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*C. M. Goodale*

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CONTAINING PAPERS AND DISCUSSIONS OF THE BUTTE MEETING,  
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RESOURCES OF MONTANA, AND THE PREVAILING PRACTICE  
IN MINING AND METALLURGY.

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# Ore Deposits at Butte, Mont.

BY RENO H. SALES, BUTTE, MONT.

(Butte Meeting, August, 1913.)

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#### INTRODUCTION.

THE geology of Butte possesses especial interest on account of the magnitude of the ore deposits, their extraordinary richness and persistence in depth. Since its discovery in the early 60's the district has yielded, in round numbers, 6,000,000,000 lb. of copper, 260,000,000 oz. of silver, 1,250,000 oz. of gold, more than 6,000,000 lb. of zinc. This enormous metal production has been derived from an ore tonnage estimated roughly at 65,000,000 tons. At the present day, most of the important mine shafts have reached a depth of 2,400 ft., while several are more than 3,000 ft. deep. At these great depths rich bodies of copper ore are being exploited, showing no diminution in metal content as compared with the ores of the higher levels.

The present (1913) daily rate of production is approximately 14,000 tons, of which 13,250 tons may be regarded as copper ore, although a small percentage of this is minable only because of the presence of

notable amounts of silver, and the remaining 750 tons are zinc ores. In addition, a small tonnage of straight silver ores is mined, chiefly by leasers, from abandoned silver mines. A small amount of copper is recovered in the precipitation plants treating the copper-bearing waters pumped from the mines.

In spite of their great importance as metal producers, the subject of the geology of these ore deposits received but scant attention at the hands of investigators until recent years. The Butte Special Folio,<sup>1</sup> the work of S. F. Emmons, W. H. Weed, and G. W. Tower, published by the U. S. Geological Survey in 1897, was the first publication to deal with the Butte district in detail. This was followed by a more comprehensive study undertaken by W. H. Weed<sup>2</sup> during the period extending from 1901 to 1905, the results of his work appearing in 1912. Other articles treating special features of the ore deposits have appeared from time to time. H. V. Winchell's paper<sup>3</sup> dealing with the artificial production of chalcocite or copper glance was timely and of great interest in connection with the problem of chalcocite formation. More recently Charles T. Kirk<sup>4</sup> has carefully studied the various phases of granite alteration found in association with the copper veins. He endeavored to determine if any genetic relation existed between these alteration phases and the deposition of certain copper minerals. He concludes from his investigations that the chalcocite of the Butte veins is almost entirely a product of descending sulphide enrichment, a view expressed also by W. H. Weed.

Weed's study was concluded in 1905 and since that time much development work has been done. New mines have been opened and the older ones have been greatly extended both vertically and laterally, bringing to light many new and interesting features concerning the vein and fault structure. The persistence of rich ore bodies to great depth has aroused a keen interest among geologists regarding the manner of formation of the abundant copper mineral chalcocite. Much information is available bearing directly upon this important question. In the presentation of this new material, together with such associated facts as are considered to be necessary and of general interest concerning the geology of these ore deposits, the writer hopes to find justification for the publication of this paper.

<sup>1</sup> Butte Special Folio (No. 38), *Geologic Atlas, U. S. Geological Survey* (1897).

<sup>2</sup> Weed, W. H., *Professional Paper No. 74, U. S. Geological Survey* (1912).

<sup>3</sup> Winchell, H. V., *Synthesis of Chalcocite and Its Genesis at Butte, Montana. Bulletin of the Geological Society of America*, vol. xiv., pp. 272 to 275 (1902).

<sup>4</sup> Kirk, C. T., *Conditions of Mineralization in the Copper Veins at Butte, Montana, Economic Geology*, vol. vii., No. 1, pp. 35 to 82 (Jan., 1912).

## GENERAL GEOLOGY.

Butte is situated near the western border of a large granite area, called the "Boulder" batholith, extending southwesterly from Helena to the Big Hole river in Beaverhead county, a distance of 70 miles. The general outline of the batholith is oblong, but it is extremely irregular in width, averaging about 20 miles. Many smaller isolated masses of similar rock occur along its western and northern borders. The granites of Marysville, Philipsburg, Clinton, Garnet, and several other mining districts are undoubtedly offshoots from a main parent magna. It is not improbable that further study will show a close relation between the Boulder granite area and the great granite batholith of central Idaho.

The Boulder batholith made its appearance subsequent to the great Rocky Mountain building period, marking the close of Cretaceous times. It is more recent than the large mass of andesite forming Bull mountain, near Whitehall, which is known to intrude upturned Palæozoic and Cretaceous rocks. There is an abundance of evidence to show that the Boulder batholith did not produce a doming effect on the sedimentary rocks now found along its borders; in fact, the orientation of these intruded rocks does not appear to have been visibly disturbed even where they are in direct contact with the granite. In nearly every instance where such contacts are open to observation, the sedimentaries are found to dip at a steep angle toward the granite; an exception, however, may be noted at Elkhorn, where dips away from the granite appear to be a coincidence and not an effect produced by its intrusion. In a broad way the batholith seems to occupy the trough of a great synclinal basin in whose dissected sloping sides may be seen remnants of the entire series of sedimentary rocks reaching from the pre-Cambrian slates and shales upward to the coal-bearing sandstones of the late Cretaceous. The manner in which this great displaced mass of sedimentaries made its escape is not known.

While the chemical composition of the granite is fairly uniform over the whole area there is a slight variation in physical character or texture, indicating the possibility of two or more distinct intrusions. The texture is usually granitic, in fact, typically so, but at times it is decidedly porphyritic, showing numerous imperfectly formed orthoclase feldspars an inch or more in length. Basic segregations composed of dark silicates are present in considerable amounts as a noticeable feature of the marginal areas of the batholith. These small dark masses, which are from 1 to 6 in. in diameter, are possibly more prevalent where the granite has the even texture and the porphyritic character is lacking. They are more resistant to weathering than the body

of the granite, so that they often stand out in relief over the surfaces of the big rounded boulders, giving a "warty" appearance to the rock.

These variations in texture may be seen in the mines of the Butte district, but there is little, if any, direct evidence to support the hypothesis of two or more separate and distinct intrusions. It is more probable that these variations in texture were developed during the process of cooling and were due to uneven temperature conditions within one great granite area.

An analysis of the typical Boulder granite is given by Weed as follows:

SiO <sub>2</sub> . . . . .	67.12
Al <sub>2</sub> O <sub>3</sub> . . . . .	15.00
Fe <sub>2</sub> O <sub>3</sub> . . . . .	1.62
FeO . . . . .	2.23
CaO . . . . .	3.43
MgO . . . . .	1.74
K <sub>2</sub> O . . . . .	4.52
Na <sub>2</sub> O . . . . .	2.76
TiO <sub>2</sub> . . . . .	0.48
MnO . . . . .	0.06
BaO . . . . .	0.07
SrO . . . . .	0.03
P <sub>2</sub> O <sub>5</sub> . . . . .	0.15
H <sub>2</sub> O below 110° . . . . .	0.09
H <sub>2</sub> O above 110° . . . . .	0.58
	99.98

The cooling of the main granite mass was accompanied in later stages by the segregation of great quantities of aplite, in the form of dikes or often as irregular masses of all sizes from a few yards to a mile or more across. These aplite areas are especially abundant near Butte, and also west and northwest of Boulder in Jefferson county. The texture of the aplite is usually fine grained, though often grading into a coarse pegmatitic structure or, in extreme stages, showing a development of pure glassy white quartz. The formation of aplite seems to have taken place at a very early period; its presence, therefore, does not influence in any manner the occurrence of ore deposits throughout the Boulder granite area.

A large body of dacite-rhyolite, partly intrusive and partly extrusive, covers a goodly portion of the western half of the Boulder batholith. Many smaller isolated plugs and dikes of rhyolite occur in various parts of the granite area, many of which are associated with ore deposits. A notable instance is at Butte, where the ore formation, however, is much older than the rhyolite. These rhyolites, which at one time probably covered a large portion of the granite

batholith, were intruded into the granite long after the latter had entirely cooled and at a time when the present-day physiographic features were strongly developed.

#### ROCKS OF THE BUTTE DISTRICT.

##### *Granite.*

Granite forms the main body of rock inclosing the Butte ore deposits. It is properly a quartz-monzonite, but the term "granite," or "Butte granite," has been so universally employed that it seems advisable to adhere to common usage in this paper. The Butte granite, which is in fact a local area of the Boulder batholith, is a dark gray-green rock of medium coarse granitic texture, but exhibiting at times a more porphyritic phase. This latter variation is especially prevalent in the Steward, Gagnon, and Colorado mines in the southwestern part of the district. The granite everywhere exhibits well-defined systems of joint planes, which, however, do not bear any definite relation to the later fracture systems. The jointings are old, and in many instances in the Butte mines show evidence of slight faulting movements along them, a condition brought about by faults or readjustments taking place within broad inter-fault blocks. While the joint planes have played no part in the determination of the larger features of the fracture systems, they have been of the greatest importance in making the granite adjacent to the fissures more permeable to ore-bearing solutions, and the existence of many of the large "stock-work" ore bodies of the Leonard mine was made possible through the presence of joint planes.

In the veins and intervening country rock in the copper vein area the granite has suffered intense alteration, so that often its original character is only in part preserved.

##### *Aplite.*

Small irregular bodies and dikes of aplite are abundant in the northwestern portion of the Butte district. This rock has been noted in unusually large amounts in the Green Mountain, Mountain Con, and Corra mines. In the main copper belt of Anaconda hill aplite is rarely seen. Immediately to the west of Big Butte it covers an area of several square miles. This exceptionally large body is separated in a general way from the copper zone by the intrusive rhyolite plug forming Big Butte. Where aplite occurs in the form of dikes, which may vary in thickness from a few inches to 50 ft. or more, there is no uniformity in dip or strike, although they generally lie at a low angle. The texture of the aplite is usually fine grained,

though pegmatitic phases are common. In general, it is not often seen as a wall rock of the ore bodies, for, by volume, it forms but a small percentage of the whole rock mass in which the veins occur.

