[Read before the Society October 25, 1930]

PRELIMINARY GEOLOGIC MAP OF THE ALMA MINING DISTRICT, COLORADO[1]

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INTRODUCTION

Field work by the United States Geological Survey in the Mosquito Range in the vicinity of Alma has been in progress since the summer of 1928. Although the work has not been completed, this paper will make available to mining men of the region a geologic map of the area that has been studied so far. The brief discussion that follows is intended to point out a few features of the geology which may be of particular value in the interpretation of the map.

In the geologic study of this area the writers have been ably assisted by Robert Butler. The assistance and courtesies of numerous mining men have also been of invaluable aid.

STRATIGRAPHY

The sedimentary rocks of this area are shown in columnar section in Figure 1. Detailed descriptions of them have been published in earlier reports[4], and the brief descriptions which follow are intended mainly to point out the

[1]Published by permission of the Director of the United States Geological Survey.

NOTE: Because of the scale of this map (1/12000) and the large area, the Colorado Scientific Society cannot afford to include this map with this paper. It can be secured from the Secretary at $5.00 a copy. The complete map will be published by the U. S. Geol. Survey.

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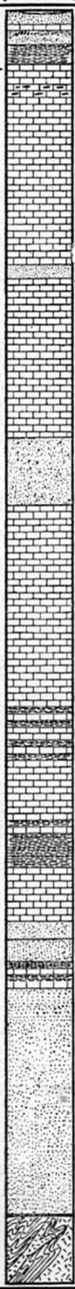
[4]Emmons, S. F., Irving. J. D., and Loughlin, G. F., Geology and ore deposits of the Leadville mining district, Colorado: U. S. Geol. Survey Prof. Paper 148, pp. 25-39, 1927. Patton, H. B., Hoskin. A. J., and Butler, G. M., Geology and ore deposits of the Alma district: Colorado State Geol. Survey Bull. 3, pp. 47-62, 1912.



Age	Description	Zone		Formation
Pennsylvanian -Unconformity-	Interbedded quartzite, conglomerate, grit, arkose, shale, and occasional limestone, all micaceous. Some shale highly carbonaceous. Shale predominates near base; arenaceous beds predominate in upper part.	Thicknesses given are approximate minimum and maximum of compilations from measured sections.		Weber (?) formation Not measured
Mississippian	Blue to nearly black, mostly dense-textured, massive-bedded dolomitic limestone. Limestone breccia common. Numerous lenses and nodules of black chert. Weathers with pitted surfaces and breaks into blocky fragments. Shatters easily.	Upper limestone zone 0-175′		Leadville ("Blue") limestone
-----------	Fine-grained to dense "cherty-looking" white quartzite. Extremely lenticular.	Quartzite zone, 0-10′		
Devonian (?)	Fairly thin-bedded, mostly dense white and blue dolomitic limestones. White beds weather cream-colored. Exposed surfaces generally smooth.	Lower limestone zone 40-75′		
Ordovician (?)	Cross-bedded and conglomeratic quartzite and sandy limestone. Quartz pebbles subangular. Locally slightly shaly. Weathers light to dark brownish gray.	0-55′		"Parting" quartzite
Ordovician	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.	Upper limestone zone 60-85′		"White" limestone
	Interbedded brownish-weathering limestone, greenish-weathering shale, and limy shale. Less shaly than "shaly zone" of Cambrian.	Shale zone 15-25′		
	Drab to brownish weathering limestone, dolomitic and somewhat sandy, with numerous limy-shale partings.	Lower limestone zone, 15-25′		
Cambrian	Thin-bedded, almost flaggy dolomitic limestone and shale. Upper limestone contains "red casts." Limestone weathers brownish, shale greenish.	Shaly zone 15-25′	Limestone-shale (Transition-shale) member	Sawatch ("Lower") quartzite
	Brownish-weathering dolomitic limestone with numerous limy shale partings.	Limy zone 15-25′		
	Dark purple to black quartzite. In places contain very small angular quartz pebbles. Slightly cross-bedded.	Purple qtz. 2-13′		
	White fine-grained, fairly thick-bedded quartzite.	Upper qtz. zone 6-10′	Quartzite member	
	Thin-bedded series of quartzite, limy quartzite, sandy limestone, shale and rare limestone. Weather brownish and "sandy-looking."	Thin-bedded limy zone. 10-12′		
	White, fine-grained, fairly thick-bedded quartzite. A few beds have small amount of carbonate cement.	Lower quartzite zone 70-100′		
	White quartzite conglomerate; pebbles less than 1″ diameter.	Basal conglomerate, 8″-1′		
Pre-Cambrian	Porphyritic or equigranular gray or pink granite, commonly gneissoid. Inclusions of schist and injection gneiss, numerous pegmatite dikes.	Granite gneiss, and schist.		

