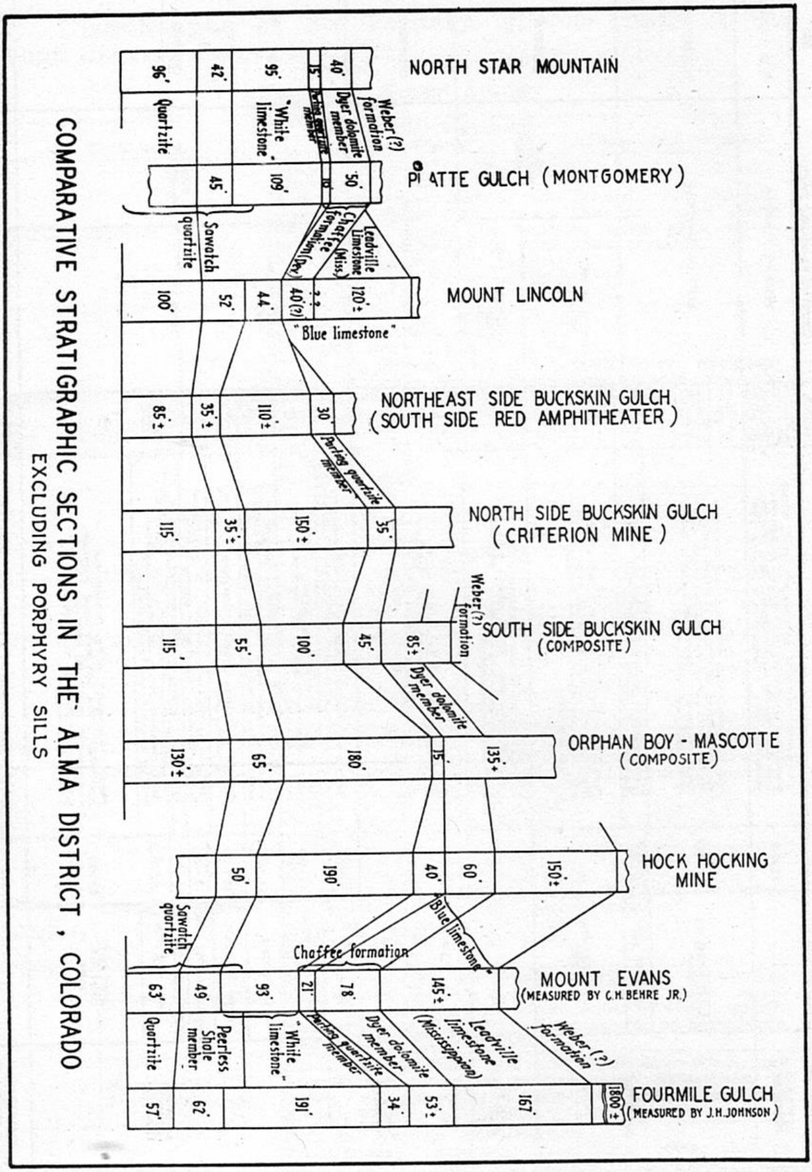


Figure 4.—Comparative stratigraphic sections in the Alma district, Colorado.

Distribution.—In distribution some difference should be noted. The early white porphyry is confined mainly to the southwestern part of the area, west of the London fault; moreover, its distribution farther south is analogous to that in the Alma district, for, as shown by Plate 11 of the Leadville professional paper, only one thin sill has been mapped east of the London fault south of Mosquito Gulch. The late white porphyry is mainly confined to a belt of dikes extending northeastward from the head of North Mosquito Gulch. The Lincoln porphyry is extensive in the eastern part of the area, but is absent in the sedimentary rocks between the Mosquito Gulch fault and the crest of the range. The monzonitic diorite porphyry is abundant only on the lower part of Loveland Mountain, but the quartz monzonite porphyry is fairly abundant throughout the district.