##### *Quartz-Porphry.*

In the copper belt of Butte the granite has been intruded by a series of roughly parallel quartz-porphry dikes which extend in a general easterly and westerly direction across the district. These dikes are relatively narrow, from 10 to 50 ft. wide, but persistent, and they follow closely the general trend of the earliest system of copper veins, thus indicating a close genetic relation between the oldest veins and the porphyry. The dikes, however, are prior to any known vein formation and apparently intruded the granite before the latter had entirely cooled. The vein and fault fracture systems intersect the granite, aplite, and quartz-porphry dikes alike, and all these rocks are similarly affected by the general alteration processes accompanying later vein formation.

##### *Rhyolite.*

Rhyolite, both intrusive and extrusive, occurs to the west and northwest of the district. Big Butte, a prominent topographic feature, is formed of intrusive rhyolite, as is the round-topped hill a mile to the south. From these two main bodies there are many offshoots and dikes having a general north and south course, some of which are known to break through silver and copper veins, thus fixing the period of the rhyolite eruptions at a much later date than that of the quartz-porphry. Extrusive rhyolite extends northwesterly from Big Butte, covering a large area, and in itself is probably the remnant of a much larger rhyolite flow which formerly covered a large portion of the western half of the Boulder granite batholith.

##### *Andesite.*

Isolated areas of a porphyritic andesite occur to the northwest of the district, the age relations of which have not been definitely determined. They are believed to be comparatively old and probably prior to the granite, corresponding, therefore, to the early andesites of Bull Mountain north of Whitehall, Mont., which are known to be intruded by the Butte granite.

##### *Sedimentary Rocks.*

The nearest sedimentary rocks are found in the Highland mountains, 15 miles south of Butte. Here Algonkian rocks, together with Palæozoic quartzites and limestones, are intruded by the Butte granite, which in turn intrudes also earlier andesite and a basic diorite.

*Lake Beds.*

Three miles west of Butte is found the eastern limit of an extensive area of a geological formation termed Bozeman Lake beds by the U. S. Geological Survey. This formation is made up largely of sand, gravel, and water-bedded volcanic ash, and at some former geologic period it covered large valley areas in south central Montana. Near Butte these beds fill a long, narrow, pre-existing drainage valley, reaching from the town of Rocker to Melrose, a distance of 30 miles. A 700-ft. mine shaft sunk a half a mile northwest of Rocker discloses a depth of more than 1,000 ft. of these beds, with the total thickness still undetermined.

*Valley Débris.*

The bottom of the level valley to the south of Butte is composed of coarse detrital sand formed from rapidly disintegrated granite. The greatest depth of this sandy material is unknown. Shafts sunk in the valley floor east of Meaderville have shown the former erosional surface to be buried to a depth of from 200 to 400 ft. in that section, or more than 200 ft. lower in elevation than the present bed of Silver Bow creek where it leaves the valley near the site of the Colorado Smelter.

The manner of occurrence of the Bozeman Lake bed formation near Rocker and the presence of the débris-filled valley south of Butte show conclusively that the former drainage level of the Butte district has been considerably disturbed, and it is probable that the present conditions were brought about either by faulting, volcanic flow coverings, or important crustal movements. (These apparent drainage level oscillations are believed by some writers to have played a tremendously important part in the formation of the bonanza chalcocite ore bodies of the Butte district.) This feature will be more fully discussed in connection with the problem of ore formation.

## GENERAL GEOLOGIC STRUCTURE.

*Regional Faulting.*

It is difficult to recognize lines of faulting in the area of the Boulder granite batholith on account of the uniformity of the rock and the frequent masking of structural features by surface débris or late volcanic flow coverings. Numerous faults are known, many of which are mineralized, but the necessary evidence is lacking to fix definitely the direction of throw and amount of displacement along these fissures. Unless dikes or veins are intersected, no clue is afforded as to their magnitude other than the width, amount of fault clay, crushed wall rock, etc.

Taking a broad view of the Boulder batholith, it is of interest to note that fissuring is a common feature over the whole area. While no mapping has been done which permits of an accurate classification of these fissures, it is known that in general they may be grouped into two main series: (a) those having a general east-west strike, and (b) those having a northwest-southeast strike; both groups corresponding in a broad way with the two most important fracture systems of the Butte district. In general, however, these fissures are more or less localized, and it is not proper at this time to regard them as planes of movement resulting from great regional disturbances.

Of the recognizable faults of this class the only one known to be directly concerned with the geology of the Butte ore deposits is the Continental fault, lying in a north and south direction along the base of East ridge near the Pittsmtont mine. There is but little doubt that this fault is of comparatively recent origin, and that it has had an important influence in determining the present topography of the district. The dip is to the west at a steep angle, Butte being on the downthrown, or hanging-wall side. The amount of vertical displacement is probably in the neighborhood of 1,500 ft., while the direction and amount of horizontal displacement have not been determined. A more detailed description of this important fault will be found on a later page. (See pp. 29-30.)

## STRUCTURE OF THE BUTTE DISTRICT.

Locally, the rocks of the district are intersected by many separate and distinct periods of fissuring. These fractures cut alike the granite, aplite, and quartz-porphry, but the rhyolite plug forming Big Butte has been found in many instances to be later, often cutting through veins belonging to certain fissure systems. These observed facts throw considerable light on the relations between the aplite, quartz-porphry and the later rhyolite eruptions, but owing to lack of mine development in the western part of the district it is, as yet, impossible to correlate definitely the rhyolite intrusion with any particular period of fracturing or mineralization in the copper or silver veins. The rhyolite is known to be younger than the earliest vein system, but further than this the exact time of the eruption is not known.

Plate I. has been prepared to illustrate the structural relations of the various fissure systems. It is a horizontal section taken approximately at an elevation of 4,600 ft. above sea level, corresponding to an average depth, in the mines, of 1,500 ft. below the surface. Owing to the small scale of the map and the complexity of the vein and fault structure it has been possible to represent only the larger

and more general features. The Anaconda fractures, which are continuously mineralized, are denoted by solid black. The vein filling other than the crushed granite, in the later fissures is also represented by solid black whether it be of commercial grade or not. Indeed, in many instances, the indicated vein filling is not of commercial grade. The structural features are well developed by mine openings, and therefore the map may be regarded as only slightly idealized.

Plate II., a north and south vertical section through the copper district in the vicinity of the Anaconda shaft, indicates the structural relations of intersected veins and fissures on dip. Since the plane of section meets the Blue and Rarus faults at acute angles the dips indicated are flatter than the true dips.

#### *Classification of Fissures.*

Grouped according to their relative ages the fissures of the Butte district may be divided into six distinct systems, as follows:

1. Anaconda or east-west system, comprising the oldest known fractures.
2. Blue system, the earliest fault fissure.
3. Mountain View breccia faults.
4. Steward system.
5. Rarus fault.
6. Middle faults.
7. Considered as a local feature the Continental faulting may be regarded as a seventh separate period of fissuring.

This classification is based on information gained through a close study of the intersections of the various fissures, aided to some extent by strike and dip and their mineralogical and physical characters. While the development by actual mine openings generally determines definitely the relative ages of intersecting veins or fissures, it is often desirable to learn in advance, if possible, the age relations of certain veins or fractures before such intersections are reached by mine workings. In these cases the vein characteristics must be relied upon for proper guidance. As a general rule the mineralogical composition offers but slight assistance, being a factor depending on geographical location rather than on relative geologic age. Where intersections are not available, the physical character of the fissure together with the determined strike and dip is of importance. As will later appear, the Anaconda fractures are more solidly and continuously mineralized and have a more nearly east and west strike than the later systems. The Blue system fissures are typical fault fissures, with ore occurring in disconnected shoots, and they have a remarkably uniform strike of about

N. 60° W. The Steward fissures are characteristic faults, with a slightly north of east strike, and contain ore more sparingly than the Blue fissures. The Rarus and later fractures are typical fault fissures of marked movement and contain no ore other than fragments or blocks dragged from older veins.

When a typical fault fissure is penetrated by a mine opening and is found to carry no vein mineral or ore where encountered, the strike and dip are the factors used in provisionally assigning it to a recognized fissure system.

The Mountain View breccia faults have certain physical characteristics by which they are readily distinguished from all other fracture or vein systems.

Difficulties in classification are met with in certain areas, where the Anaconda fractures are but slightly mineralized and some secondary movement has taken place along them, resulting in a vein which closely resembles the later faults. Again, in the Mountain View, West Colusa, and Leonard mines, many of the Blue fissures are solidly mineralized over hundreds of feet, making them identical in physical appearance with the older veins. A further complication arises in this section owing to the presence of many ore-bearing cross fractures, which, though parallel to the Blue fissures, are in fact older and belong to the Anaconda system.

A more general classification or grouping of these fissures may be made which is to some extent a genetic one, but largely one having to do with the physical nature of the fissures. This reclassification or grouping is offered here in an endeavor to set forth more clearly to the reader the physical differences between the earliest-formed veins and those of later age known as fault veins. A clear understanding of these differences will be of material aid in forming a proper conception of the main structural features of the faults and ore deposits, which at times are bewildering in their complexity.

From a study of the occurrence and nature of the various fissures of the district it is found that they may be arranged in three general groups, as follows:

Group A.—Remarkably continuous complex fractures or fissures of but slight displacement, with but little or no crushing of the wall rock; varying greatly in strike and dip, and exhibiting at times a tendency to develop highly fissured areas in which there may be found a multiplicity of transverse fractures more or less at right angles to the general direction or strike of the main fracture planes. The whole Anaconda fracture system falls within this group. As mineral veins they are in general uniformly and continuously mineralized.