Fig. 1.—General stratigraphic column of the Alma district, Colo.

lithologic units within certain of the formations. These units, for the most part, lack definite boundaries, nevertheless their recognition permits more accurate determination of displacement along faults and interpretation of other structural features than is possible where an entire formation is considered a lithologic unit.

Sawatch ("Lower") Quartzite (Cambrian)

At Alma, as at Leadville, the Sawatch formation is known locally as the "Lower" or Cambrian quartzite. It is readily divided into a lower quartzite member and an upper limestone-shale ("transition shale") member.

Quartzite member.—The quartzite member tends to form prominent cliffs. It may be subdivided into the following zones:

Purple quartzite.
Upper quartzite zone.
Thin-bedded limy zone.
Lower quartzite zone.
Basal conglomerate.

At the base is a conglomerate 8 to 12 inches thick, in which quartz pebbles of various sizes, but few exceeding an inch in diameter, are inclosed in a matrix of fine-grained white quartzite. This grades upward through several feet of quartzite and quartzite conglomerate into the rather thick-bedded fine-grained white quartzite that constitutes most of the formation. Interbedded in the lower quartzite zone are a few layers having a calcareous cement. Where weathered these appear brownish and sandy, but where fresh they are indistinguishable from the pure quartzite. The thin-bedded limy zone consists of fine-grained quartzite, sandy limestone, shale, and, rarely, dense limestone. These rocks are overlain by fine-grained white quartzite of the upper quartzite zone. At the top of the quartzite member is an easily recognized zone of slightly conglomeratic quartzite, weathering purplish to blackish.

Limestone-shale ("transition shale") member. — The quartzite member is overlain by a series of interbedded rocks ranging from calcareous quartzite to limestone and shale, which has been termed the "transition shale". These rocks are easily eroded, tending to form distinct benches, in places covered by talus, between cliffs of "White" limestone above and quartzite below.

Two zones, a lower limy zone and an upper shaly zone, may be recognized in this member, although there is no marked lithologic difference between them. The predominant rock in the lower zone is somewhat sandy dolomitic limestone; that in the upper is siliceous, rather indurated shale. The entire member is relatively thin-bedded, and the upper shaly portion is almost flaggy. The limestone is white to brownish or greenish gray, but weathers brownish; the shale weathers to green platy or fissile fragments, but on a fresh surface some are light and others are dark colored.

The lower contact, with purple quartzite, is sharp in places, but more commonly gradual. The upper contact, with "White" limestone, is gradational. The so-called "red casts" are not confined to one bed but usually may be found in several limestones of the upper 10 feet.

"White" Limestone (Ordovician)

The "White" limestone was for a long time tentatively correlated with the Yule limestone of the Anthracite-Crested Butte region, but in 1929 Edwin Kirk, of the United States Geological Survey, collected fossils that prove it to be equivalent to the Manitou limestone to the southeast.