Sills occur in all the sedimentary formations, but throughout the Alma district, as well as at Leadville, by far their greatest development is in the basal part of the Weber (?) formation. The thickest and most extensive sills occur south and west of London Mountain, in the southern part of the district. Perhaps next in extent is the sill-like body in the east-central part of the district, in the vicinity of Windy Ridge, extending from Quartzville Creek to Buckskin Gulch. Third is the thick sill cropping out on Mount Lincoln and Mount Bross. Other thick intrusions, which have not been mapped in detail, are known to exist at Beaver Ridge and at Bald Hill and in the region to the southeast.

Dikes are confined mainly to the pre-Cambrian rocks, yet some occur in the sedimentary rocks. They are most abundantly exposed in a belt not more than 3 miles wide, extending in a southwesterly direction from North Star Mountain toward Leadville. Their prevailing trend is northeasterly, approximately parallel with the belt, although within the schist areas there is a tendency for the dikes to strike parallel with the schistosity. The dikes are shown on the large-scale map that supplements this paper, but only the most continuous ones are shown in **Figure 2**.

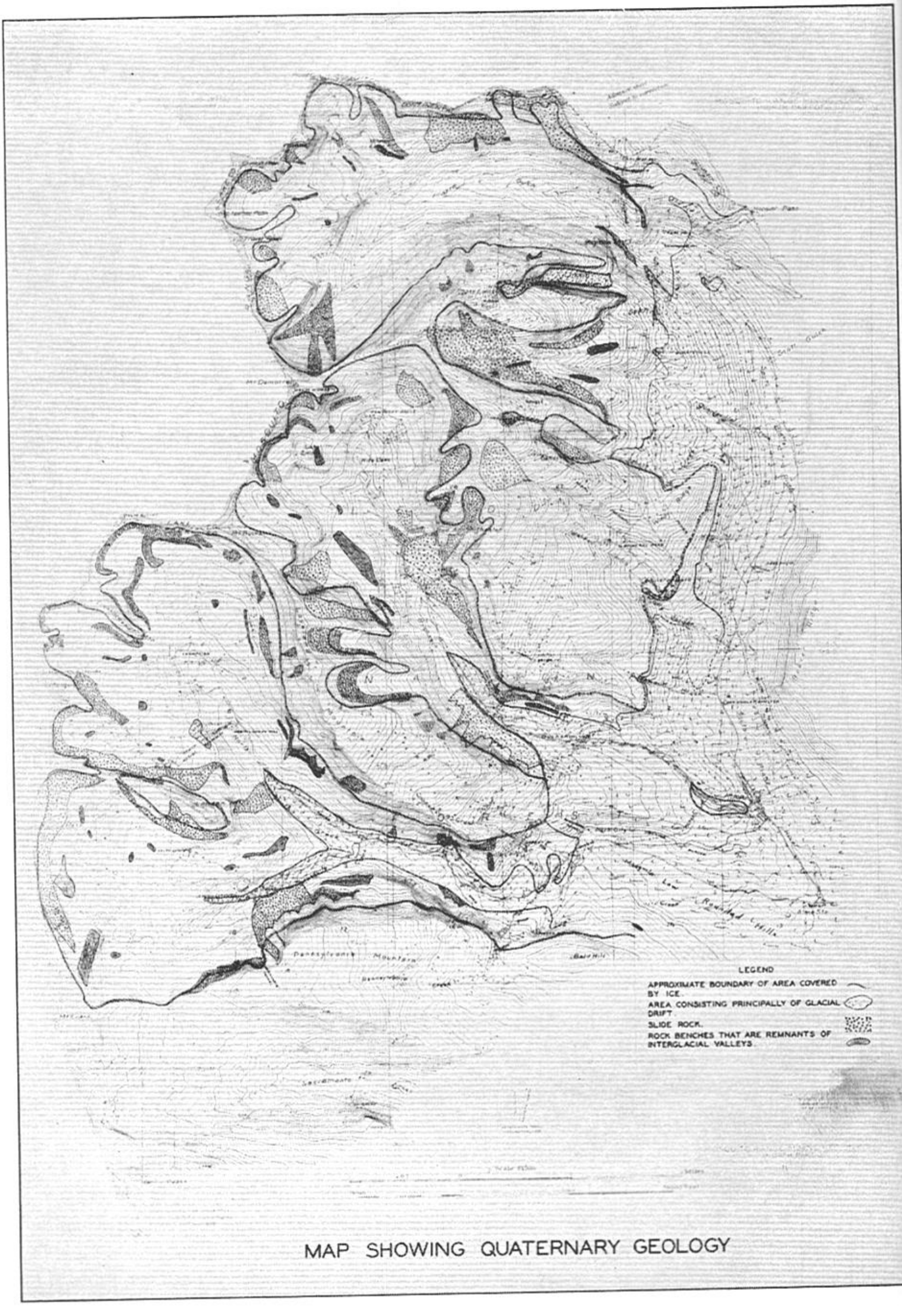
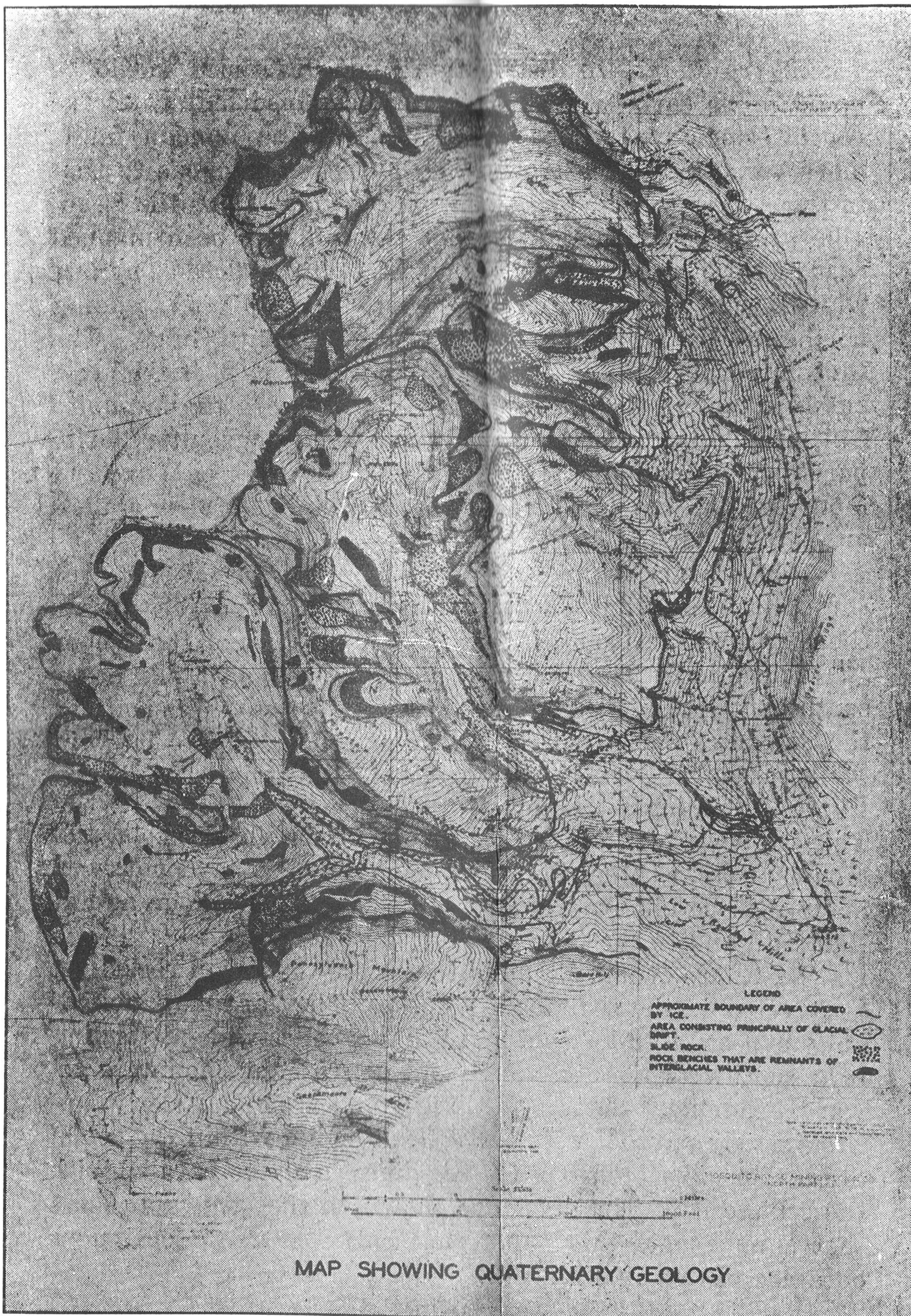