Group B.—Persistent well-defined fissures of marked displacement and of later age than Group A. The fissures of this group are typically fissures of faulting, being invariably accompanied by crushed granite, attrition clay or gouge, etc. It is seldom that these evidences of movement are entirely obscured by later mineralization. In marked contrast to the fractures of Group A, these fissures are not continuously mineralized, the mineral bodies occurring in disconnected shoots. Included in Group B are the ore-bearing faults of the Blue and Steward systems, also the later unmineralized fissures such as the Rarus, Bell, Middle, and Continental.

Group C.—Breccia-filled angular cracks or fractures later in age than Group A, but prior to some of the faults of Group B. These angular cracks exhibit no displacement. They appear to have been formed by the simple drawing apart of the wall rocks. The Mountain View breccia faults and the ore breccias of the Gagnon mine are the important examples of this group.

#### *Anaconda Fracture System.*

The Anaconda system includes the earliest-formed fractures of the district. It embraces, therefore, all fissures known to be earlier than the oldest known faults, which are those comprising the Blue system. It is not absolutely certain that all of the old fractures provisionally placed in the Anaconda system are exactly of the same age, but they are practically so. Such additional, recognizable fractures which are older than the Blue fissures and yet are later than the oldest known mineralization are of minor importance and not resolvable into a distinct system. Where such early fissuring is observed, cutting older fractures, it is believed to have resulted from continued movement or slight readjustments along the main fracture lines during the active period of mineralization.

The Anaconda fissures are the oldest geologically and the most important commercially in the district. This group has formerly been called the "East-West" or "Quartz-Pyrite" system of veins, both misnomers, strictly speaking, because the fractures exhibit wide variations from an east-west strike, and the mineral content of the Butte veins is not necessarily an incident of geologic age, but rather one of geographic position. This system is represented by a series of complex fractures, of a general east-west strike, extending across the district. In a broad way, in the copper-producing area they may be divided into two groups, one north of the other and separated from the latter by a relatively barren area. The northerly group embraces the Syndicate, Bell-Speculator and nearby fractures, and

the southerly comprises the Anaconda, Moonlight, O'Neill, and others.

*North Group.*—The most important fracture zone of this group is the Syndicate vein. In adjoining properties it is successively called the Yellow Jacket, Poulin, Buffalo, Mountain Con, Wake Up Jim, Middle vein, Bell-Speculator vein, etc. Westerly from the Mountain Con and Green Mountain mines the Syndicate vein is usually a well-defined, single, mineralized fissure, rarely branching excepting for short distances, forming "horses," or included barren granite blocks. Toward the east, however, it divides, and its various branches take a southeasterly course toward the Mountain View mine and split further into smaller veins until the identity of the major fissure is completely lost. These smaller branches form in a general way, no doubt, a connecting link with the great Anaconda complex in the vicinity of the Mountain View mine.

Other important fissures of the north section of the copper-producing district belonging to the Anaconda system are the Badger State, Berlin, North Wild Bill, Modoc, Mountain Con South, Eastwest Gray Rock, and the North vein of the Mountain Con mine. In addition to those above named there are numberless small cross fissures and cracks, associated with the larger fissures, and of geological interest, but not important as ore producers.

The main Syndicate vein in the Mountain Con and Buffalo dips  $88^\circ$  to the south. It is variable, however, at times dipping slightly north. Southeasterly it has a southerly dip of  $60^\circ$ . The North Wild Bill is vertical or slightly south dipping. The Badger State dips north at the surface, changing to a steep south dip in depth. The Eastwest Gray Rock and Modoc fissures dip  $65^\circ$  south, and the North vein of the Mountain Con dips  $50^\circ$  to the south.

*South Group.*—The south fracture complex known as the Anaconda vein in the Never Sweat, Anaconda, and St. Lawrence mines is of vastly more commercial importance than the north group. Beginning on the extreme west in the Gagnon mine, where it forms a compound fissure zone combined with later faulting, and passing easterly, it is known successively as the Gagnon, Original, Parrot, Anaconda, and Mountain View South vein, etc. Although intersected and displaced many times by later faults the identity of the main fissure is not lost. Easterly from the St. Lawrence mine this fracture exhibits great complexity. Passing through the Mountain View mine there is developed a great fissured zone bounded on the north by the Shannon vein, the easterly extension of which is the Colusa vein, and on the south by the Mountain View South No. 2 vein, the last named being

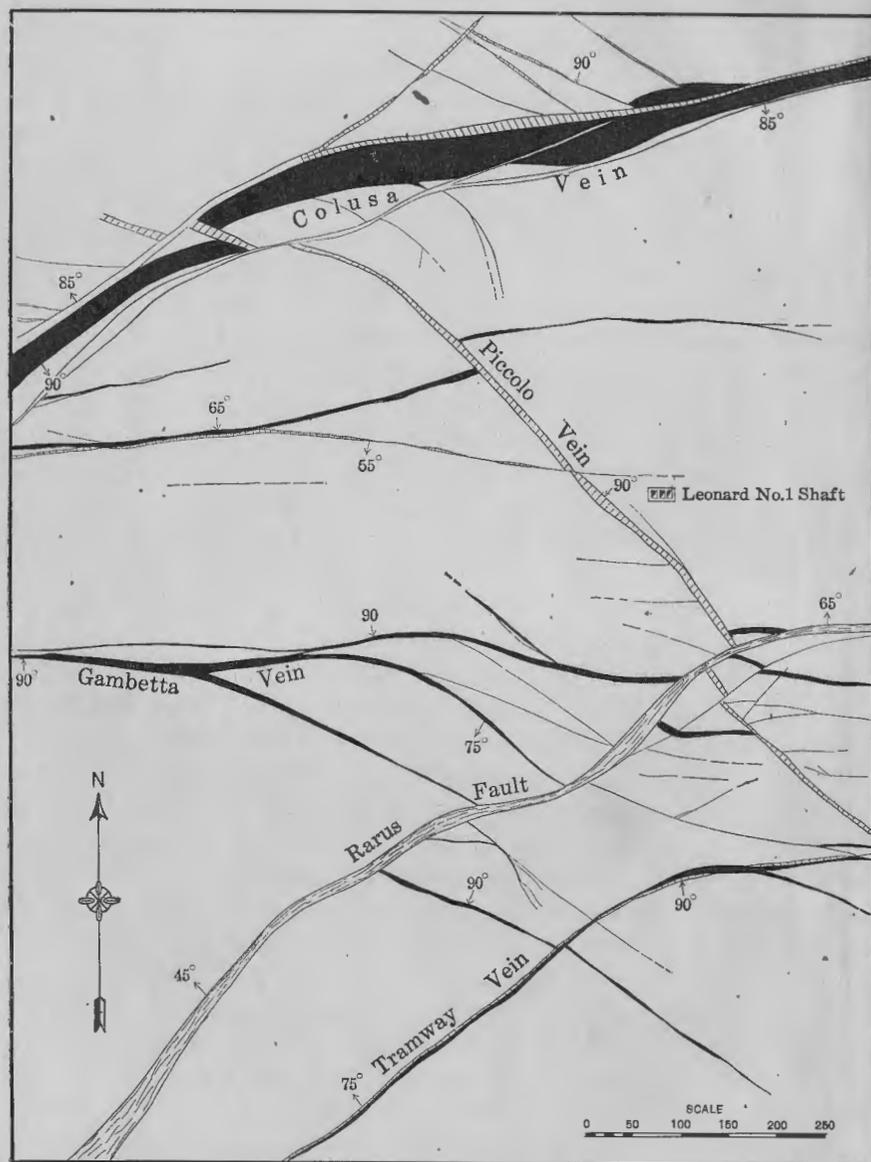


FIG. 1.—PLAN OF A PORTION OF THE 300-FT. LEVEL OF LEONARD MINE, SHOWING VEIN STRUCTURE.

the faulted extremity of the main Anaconda fissure. The Shannon or north bounding fissure has a strike of N. 75° E., and a dip of 85° north, while the South No. 2 vein strikes S. 75° E., and dips 65° south. In its southeasterly course the latter branches into many fissures, forming many smaller veins of the Rarus and Berkeley mines; the identity of the principal fissure, however, is lost.

The distance between the limiting Shannon and South No. 2 fissures at the Mountain View shaft is 400 ft. For several hundred feet east of the Mountain View shaft there are a great number of connecting cross fractures between the Shannon and South No. 2 fissure. These cross fractures have a general strike of N. 20° W., with a westerly dip of about 75°. In many instances these cross veins have proved to be good producers of ore, although they are not of great width. The structure here is much complicated by the presence of several mineralized fissures belonging to the Blue system, being in fact the southerly extensions of the Gray Rock fault veins.

Owing to the divergence on strike of the Shannon and South No. 2 veins, the space between these limiting fissures becomes greater toward the east. There is an increasing tendency on the part of the Shannon vein to throw off north-south fissures in a southerly direction. In the West Colusa upper levels enormous stopes were made, using the north boundary of the Shannon fissure as the north wall, while the larger portion of the material mined out was mineralized granite intersected by a multiplicity of closely spaced fissures having a general strike of about N. 20° W., or nearly at right angles to the strike of the Shannon fissure. In the Leonard mine the north and south fissuring is not present in the upper levels. (See Fig. 1.) The first tendency toward a development of transverse fracturing appeared on the 600-ft. level. At greater depths the north-south fissuring became more intensified, while the east-west fissures became gradually less prominent, until it was found that below the 1,200-ft. level only the great areas of closely spaced north-south fissures remained, bounded on the north by the limiting north wall of the Shannon fissure, and forming the great "horse-tail" ore bodies of the Leonard, Tramway, and West Colusa mines. (See Fig. 2.)

Going northeasterly, the termination of the Shannon-Colusa-Leonard vein is remarkably abrupt and gives rise to a most peculiar geological condition. The throwing-off tendency of the Shannon fissure reaches a climax near the Leonard shaft, where the east-west fissuring ceases and the identity of the Shannon-Colusa vein is completely lost in a perfect maze of north and south fissuring without definite boundaries. (See Plate I.)