Three lithologic units are recognizable, but there are no definite boundaries between them. They are a lower limestone zone, a middle shaly zone, and an upper limestone zone. Limestone beds of the lower zone are mostly dolomitic, but in places some of them contain considerable calcite; they are also a little sandy. They are white to pinkish on a fresh surface but weather brown. They are separated by partings or thin layers of limy shale. The shaly zone is very calcareous but in places includes beds of nearly pure shale. The upper limestone zone is nearly everywhere thin-bedded, dolomitic, and siliceous. Its colors is predominantly pale bluish gray, but some beds are nearly white; it weathers to gray or white. A few beds have dense texture, but most of them consist of fine to medium grained crystalline rock. A diagnostic characteristic of the upper limestone zone is the presence of thin siliceous bands that on a weathered surface project beyond the limestone and produce a pronounced ribbing. The ribbing is most common in the upper part, where a few individual bands are as much as an inch thick; most bands are less than one-sixteenth of an inch thick.

"PARTING" QUARTZITE (ORDOVICIAN?)

The "Parting" quartzite, so called because it separates the "White" limestone from the "Blue" limestone, has on very slender evidence been tentatively regarded as Ordovician, but study in the Alma district, as well as at Leadville and Iowa Gulch, on the west side of the range, indicates that it is more closely associated with the overlying Devonian (?) member of the Leadville limestone than with the underlying Ordovician limestone.

In the vicinity of Alma the "Parting" quartzite varies greatly in thickness and lithology. Near Mt. Lincoln and Mt. Cameron, which are just outside of the area mapped, it is absent. In the area from Quartzville to Montgomery and also in the area extending from the peak of Loveland Mountain to Park City it is thin; but between these areas it is thick. The "Parting" quartzite has a maximum thickness of 55 feet near the Hock Hocking mine and also in and near Mineral Park. A future paper will show that these variations in thickness are due to variations in amount of material deposited and not to erosion subsequent to deposition.

In general the "Parting" quartzite consists of brownish-gray gritty and conglomeratic cross-bedded quartzite with which is interbedded white fine-grained quartzite. It contains variable amounts of calcareous conglomerate, limestone, and shale. Where thick it is almost pure quartzite, but where thin it is limestone containing quartz grains and pebbles. Few pebbles of the conglomerate exceed half an inch in diameter, and very few exceed an inch. A sharp contact separates it from the underlying "White" limestone.

LEADVILLE ("BLUE") LIMESTONE (DEVONIAN? AND CARBONIFEROUS)

The Leadville ("Blue") limestone is well known to miners of the region because in it have been found large bodies of replacement ore. It rests with concordant dip upon the underlying "Parting" quartzite or, where that formation is missing, upon the "White" limestone. At places the contact is sharp, but elsewhere at the base of the "Blue" limestone is a transition zone consisting of a few feet of limestone in which are bands of numerous angular quartz pebbles. The upper contact with the Weber (?) formation is sharp. Where the "Blue" limestone is thin it is the upper beds that are missing. A striking characteristic, particularly in the upper part, is its tendency toward intense shattering. This property has an important influence on ore deposition, for it provides an otherwise nonporous limestone with channels of circulation, so that large rock masses may be completely penetrated. The weathered "Blue" limestone may have either very smooth or intensely pitted surfaces.

Within the "Blue" limestone three lithologic zones may be recognized—a lower limestone zone, a quartzite zone, and an upper limestone zone. The lower limestone zone, on the basis of field work done in 1929 by Edwin Kirk and W. S. Burbank, is tentatively regarded as Devonian; the rest of the formation is regarded as Mississippian. The lower zone consists of thin to moderately thick, well-bedded, mostly dense-textured dolomitic limestone of either creamy-white or dark-blue color; layers of the one color alternate with those of the other. Siliceous ribs, like those in the "White" limestone, exist at places. The lower part of this zone is locally transitional with the "Parting" quartzite. At 40 to 75 feet above the base of the "Blue" limestone a bed of white fine-grained, in places cherty-looking quartzite occurs sporadically; this bed, which lacks the gritty conglomeratic structure of the "Parting" quartzite, is not persistent but forms lenses several hundred feet long and several feet in maximum thickness. On the west side of the range the quartzite zone is more persistent.[5]