Figure 5.—Map showing Quaternary geology of the Alma district, Colorado.



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Only one stock is exposed in the Alma district. It occurs in the upper part of Buckskin Gulch, within the belt of dikes, and is elongated in the direction of that belt. Moreover, its location apparently was influenced by the Cooper[11a] Gulch fault, for the stock lies in the line of probable northward extension of the main branch of the fault. The stock already has been described in detail.[12]

Quaternary Deposits

The glacial geology of the Mosquito Range has been described and mapped by Capps.[13] His map shows the position and extent of the ice during the later of the two glacial stages. It has economic interest because of the erosion that was accomplished in the higher areas and the deposition in the lower areas. The steep-sided basins near the crest of the range and the broad, U-shaped valleys resulted from glacial erosion. Some of the eroded material was deposited along the floors and sides of the valleys, but most of it was carried out of the range and deposited in the lower reaches of the valleys or transported away by streams issuing from the glaciers.

Glaciers occupied nearly all valleys that head above an altitude of 12,000 feet, and the larger glaciers extended down the valleys at least to an altitude of 10,000 feet. As a result of the glacial action, the upper parts of the valleys were swept clear of all debris and the bare rocks were exposed, whereas the floors and sides of the lower parts of the valleys are covered with debris dropped by the glacier. Figure 5 shows the approximate outline of the areas within the Alma district that were covered by ice during either or both stages and also the principal glacial deposits and recent talus accumulations.

Structure

In its broader relations, the Mosquito Range lies along the eastern flank of the Sawatch uplift, and its regional dip

[11a] To avoid confusion with the Mosquito fault, "Cooper Gulch fault" is the U. S. Geol. Survey new name for the "Mosquito Gulch fold-fault" of Patton, Hoskin, and Butler, Colorado Geol. Survey Bull. 3, pp. 121-127, 1912. [Colorado Sci. Soc. editors.]

[12] Singewald, Q. D., Igneous history of the Buckskin Gulch stock, Colo.: Am. Jour. Sci., 5th ser., vol. 24, pp. 52-67, 1932.

[13] Capps, S. R., Pleistocene geology of the Leadville quadrangle, Colo.: U. S. Geol. Survey Bull. 386, 1909. Map of glacial deposits reprinted as Plate 8 of U. S. Geol. Survey Prof. Paper 148.

is therefore eastward. This regional dip is modified by folding and faulting.

Folding

The most conspicuous folds are associated with faults, especially reverse faults. These faults are really asymmetrical folds that have been broken. During its early stages movement took place by folding, but after rupture of the fold the movement was continued by faulting with additional drag of the beds along the fault. On each side of the fault the beds are bent in the direction of the movement. The London and Cooper Gulch faults and the folds associated with them are features of this type.

Folding of the more ordinary type is inconspicuous and is represented by slight warpings that interrupt the regional dip and form structural terraces and gentle anticlines and synclines, notably on Mount Bross and Mount Lincoln. (See fig. 6.)

A third, more local type of folding is represented where thick laccolithic sills of porphyry have been intruded into the basal part of the Weber (?) formation, as at Mount Lincoln, and have gently domed the overlying beds.