Lying to the south and parallel to the main Anaconda fissure are two important veins known as the Moonlight and O'Neill veins. The O'Neill fissure is distant about 1,000 ft. from the Anaconda, and it forms the general southern boundary of the great zone of alteration. The eastern extension of the O'Neill vein is known as the Pennsylvania No. 1 vein in the Pennsylvania mine, and as the Silver Bow vein farther to the southeast. The Moonlight fissure is prominent in the Moonlight and Anaconda mines, but dies out in an easterly direction before reaching the Pennsylvania shaft.

Many small unimportant fractures belonging to the Anaconda series occur south of the O'Neill vein, notably the Cambers, J. I. C., Glengarry, Silver Bow No. 3, and others, but these have been only slightly developed, owing to their non-productiveness in depths greater than 400 ft.

Southeasterly from the Rarus, Berkeley, and Silver Bow mines, fissures of the Anaconda system pass into the property of the East Butte Mining Co., following in a general way the course of the quartz-porphry dikes. These relations may be readily understood by referring to Plate I.

The principal veins of the so-called silver area are believed to be mineralized fractures of Anaconda age. Owing to the mining inactivity for many years past in this area, and through the general lack of definite information concerning the geological conditions, it is not possible to map with any degree of accuracy the vein structure in that section.

#### *Blue System of Fissures.*

In the Blue system of fissures is included a series of northwest-southeast fault fissures which cut and displace the fractures of the Anaconda system, but are themselves older geologically than the Steward faults. Their general strike is in the neighborhood of N. 55° W., with extreme variations within a range of N. 30° W. to N. 75° W. There is a notable uniformity in the arrangement or spacing of the important members of this series of faults in a northwest-southeast direction, or at right angles to the general line of strike. This feature is well illustrated in Plate I.

The important fissures of the Blue system, named in order of their occurrence, beginning on the southwest, are the No. 2, No. 1, Clear Grit, Blue, Diamond South or Dernier, High Ore, South Bell, Skyrme, Edith May, Jessie, Gem, and Croesus, all of which are mineralized and most of which contain ore bodies of immense value.

In contrast to the marked uniformity in strike, permitting accurate projections over hundreds or even thousands of feet, the dip of the

Blue veins tends toward the opposite extreme. The fissures as a rule are steep, but the variations in dip along a single fissure may cover a wide range. It is not uncommon to note a change from a north dip to a south dip, followed by a change again to the north, all taking place within a vertical range of 1,600 ft. The Edith May vein, for example, dips 80° north from the surface to the 700-ft. level; it is vertical from the 700-ft. to the 1,600-ft. level, and has a south dip below the 1,600. The Jessie exhibits tendencies even more erratic. In the Modoc mine it is very steep or slightly north, dipping near the surface, changes to a 60° south dip at a depth of about 500 ft., retaining this flatter dip to the 700-ft. level or thereabouts, where it again assumes a vertical dip to the deep levels.

While the general tendency of the fissures of this system is to dip south, some of them do not follow this rule. The most southerly ones, the Clear Grit, Flat, and Blue, have decided south dips, from 45° to 65°. Those intermediate, the Skyrme and Edith May, are more nearly vertical, while on the extreme north the tendency is to dip steeply north in the upper levels, with a change to the south at greater depths. The general variations in dip are well illustrated in Plate II. The Skyrme vein is of a particularly wavy habit on its descent into the earth.

The fissures of the Blue system are faults of marked displacement. Owing to the uniformity of the country rock in which the fissures occur it is difficult to determine accurately the direction of movement and amount of displacement. Where, however, a fault plane intersects two or more veins having different strikes and dips, these factors may be closely approximated. The amount of movement along the more important Blue fissures ranges from 150 to 300 ft. The High Ore fault vein displacement has been determined by Paul Billingsley to be in the neighborhood of 270 ft., with the line of direction of movement making an angle of 35° with the horizontal. In all of these fissures the south or hanging wall has apparently moved to the southeast and downward relatively to the foot-wall and the direction of movement of the hanging-wall has been along a line making an angle of 15° to 35° with the horizontal. The Blue faults more properly fall under the head of thrust faults, rather than normal faults as the latter term is commonly understood.

In cases where but one vein is cut by the fault plane there is a certain feature to be observed which offers a clue to the direction of movement. Large grooves, or striations, may be seen in the hard ore or the wall rock adjacent to the principal planes of movement. These grooves, or waves, measure from a few inches to a foot or

more from crest to crest, with depths of an inch or more. The writer is led to believe that they are good indications of movement because they exhibit a remarkable uniformity in dip or pitch along the walls where recognized in widely separated members of the series, and they correspond in this respect to the larger fault vein structure earlier described. This belief is corroborated by the determination in the case of the High Ore fissure above noted. The small scratches and parallel lines so commonly seen in the soft fault clay are of no value whatever as indications of direction of important movements. In a single slab of clay an inch thick striations or lines may be found extending in every conceivable direction.

Viewed in a broad way the fissures of this system show a strong tendency to branch toward the southeast, a feature well marked in the Blue, Skyrme, Edith May, and Jessie veins. Toward the west and northwest there is a noticeable swerving to a more westerly strike and many instances of unions on strike of important fissures are noted. A good example of this condition occurs in the Corra mine where the High Ore, South Bell, and Skyrme veins unite, forming a single fissure. (See Plate I.) This evident tendency to unite westerly on strike with a possible greater displacement along the large single fissure may have some significance when taken in connection with their origin.

#### *Mountain View Breccia Faults.*

A curious and interesting feature in connection with the copper veins is the occurrence of peculiar breccia faults (filled cracks) in certain localities within the copper-producing area. They are of frequent occurrence in the Mountain View and Leonard mines in the eastern part of the district and in the Gagnon mine on the west.

These breccia faults, or veins, are persistent angular fissures filled with fragmental material composed of country rock or with some fragments of earliest veins. The size of the fragments ranges from pieces a foot or more in diameter down to fine sand. Generally the breccia is a mixture of all sizes, although at times it is all fine material so arranged in the fissures that it resembles stratified sandstone. As a rule it has the general appearance of ordinary concrete, showing angular rock fragments loosely set in a matrix of finer disintegrated granite grains. Often the larger pieces are rounded and look water-worn like stream pebbles. At or near the contact or intersection with older veins the breccia frequently contains many fragments of the vein filling, in sufficient quantities at times to constitute ore. This feature is especially important in the Original and Gagnon

mines, where big stopes have been made in ore breccia associated with older veins. In fact, from the surface to the deepest levels this has been a characteristic feature of the Gagnon-Original vein.

The general strike of the Mountain View breccia faults is about N. 75° E. They extend from the most westerly workings of the Gagnon easterly through the Original and Steward mines, thence northeasterly toward the Mountain View mine. At the present time there is not sufficient mine development to determine whether a general continuity exists between the breccia faults of the Mountain View mine and those of the Original-Steward mines. In the St. Lawrence mine they are found in abundance extending northeasterly into and through the Mountain View and West Colusa mines; most of them, however, die out in the vicinity of Leonard No. 1 shaft. While the general northeasterly course is well defined, locally and in greater detail, the strike is extremely irregular. They are angular and zigzag in plan, resembling streaks of lightning. A fissure from 12 to 18 in. in width may be found regular in course for several yards, when it will suddenly offset at right angles, following a joint plane or vein wall for a distance of several feet, after which it again resumes a normal course. These freakish tendencies are well illustrated in the general vein map, Plate I.

The breccia faults vary greatly in width, even within short distances along their strike and dip. Widths of from 6 in. to 2 ft. are common in the Mountain View mine, while thicknesses of from 10 to 30 ft. are prevalent in the Gagnon mine. The north cross-cut of the 1,900-ft. level of the St. Lawrence mine develops a body of breccia 135 ft. in width. A cross-cut on the 1,800-ft. level of the Mountain View mine has been extended 80 ft. into breccia, disclosing but one wall.

*Age of the Breccia Faults.*—The formation of these interesting faults undoubtedly followed the period of Blue vein formation. Without exception the breccia is found to cut through the ore of both the Anaconda and the Blue vein systems. Instances have been noted where secondary unimportant movements have taken place along the Blue vein fissures, intersecting and displacing slightly the Mountain View breccia. The Rarus fault cuts and displaces the faults, but the relation between the Steward faults and the breccia has not been satisfactorily ascertained. In the Gagnon mine the breccia is often much squeezed and faulted by northeast fault movements apparently of Steward age. On the whole the evidence indicates that these breccia faults were formed subsequent to the Blue fissures and later than the ore filling in the Blue vein fissures. They were formed, however, prior to the Rarus faulting and probably slightly antedate

the Steward faults. There are indications that the breccia veins were not all formed at the same time, but that in certain instances in the Mountain View some were formed as late as the Middle faults.

*The Steward Fissure System.*

In the Steward system is included a series of northeast-southwest fault fissures extending across the district. They cut and displace the quartz-porphry dikes and the veins belonging to the Anaconda and Blue systems. The Steward fissures strike slightly more northeasterly than the veins of the Anaconda system, though the angle of intersection is very acute, often forming strike faults along them. Referring to Plate I., it will be noted that these fissures are more or less regularly spaced from north to south and that the strike does not vary much from a N. 65° E. course. The dip is uniformly to the south, ranging from 50° to 75°, with an average approximating 65°.