The upper limestone zone consists of massive and rather obscurely bedded dark-blue to nearly black, dense to very fine-grained dolomitic limestone and a few beds of limestone breccia. Chert nodules and streaks are common; they are usually black but rarely are light colored. The limestone weathers mostly to dark blue, much of it presenting a surface that has alternating bands of slightly different shades; a few beds weather brownish. Throughout the zone so-called "zebra rock" is very common. "Zebra rock" is "Blue" limestone that has been recrystallized and partly replaced by veinlets of white dolomite so spaced as to give the rock a striped appearance. Patches of "zebra rock" range from an inch to many feet in longest dimension and have irregular shape. Silicification of the limestone, later than the formation of the "zebra rock", has occurred at several places at different stratigraphic positions; the most common position, however, is at the top.

At many places, particularly where mineralization has occurred, the upper zone of the "White" limestone is difficult to distinguish lithologically from the "Blue" limestone. The following features may be noted as aids in distinguishing them:

1. The "White" limestone is thin-bedded and therefore tends to break into slabby fragments. The "Blue" limestone, on the other hand, is more massive and tends to break into blocky fragments.

2. The ribbed appearance of a weathered surface of "White" limestone, produced by the siliceous streaks, is quite different from either the smooth or the intensely pitted sur-

[5]Behre, Chas. H., Jr., Revision of structure and stratigraphy in the Mosquito Range and the Leadville district, Colo.: Colorado Sci. Soc. Proc., vol. 12, p. 38, 1929.

faces of weathered "Blue" limestone. Except in a few places, where the light-colored beds of the lower "Blue" contain these siliceous streaks, this feature is diagnostic.

3. The "White" limestone typically appears crystalline whereas the "Blue" appears dense to the naked eye. However, some beds of the "White" have dense texture, and some of the "Blue" are crystalline. Moreover, in many places, where the "Blue" is recrystallized or mineralized, it is crystalline.

4. Color alone is of little value for distinguishing between the two formations. Bluish beds are very common in the upper part of the "White" limestone. However, the color of the "Blue" limestone is usually a little darker than that of the bluish beds of the "White" limestone.

5. The "Blue" limestone is commonly a little softer and more easily scratched with a hammer than the "White" limestone.

None of the above criteria are diagnostic by themselves. Nevertheless, the combination of texture, color, hardness, and particularly appearance of weathered surfaces usually permits ready identification of the two formations when the "Parting" quartzite is absent or not exposed.

WEBER (?) FORMATION (CARBONIFEROUS)

The Weber(?) formation rests upon the "Blue" limestone, apparently with concordant dip, but is separated from it by an erosional unconformity. The strata constituting the Weber(?) formation consist of interbedded lenticular and commonly cross-bedded micaceous quartzite, sandstone, grit, arkose, conglomerate, sandy shale, and shale with a few beds of limy shale and limestone. The presence of mica is a distinctive feature even in most of the limestones. Some strata contain marine fossils, but many have root and tree imprints that indicate a continental origin. As no two sections show the same sequence of beds, lithologic subdivision of the formation is impossible. Although the lower part is more shaly than the upper, no definite subdivision can be made in this area between the lower "Weber(?) shales" and the upper "Weber(?) grits."

Arenaceous beds constitute most of the formation. Their color ranges from whitish to dark gray. Almost all are conglomeratic, more or less arkosic, and cross-bedded. The highly arkosic strata are rather friable on weathered surfaces; the others are so firmly cemented as to be quartzitic. Pebbles of the conglomerate are predominantly quartz and subordinately feldspar, the amount of feldspar varying considerably from place to place and from bed to bed; a few pebbles are of pre-Cambrian pegmatite and, less commonly, schist.