Faulting

Although faulting doubtless occurred as far back as pre-Cambrian time, this paper will consider only the faulting that has taken place from the Laramide revolution (late Cretaceous and early Tertiary) to the present. One of the early events of the Laramide revolution in this range was the intrusion of vast amounts of igneous material in the form of sills into the sedimentary rocks. Most, at least, of the sill intrusions preceded the main folding and faulting. Intrusion of dikes and stocks continued after the initiation of the faulting, and the faults doubtless had a considerable influence on the intrusions and the ore deposition that followed them. Faulting has continued during and after ore deposition, and perhaps to the present time.

The faults may be divided into major and minor groups, although the two groups clearly grade into each other. The major faults of the Alma district include the London fault and the Cooper Gulch fault, which are reverse. No major normal faults like those so prominent in the Leadville district are present. Most of the minor faults are normal and die out within short distances. The largest of them, however, has a displacement of 200 feet and extends horizontally for a distance of at least a mile.

The faults may also be classified as premineral and postmineral, although some postmineral movement has taken place along many faults that were formed in premineral time. This statement applies especially to the major reverse faults, along which slight movements continued for a long time.

The largest fault within the Alma district is the London fault, which strikes northwest and dips steeply northeast. Its stratigraphic throw at Pennsylvania Mountain may be estimated at 2,500 feet. The London fault has been traced from its junction with the Mosquito fault, a short distance northwest of Mosquito Peak, for about 14 miles, to the area where it is covered by the Recent alluvium of South Park.

East of the London fault is the Cooper Gulch fault, which strikes north and dips gently to the east. Its stratigraphic throw at Mosquito Gulch is about 450 feet. This fault is well exposed along the cliffs on each side of Mosquito Gulch. On Loveland Mountain it splits into several branches that diverge northward. None of the branches is exposed across Loveland Mountain, but their approximate positions may be determined from the outcrops of the Parting quartzite. All the branches are well exposed along the cliffs formed by the sedimentary rocks on the southwest side of Buckskin Gulch, but none of them can be traced northward after they pass into the pre-Cambrian rocks; however, the relative altitudes of the base of the Sawatch formation on each side of Buckskin Gulch suggest that the main, most westerly branch, continues up the gulch for some distance beyond its northernmost exposure.

A fault of unknown character apparently exists between the eastward-dipping strata west of Windy Ridge and the southwestward-dipping strata east of the ridge. It is possible that the igneous material that crops out on Windy Ridge rose along this fault.

None of the profuse minor faults are here described in detail. The larger ones are shown in Figure 2, and all of those exposed are shown on the larger-scale map that supplements this paper.

ORE DEPOSITS

HISTORY AND PRODUCTION

It is not the purpose to give in this paper a history of mining in the district. Henderson has given the history of Park County,[14] which, with the exception of placer mining, is mainly the history of the Alma district. Lode mining began about 1860 and has continued ever since. The county was active in the seventies and eighties, and its production in 1888 was valued at $763,000. There was a decline during the nineties but a revival from 1905 to 1910, with a production of $729,000 in 1909. A second decline lasted until the last few years, during which the production has been $270,223 in 1928, $221,204 in 1929, $474,143 in 1930 and $910,822 in 1931. Altogether the county has produced from 1859 to 1931, inclusive, $12,490,387 in gold (of which $3,685,802 was from placers), 7,057,033 ounces of silver, 2,130,086 pounds of copper, 42,875,815 pounds of lead, and 2,993,532 pounds of zinc, with a total gross value for the five metals of $21,965,773. The zinc, produced between 1906 and 1916, came from the Horseshoe district, south of area included in this report. The Horseshoe district also produced much lead and silver. In 1932, the county, all from the Alma district, produced $2,741,023 in gold, 64,752 ounces of silver, 14,000 pounds of copper and 1,586,000 pounds of lead, with a total value of $2,804,545.

REGIONAL DISTRIBUTION

Some mineralization has occurred throughout the Mos-

[14]Henderson, C. W., Mining in Colorado: U. S. Geol. Survey Prof. Paper 138, pp. 36-38, 186-196, 1926.