The most prominent members of this series, naming them in order from south to north, are, the Rob Roy, No. 16, Mollie Murphy, No. 6, Steward, Modoc, La Plata, and Poser. In addition to those named there are many smaller and less important fractures of Steward age, in part branches from the larger fissures, and in many instances sympathetic fractures of apparently limited lateral extent. The Bell fault of the Mountain Con and Diamond mines is a prominent northeast fissure paralleling the Steward faults, but of doubtful age. It is provisionally placed in the Steward system, but later developments may prove it to belong to a later period, possibly as late as the Middle faulting. The Bell fault dips 65° to the south in the upper 500 ft., 85° to the north for the next 700 ft., and 80° southerly again in the deep levels. With the general dip to the south, the north or foot-wall has moved downward relatively to the hanging-wall. (See Fig. 3.) The Bell fault is not known to contain ore other than drag from older veins. No intersections between the Bell fault and undoubted Steward fissures have been developed by mine workings. It is therefore impossible to learn their true relationship, since both exhibit the characteristic fault structure.

The Middle fault of the Mountain View mine was formerly believed to be of the same age as the Steward and it was long considered a member of that system. More recent developments prove beyond question that the Middle fault is later. It is believed that the Middle fault is, in part, a strike fault, along an earlier fissure belonging to the Steward system. This feature will be more fully discussed in connection with the Middle fault.

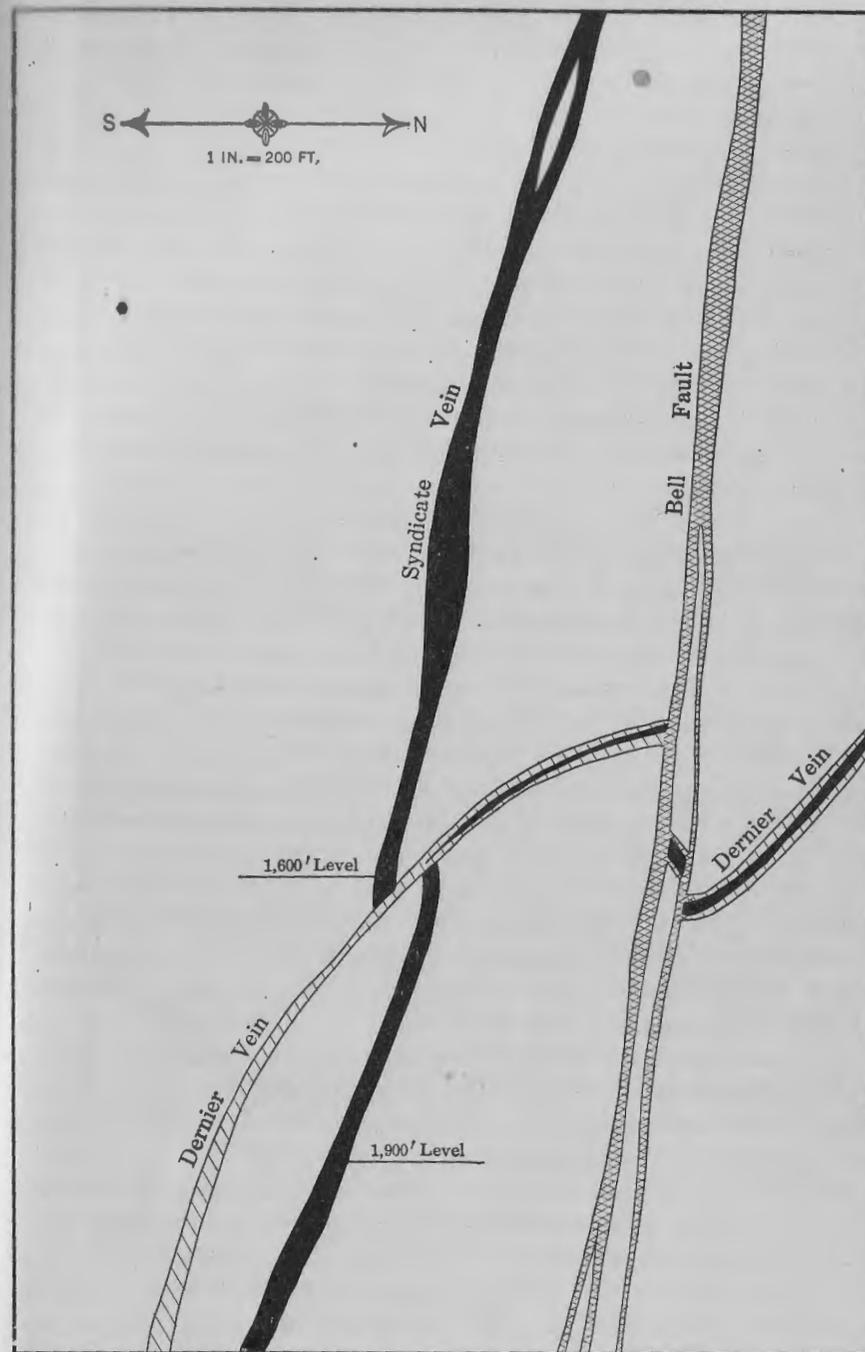


FIG. 3.—VERTICAL SECTION SHOWING DOWNWARD MOVEMENT OF FOOT-WALL COUNTRY ALONG BELL FAULT.

The Steward faults are characteristically fissures of movement. They are narrow zones, or belts, of crushed granite accompanied by well-marked seams of attrition clay. The widths vary from a few inches up to 10 ft., depending largely on the magnitude of the faulting. The total displacement along the faults varies from 50 to 150 ft. in the important fissures. The Steward fissures are normal faults inasmuch as the hanging-wall has moved downward relatively to the foot-wall. The movement, however, did not take place downward on a line normal to the strike, but along a line within the plane of the fault making an angle of approximately  $70^\circ$  with the horizontal.

With but few exceptions the Steward faults carry no ore; but it appears that in certain instances they have exerted an important influence on the veins of the earlier Anaconda system. This feature will be taken up later in the description of the Steward fissures as ore producers.

#### *The Rarus Fault.*

*Age.*—The Rarus fault is a complex fissure of later age than the Anaconda and Blue systems of fissures. It is more recent also than the peculiar Mountain View breccia veins. It cuts and displaces the principal fissures of the Steward system, but the true age relationship of the Rarus fissure and the Bell and Continental faults is not known. In the St. Lawrence, Mountain View, and West Colusa mines the Rarus fault is faulted by a series of closely spaced south-dipping fissures called the Middle fault, as illustrated in Plate I. Northeasterly in the Leonard and to the southwest in the Moonlight mine the displacement along the Middle fault is slight and not readily recognized. Other northeast fissures in the Mountain View mine, parallel to the Middle fault, are also known to cut and displace the Rarus fault. It was first believed that the displacement of the Rarus was due largely to block readjustments locally in the Mountain View mine, where the whole body of the granite is intensely altered and there exists a multiplicity of fractures. Later evidence seems to indicate that these late movements have been more widespread than first realized, and it is not improbable that the Middle fault may mark but one of a more extensive series of movements taking place subsequent to the Rarus fault.

*Geographic Position.*—The Rarus fault has been opened up by numerous mine workings from the East Colusa mine on the northeast to the Belmont on the southwest, and on dip from the surface to the 2,800-ft. level. The dip is remarkably uniform throughout, varying but little from  $45^\circ$  to the northwest. The strike is variable, ranging from N.  $30^\circ$  E. to N.  $80^\circ$  E., the average being roughly N.  $50^\circ$  E. Although a well-defined compound fissure, broadly speaking, the Rarus fault in

detail is exceedingly complex. In places there are two separate limiting movement planes defined by heavy dark gray fault gouge from 1 to 8 in. thick, usually accompanied by from 10 to 30 ft. of finely crushed altered country rock, and ore fragments where in the vicinity of older veins. The perpendicular distance between the two limiting planes varies from 20 to 250 ft. Where the distance is less than 50 ft. the whole intervening rock mass is thoroughly crushed. With greater separation of the two planes the interfault ground becomes less and less affected, so that in extreme cases, as exhibited in the Rarus mine, the ground between the ultimate boundary fissures shows but little, if any, effect of fault movement. Generally, however, the included country is intersected by parallel or sympathetic fractures crossing diagonally from wall to wall. In the Rarus mine the limiting fissures are distinct and well marked and were early termed the Rarus "hanging-wall" and Rarus "foot-wall" faults.

*Displacement.*—The displacement along the Rarus fault is greater in the southwestern part of the district than toward the northeast; in fact, in the Leonard and Colusa mines the fissure becomes so split up that its identity cannot be established northeasterly from the Leonard shaft. It does not displace the Colusa vein in the upper levels and is believed to die out rather suddenly in this region. The movement along the fault plane is not normal to the strike at all points. The hanging wall has moved downward, the line of movement within the fault plane making an angle of  $90^\circ$  with the horizontal in the Belmont and  $60^\circ$  or even less in the Leonard. In the Belmont the displacement is 350 ft., in the Rarus mine 240 ft., and in the Leonard less than 120 ft.

An interesting feature in connection with the Rarus fault is the shifting of the movement from hanging-wall to foot-wall, or *vice versa*, through the medium of diagonal movement planes intersecting the interfault granite. This is well illustrated in Fig. 4, which shows the faulting effect on certain veins of the Pennsylvania mine. At times the whole fault displacement is so evenly distributed between the limiting boundaries by means of small movement planes that no actual cut-off of the intersected vein occurs. In certain instances the movement has been entirely taken up by interior adjustments within the granite blocks so that no visible movement planes are developed. (See Fig. 4.) The phenomenon of step faulting of veins is a result of the frequent shifting of the movement from the wall through the intervening country rock and veins. The cause seems to be found in the fact that the direction of downward movement of the hanging-wall was not normal to the strike at every point.