The shale is dark gray to black, green, less commonly light gray or yellow, or rarely red. Weathered outcrops commonly have fissile structure. Most of the shale is sandy, probably having been deposited as silt; other beds are clayey, and a few are limy. Some of the black shales, especially those near the base, are highly carbonaceous. The limestone of the Weber(?) formation is dark gray to black, has fine-grained or dense texture, and weathers brown.

Throughout a large part of the area there occurs at or near the base a bed of yellow shale which has undergone considerable alteration. This is known locally among mining men as "cap rock" or "yellow porphyry,"

IGNEOUS AND METAMORPHIC ROCKS

Pre-Cambrian Complex

The predominant types of pre-Cambrian rocks, named in their order of abundance within the region mapped, are injection gneiss, pegmatite, granite, quartz-mica schist, and granite gneiss. These are described by Patton[6]. All the pre-Cambrian rocks are cut by numerous intrusives of late Cretaceous or early Tertiary age. As mapping has not yet been completed within their area of outcrop, these rocks are undifferentiated on the map that accompanies[7] this paper.

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[6]Patton, H. B., Hoskin, A. J., and Butler, G. M., op. cit., pp. 35-47.

[7]See note, bottom p. 295.

TERTIARY (?) INTRUSIVES

Igneous rocks of late Cretaceous or early Tertiary age occur as dikes and small stocklike masses in the pre-Cambrian rocks and as sills, laccolithic sills, and dikes in the sedimentary formations.

Gray porphyry group[8]—Rocks of the Gray porphyry group include those described by Patton as quartz monzonite porphyry, Lincoln porphyry, and diorite porphyrite. Although the group includes several distinctive and easily mapped rock types, they have been grouped together on the accompanying map, because a discussion of their petrographic relations would be too lengthy for this paper.

White porphyry group[9]—The White porphyry group includes an early white porphyry and a late white porphyry. The former, which is older than the Gray porphyries, is equivalent to the White porphyry of Leadville; the latter, which is younger than the Gray porphyries, is perhaps related in age to the rhyolite agglomerate of Leadville. The two white porphyries resemble each other lithologically and can be distinguished with certainty only where their age relations can be established.

At a few places, where it has been bleached by intense alteration, the Gray porphyry resembles the White porphyry. At such places, however, close inspection usually reveals the outlines of numerous altered phenocrysts in the bleached Gray porphyry, those of former biotite being most readily recognized; whereas phenocrysts are sparsely distributed in the White porphyry. Where the rocks are fresh or only moderately altered, the darker color and usually the abundance of phenocrysts make the Gray porphyry easily recognizable.

STRUCTURE

General features—The dominant structural features are the regional dip of the strata of 15° to 20° in a direction a little south of east and the numerous faults. A departure from

[8]Emmons, S. F., Irving, J. D., and Loughlin, G. F., op. cit., pp. 46-52. Patton, H. B., Hoskin, A. J., and Butler, G. M., op. cit. pp. 74-92.
[9]Emmons, S. F., Irving, J. D., and Loughlin, G. F., op. cit., pp. 43-46. Patton, H. B., Hoskin, A. J., and Butler, G. M., op. cit., pp. 70-74.

the normal dip is found at only a few places, the most conspicuous of these being near the thrust faults, and in the Windy Ridge area. There are not sufficient exposures to determine the exact structure along Windy Ridge.