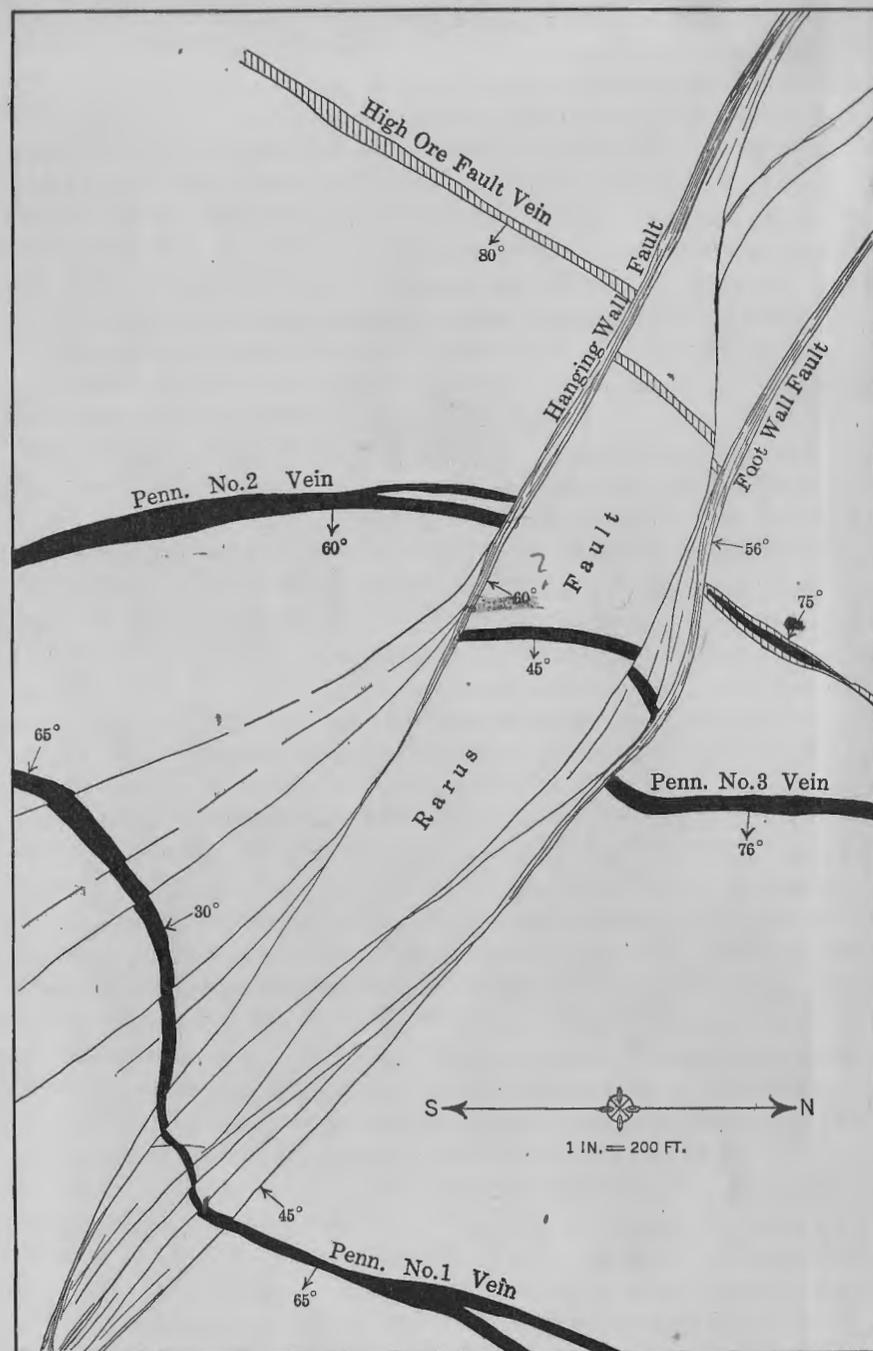


FIG. 4.—PLAN OF 500-FT. LEVEL OF PENNSYLVANIA MINE, SHOWING EFFECT OF RARUS FAULT ON DIFFERENT VEINS.

*Mineralization.*—The Rarus fault has not been found to carry ore other than fragmental ore dragged from older formed veins. These included blocks or fragments varying in size from small bits, or pebbles, etc., up to large blocks or slices of veins which reach from wall to wall of the fault. In thickly veined areas it frequently happens that segments of one vein are moved within the fault to a position where the ends are brought opposite an entirely different vein lying without the fault zone. This phenomenon formerly gave rise to the belief by some geologists that no displacement occurred along the Rarus fault, for it was found to be possible in rare instances to extend a drift entirely through the fault zone on vein, although the faulted portions of three separate veins were required.

Mine developments so far indicate that the only indigenous minerals of the Rarus fault are quartz and pyrite in sparsely disseminated amounts. The influence of the Rarus fault on intersected veins will be further treated under vein descriptions.

In the Corra and Gray Rock mines a small fault fissure, known as the Corra fault, having a normal displacement of 40 ft., striking N. 75° E. and dipping 50° to the north, is believed to be of Rarus age. It cuts the Anaconda, Blue, and certain fissures of the Steward system. The age relation between the Corra and Bell faults has not been determined. The Corra fault carries no ore.

#### *The Middle Fault.*

Formerly it was believed that the Rarus fault was the latest geologically in the entire district, with the possible exception of the Continental fault at the base of East ridge. Recent mine developments, however, have disclosed the fact that the Middle fissures of the Mountain View mine represent a period of movement later than the Rarus. On account of its strike, dip, and general physical character, the Middle fault was early assigned to the Steward fissure system. It was thought that the No. 16 vein of the Rarus mine, a Steward fissure, was the faulted segment of the Middle fault, lying beneath the Rarus fault. It has been abundantly shown, however, by the recent development of many intersections of the Rarus and fissures of Middle fault age that the latter are post-Rarus.

Owing to the extreme complexity of fissuring in the region of the Mountain View mine the relation between the numerous fractures has not been satisfactorily worked out. The available evidence indicates that the Middle fault is coincident with, and, in fact, forms a strike fault along the segment of the No. 16 vein lying above the Rarus fault. (Fig. 5.)

According to the best information available, the Middle fault exhibits the greatest displacement in the Mountain View mine and vicinity, where it approximates 75 ft., with a lessening amount of movement both to the northeast and southwest. There is certain evidence indicating that the Middle fault is the manifestation of a

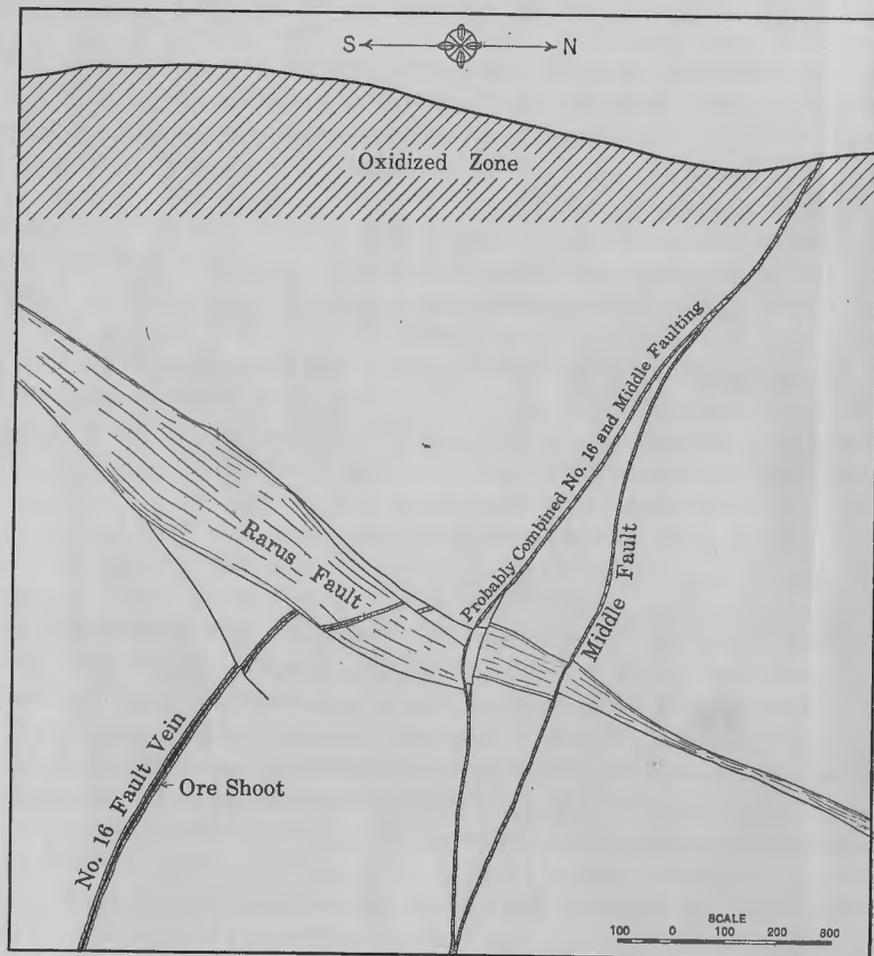


FIG. 5.—VERTICAL SECTION THROUGH THE MOUNTAIN VIEW MINE, SHOWING THE RELATION BETWEEN CHALCOHITE ORE SHOOT OF NO. 16 VEIN, OF THE STEWARD SYSTEM, AND THE RARUS AND MIDDLE FAULTS.

sagging tendency within this particular section, caused by unusual weakness in the earth's crust due to extreme alteration and intense fissuring.

The Middle fault fissure is of the same general character as the typical faults of the district. It carries no ore and exhibits no min-

eralization whatsoever. The strike is N. 65° E. with a general southerly dip, although in deep levels and to the northeast it dips slightly north. The average dip down to the 1,200 Mountain View is 65° to the south, below which level it quickly steepens to a vertical or slightly north dip, which is maintained to the deepest mine levels.

#### *The Continental Fault.*

The Continental fault lies almost entirely without the copper-producing district. It is a complex fissure zone from 200 to 1,000 ft. wide, having a general north and south strike following close to the base of East ridge. It may be seen outcropping in the Great Northern railroad cuts at Horseshoe Bend, from which point it passes southerly through the Six o'Clock, Greenleaf, Bullwhacker, Montgomery, and Amazon-Butte properties. Continuing to the south it follows closely the base of East ridge in a direction toward Nine Mile canyon.