The faults may be divided into two main groups, "major

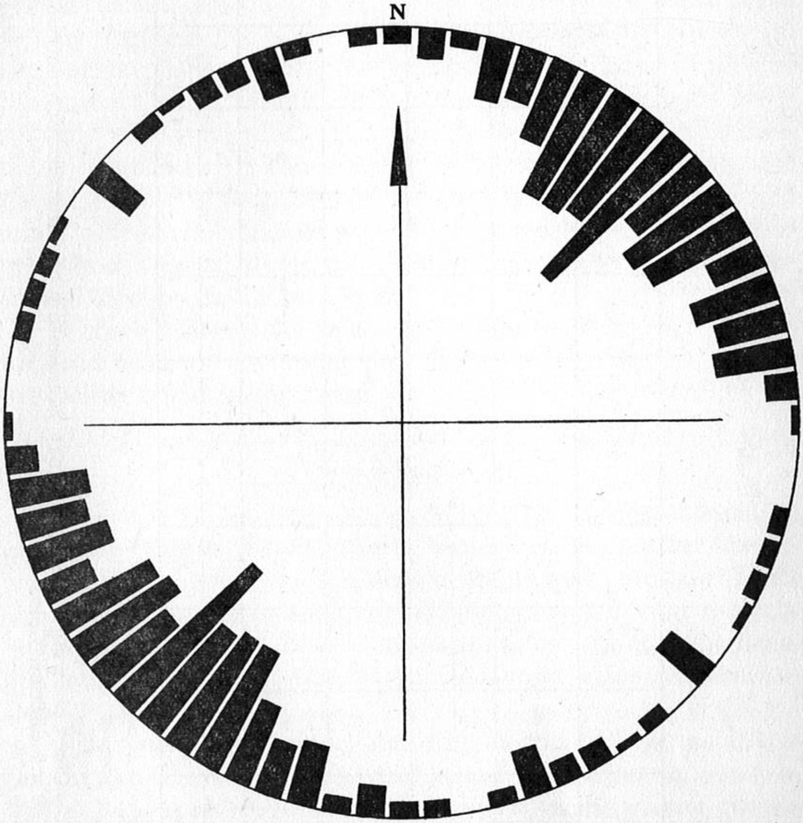

Fig. 2.—Chart showing trend and relative intensity of fissuring and "minor" faulting, in the Alma district, Colo.

thrust" faults and "minor" faults. To the first group belong the London and some of the faults that cross Loveland Mountain. These are not numerous but are of economic importance because, as at Leadville, they seem to have localized certain of the ore bodies. The location of the London fault on the map may be taken as nearly correct, even where exposures

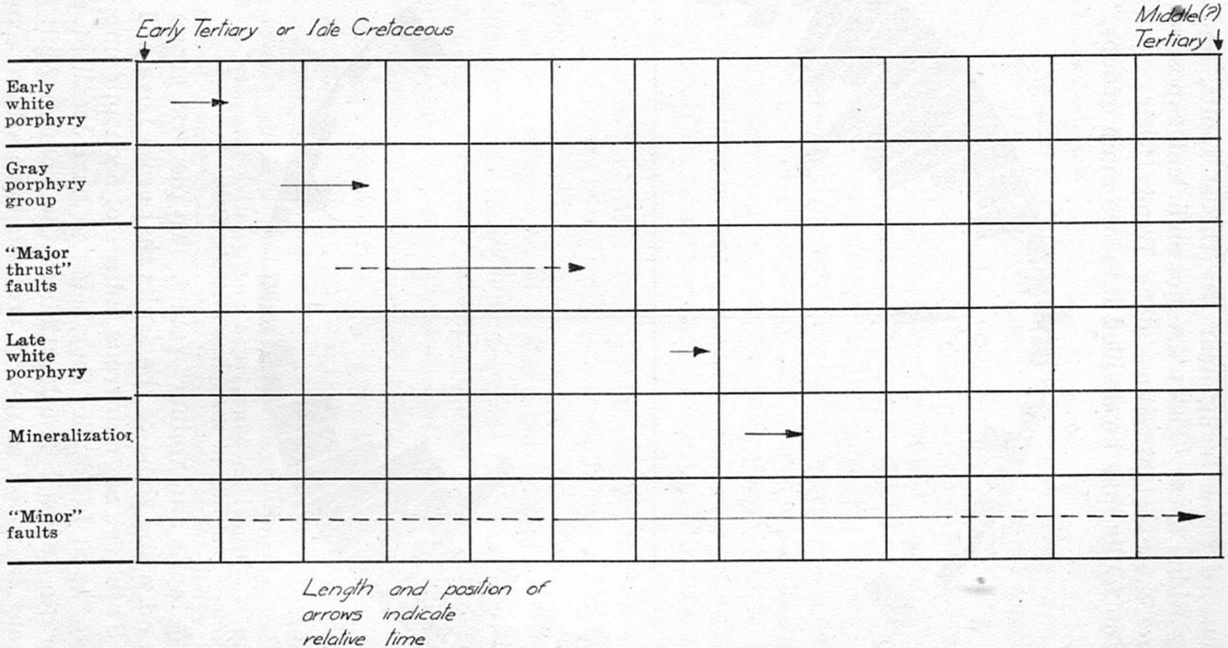

Fig. 3.—Chart showing approximate age relationship of mineralization, intrusion, and faulting, in the Alma district, Colo.

are poor. The locations of the thrust faults crossing Loveland Mountain are correct along the cliffs on each side, but are doubtful across the mountain, having been inferred from sparsely scattered outcrops.

By far the greater number of the faults of the area belong to the second group. Most of them are vertical or steeply dipping, but a few are nearly horizontal. Nearly all are normal faults. With few exceptions they have small displacements and die out within short distances, both horizontally and vertically. In general, the amount of displacement is greater at the contact between pre-Cambrian and Cambrian rocks than higher in the sedimentary series. At many places slickensides show that at least the latest movement had a large horizontal component. Many faults of the second group are mineralized.

Figure 2 shows the relative abundance of faults and mineralized fissures, excluding the "major thrust" faults. Their prevailing trend is northeast.

Age Relationship of Faults to Intrusives and Mineralization
(See Figure 3)

There is no evidence to show whether or not movement along the "major thrust" faults began before or after the intrusion of the porphyries. Most of the displacement, at least, occurred after the intrusion of all porphyries except the late white porphyry and before mineralization. Slight displacements along some of the faults continued after mineralization.

The period of "minor" faulting began before the intrusion of the Gray porphyries and lasted until after mineralization. Repeated movements took place along some faults throughout this period. Along others, however, displacements occurred through only part of the period. Relatively little of the faulting is preintrusive. Most of it took place before mineralization, but considerable of it appears to be postmineral. Faults that are entirely of postmineral age are fairly common in the area. In places "minor" faults displace thrust faults, such as the London.

The late white porphyry is not displaced by premineral faults and in many places cuts across them. On the other hand, in a few places it is mineralized. Therefore its age is regarded as being immediately premineral.

The "major thrust" faults are but slightly mineralized themselves but appear to have localized many ore bodies near them. The first movement on most of the "minor" faults and fissures was premineral, and they have served as channels of circulation for ascending mineralizing solutions. The ore bodies in formations below the "Blue" limestone have been formed as veins along these faults and fissures and as replacement bodies extending out from them. In many places definite fissures that acted as feeders to ore bodies in the "Blue" limestone are absent. The reason for this appears to be that fissures in the underlying formations tended to dissipate into wide fracture zones when they entered the upper part of the "Blue" limestone, because of the strong tendency toward shattering which this rock possesses.

PROSPECTING

More geologic work must be done before a detailed description of the ore deposits can be presented. The most favorable stratigraphic horizon for ore deposition, as measured by past production, has been the top of the "Blue" limestone. Areas where this horizon has not been prospected should be considered in future search. Such areas are those where the Weber(?) formation now crops out, but where a nearly full thickness of the "Blue" limestone may be expected at a small to moderate depth. The most favorable localities within Weber(?) areas should be (1) beneath mineralized fissures, even though they may not be rich enough to work within the Weber(?) formation, and (2) along the upward projections of zones that have been strongly mineralized in the lower formations. Beds at other horizons than the top of the "Blue" limestone have yielded ore deposits in the past and probably will in the future, and these together with productive veins that are not confined to any definite stratigraphic horizon will be discussed when the work is completed.