The general dip of this fault is to the west at an angle of 75°. Within the ultimate boundaries of the main fissured zone, wide variations in dip are commonly met. In the Greenleaf mine many of the important movement planes are vertical or slightly west dipping. It appears that the western or hanging wall has moved south and downward, the amount of vertical throw being unknown, but possibly in the neighborhood of 1,500 ft. The horizontal throw is probably several hundred feet, but the evidence is not sufficient to even approximate the amount. The movement of the fault is rarely concentrated along a single plane, but is distributed over a series of roughly parallel fissures, accompanied by a variable amount of breaking or crushing of the intervening country rock. In the Six o'Clock mine a thickness of 4 ft. of tough, dry gouge, dipping 67° to the west, marks the foot-wall fissure. At this point the fault movement is much more concentrated along a single fissure than at points farther south.

No primary mineralization has been recognized in this fault. The intense alteration of the granite, so characteristic of the Blue and Steward faults, is absent. The movement planes of the Continental fault are marked by a tough gouge composed of finely comminuted, unaltered granite. The waters now found within and along the fissure are no doubt of meteoric origin and have effected but slight changes in the crushed country rock. It would seem reasonable to infer from these observed facts that the Continental fault is of comparatively recent origin, and that, at great depths, it did not reach a source of primary vein-forming waters.

The age of the Continental fault relative to the various fractures

of the district is proved by evidence obtainable in the East Butte mines, where two north and south fractures, undoubtedly as a part of the Continental complex, cut and displace veins of the Anaconda and Blue systems, and in one instance a northeast south-dipping fissure probably of Steward age. The relatively recent date of this fault is also suggested by Plate IV., a vertical section taken along the general course of the Anaconda vein showing the probable relation between the fault and the oxidized and sooty chalcocite zones.

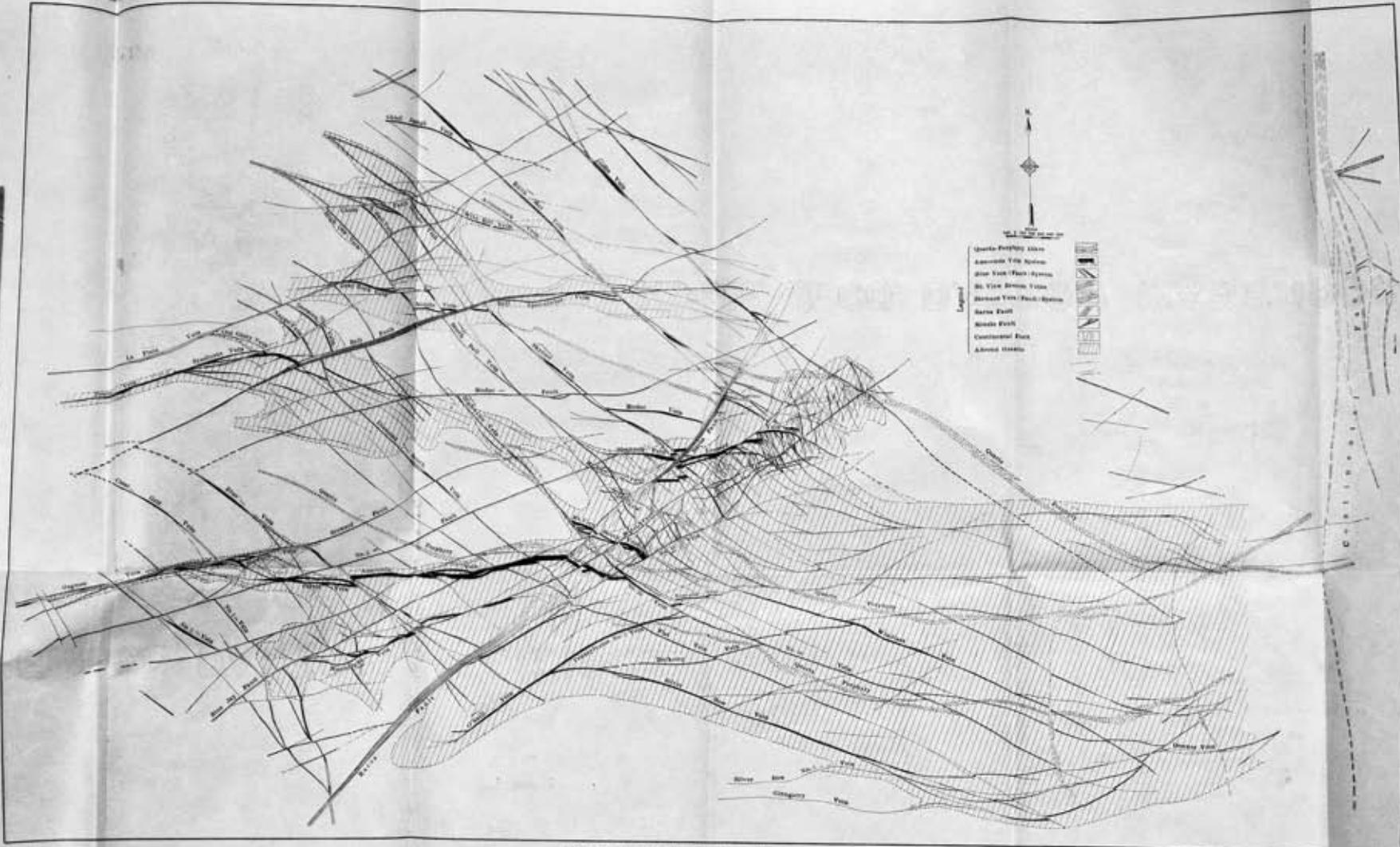
#### ROCK ALTERATION.

Extensive alteration of the rocks has taken place in the Butte district. There are two principal zones or areas associated with the copper veins in which the rocks are altered to an unusual degree. These areas are closely related to the more important developments of the earliest-formed veins, or those of the Anaconda system. One of these alteration zones follows rather closely the Syndicate and other early veins in the Mountain Con, Gray Rock, and Diamond mines. In the two last-named properties the zone reaches a maximum development where intersected by many fault veins belonging to the Blue system. The outline of this zone is so irregular that it cannot be mapped with any degree of accuracy. On Plate III. an attempt has been made to indicate the general conditions. The northerly zone is seen at this elevation to be composed of three or more disconnected areas, all of which merge into one more or less continuous area at greater depths. When referring to the map, Plate III., it should be kept in mind by the reader that only the more important areas of rock alteration are shown by the cross hatching; furthermore, there has been a marked alteration of the granite along nearly every vein and fissure shown on the map, but usually not extending outward for appreciable distances from the immediate influence of the fissures, at least not extensive enough to be accurately represented on a map of this scale.

The largest and most important area of altered granite is in the vicinity of Anaconda hill. In this part of the district a great altered belt extends easterly from the Parrot mine through and including the Never Sweat, Anaconda, Mountain View, West Colusa, Berkeley, and Silver Bow mines, and within this whole area it is next to impossible to find a hand specimen of rock which has not undergone marked chemical and physical changes. As in the case of the north belt above described, there is an unmistakable close genetic relation existing between the widespread rock alteration and the Anaconda vein system, a fact more readily understood by reference to Plate III.

In these two general zones intense alteration has taken place not





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PLATE III.—SECTION-MAP OF IDARADO AREA OF ROCK ALBERATION.

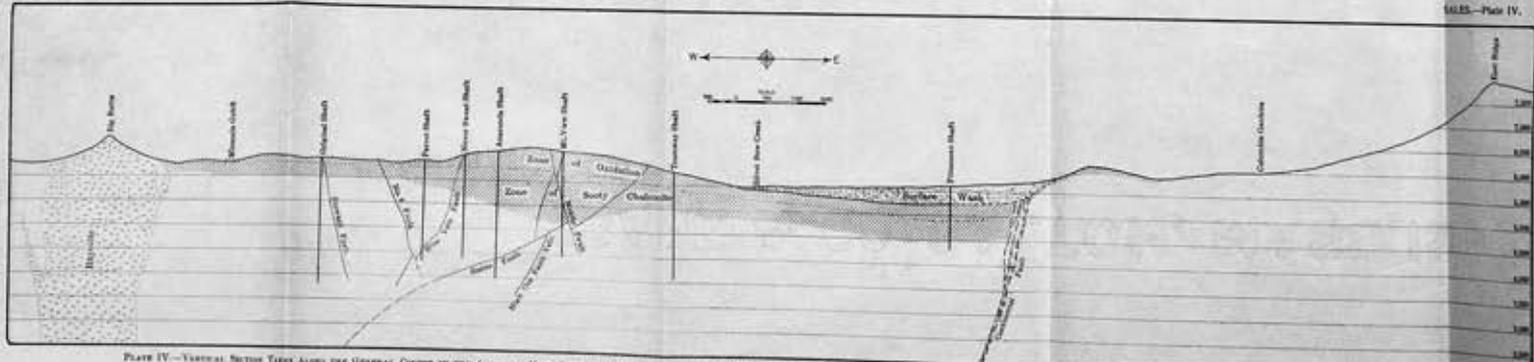


PLATE IV.—VERTICAL SECTION TAKEN ALONG THE GENERAL COURSE OF THE ARAPAHOE VEIN, SHOWING RELATION BETWEEN THE UNOxidized AND SULFIDE CHARACTER ZONES AND THE CONTINENTAL FAULT. THE SECTION IS IDEALIZED IN BEING EAST OF PITTSBURGH SHAFT.

necessarily the case is believed to be due to the following conditions:

1. The earliest ascending waters and gases were much more active chemical agents than later solutions, owing to higher temperature and pressure conditions, and to some extent, possibly, to their chemical composition.

2. The earliest fractures were fissures of but slight dislocation, therefore they were unaccompanied by impervious crushed granite and fault clay. The solutions and gases were thus accorded easy access to the wall rock at all points along the fissures. In later faults exhibiting much movement the circulating solutions were often closely confined within impervious fault-clay seams, and as a result unaltered wall rock is commonly found within a few feet of extensive ore bodies.

3. The regions traversed by the oldest fractures have been subjected to the action of vein-forming processes over a much longer period than regions adjacent to later fault veins.

There can be no question but that chemical agents have been greatly aided in their attack upon the granite and other rocks by dynamic processes. The breaking and crushing of the country rock in the Butte district has been on a profound scale. Dynamic agencies have not only furnished the avenues of travel within the rock for the gases or highly heated water, but, through accompanying crushing and mashing, the rocks are made more susceptible to attack by solutions. The true nature of the changes in the rocks, other than crushing, wrought by dynamic agencies, has been in a large measure obscured by subsequent metasomatic processes accompanying vein formation.

*Vein-Forming Processes.*—The alteration from this cause took place along and outward from fractures which acted as channels for the uprising solutions. These waters, of deep-seated origin, traversed not only the main trunk channels and associated fractures, but in highly fissured areas they followed also the joint planes, and penetrated, by slow stages no doubt, the whole mass of the granite in the more highly fissured areas. The remarkable activity of these thermal processes is evidenced by the development of the extensive altered zones accompanying the oldest fracture systems.

The initial stage of these changes, which were metasomatic in their nature, seems to have been the development of chlorite accompanied by the formation of pyrite. The uprising thermal waters or gases attacked first the iron silicates, augite, hornblende, and biotite, forming chlorite, epidote, secondary silica, and iron pyrite. Pyrite was developed also from the iron of the magnetite, the sulphur in this case, as in the former, being furnished by the attacking thermal waters, in

which it existed as hydrogen sulphide or as an alkaline sulphide. Plagioclase and orthoclase feldspars give way to continued attack, resulting in the formation of sericite and secondary silica. The result of the continued action of these metasomatic processes upon the granite has been the development of "pyritized" granite. The early-formed chlorite and epidote largely disappear; practically all of the iron of the original granite is converted into pyrite; and the feldspars are broken up into sericite and quartz. "Pyritized" granite, therefore, where representing the extreme development of the sericitic stage, consists principally of sericite, quartz, and disseminated pyrite.

Since the abundant fractures of the various systems form the medium through which thermal waters, or vein-forming solutions, traverse the body of the rock, the alteration necessarily proceeds, generally speaking, outward from these channels. The alteration is therefore usually more intense immediately along and within the fractures or fracture zones. Vein-forming processes have altered large areas of rock within and tributary to the Anaconda fissures; the Blue veins show less alteration of the wall rock than the Anaconda fissures, and similarly the Steward faults exhibit less alteration of the wall rock than the Blue veins, although in every case alteration has been intense within the fissures themselves.

Charles T. Kirk's<sup>5</sup> studies indicate that these various alteration phases are seldom free from the presence of kaolinite, a mineral of uncertain origin. It may be here stated that the relative quantity of kaolinite present in the deeper levels is insignificant when compared to the amount present near the surface, where it is known to result from the action of cold meteoric waters on pyritized or sericitized granite. There seem to be excellent reasons, to be later given, for believing that a large part of the present-day existing ground-water, even to great depths, is of meteoric origin, carrying appreciable quantities of iron sulphates and sulphuric acid. In the presence of such waters a slight development of kaolinite might be reasonably expected, while an important actual movement of these waters need not be inferred.

*Common Hydro-Metamorphism.*—Cold meteoric waters penetrating and passing downward through areas of unaltered Butte granite have effected but slight changes. The chemical activity of such solutions has apparently been slightly increased where preceded by crushing, and notably increased where preceded by rock alterations caused by vein-forming waters. The action of meteoric waters has, therefore,

<sup>5</sup> Kirk, C. T., Conditions of Mineralization in the Copper Veins at Butte, Montana, *Economic Geology*, vol. vii., No. 1, p. 60 (Jan., 1912).

been most intense in veins and in the great alteration zones associated with the Anaconda fractures earlier described. The reasons for this increased activity in veins and in regions of altered granite are many. The oxidation of the pyrite of the veins and the disseminated pyrite of the altered granite results in the formation of iron sulphates and free sulphuric acid, which readily attack the already altered granite below, converting the sericite largely to kaolin. This process develops greater porosity in the granite, thus affording a more ready passage for the surface waters to greater depths.

The most noticeable effects upon the pyritized altered granite of descending meteoric waters have been kaolinization and chalcocitization, accompanied by greater porosity. In general, the ordinary meteoric waters have had no noticeable chemical effects upon the normal Butte granite at depths greater than the vertical thickness of the oxidized zone, which is seldom more than a few feet in unaltered granite.

*Depth Reached by Meteoric Waters.*—The maximum depths reached by meteoric waters in the Butte district cannot be definitely determined. It is probable that they have descended to greater depths than any yet reached by mine workings. A study of the physical and chemical changes that have taken place in the veins and country rock known to be due to the presence of waters of meteoric origin, offers the only criteria for a partial solution of this problem.

The oxidized zone, resulting from the oxidizing influence of meteoric waters, varies in depth from 10 to 500 ft., an exceptional case in the Mountain View mine measuring over 900 ft. from the surface. The average depth, however, along the Anaconda vein is not more than 300 ft. That surface waters move downward to depths much greater than the lower limit of the oxidized zone is proved by the occurrence of an abundance of minerals in the veins and country rock known to be of secondary origin. Of these, chalcocite and kaolinite furnish the most reliable indicators of meteoric water influence. In veins and pyritized granite wall rock below the zone oxidation, the processes of chalcocitization and kaolinization go hand in hand, with the important difference, however, that while chalcocitization is always accompanied by kaolinization, the reverse is not necessarily true. Kaolinite, probably resulting from meteoric water action, is found at much greater depths than undoubted secondary chalcocite, and from this fact it is believed that down-seeping sulphate solutions continue to act on altered granite, forming kaolin, long after the last trace of copper has precipitated out as chalcocite in the zone of secondary chalcocite at higher levels.

Since primary chalcocite occurs in great abundance in the Butte veins, the mere presence of mineral chalcocite is not indicative of the presence of meteoric waters. The presence of the "sooty" chalcocite, however, which is known to be a product of descending meteoric waters, may be generally taken as proof of surface water action.

As a reliable means of determining more or less accurately the amount of vertical descent of meteoric waters, secondary chalcocite loses much of its importance when it is considered that the depth of the zone of secondary chalcocite is dependent upon many variable factors such as topography, mineralogical and physical character of the vein, etc. The depth of the zone of secondary chalcocite varies from 50 to 200 ft. in the fault veins to a maximum of 1,200 ft. in the veins of the Anaconda system. With the aid of a reliable method for distinguishing between primary and secondary chalcocite when in the massive form, the value of this mineral as a criterion of descending sulphide enrichment will be greatly increased.

If kaolinite is characteristically a product of meteoric water action, it is safe to conclude that surface waters have descended to depths greater than any yet reached by mine shafts. However, if, as Gregory<sup>6</sup> holds, kaolinite may also result from hydrothermal action at great depths, the small quantities of kaolinite present in the deep Butte levels may not be properly regarded as proof of the presence of waters of meteoric origin.

*Oxidation.*—Oxidizing processes acting upon veins and altered granite tend to transform the sulphides into oxides and native metals. The results of these processes acting on Butte ores and rocks are briefly described in the chapter following.

#### SUPERFICIAL ALTERATION OF THE BUTTE VEINS.

##### *Outcrops of Copper Veins.*

The mantle of "wash," or debris from disintegration and weathering, often masks the intersection of the veins with the surface of the bed rock. This condition is especially prevalent in areas of intense granite alteration, notably eastward from the Parrot and Moonlight and in the vicinity of the Diamond mine. The thickness of the surface wash varies from 2 to 10 ft., although an exceptional thickness of from 200 to 400 ft. occurs in the valley in the vicinity of the Pitts-mont smelter. (See Plate IV.) This unusual thickness, however, has probably resulted from certain conditions brought about by the Continental fault movement, rather than from natural processes of erosion and decay.

<sup>6</sup> Gregory, J. W., Criteria of Downward Sulphide Enrichment, *Economic Geology*, vol. v., No. 7, p. 680 (Oct.-Nov., 1910).

A number of copper veins, notably the Anaconda, Syndicate, and Colusa, have more prominent outcrops characterized by unusual amounts of strong iron-stained quartz and vein matter projecting well above the wash. As a general rule, however, the position of the copper vein outcrops, especially within the alteration zones, cannot be accurately determined without the aid of shafts or tests pits, although the general location and direction may be known by the presence of detached fragments of the veins, or "float." The degree of prominence of vein outcrops appears to be governed largely by their mineralogical content and physical character, and also by the nature of the inclosing wall rock.

The outcrop of a typical copper vein of the Anaconda system is marked by altered granite, quartz, and oxides of iron. There may also be present a small band of oxidized clay or crushed granite within or along the vein. The granite included within the vein boundaries or adjacent to the vein is irregularly seamed and stained with iron oxides. The quartz commonly exhibits the well-known honeycomb structure.

The outcrop of a fault vein of the Blue or Steward systems consists of a slightly iron-stained mass of soft, crushed and altered granite with one or more seams of fault clay of a blue-gray or yellowish color. Where a fault-vein ore shoot outcrops, the composition is very similar to that of the Anaconda veins, with the possible addition of one or more well-defined bands of fault clay.

Almost without exception the copper veins are practically barren of copper at the outcrop and in the zone of oxidation below. There are no visible copper minerals, and it rarely happens that an assay of the oxidized material yields more than a trace of copper. (Compare Table I., following.) Some exceptions, however, may be noted. Small quantities of carbonates and oxides of copper were found in the outcrop of the Gagnon-Parrot vein, also in the Syndicate vein and others. The discovery shaft of the Mountain Chief claim, located on the southeasterly extension of the Jessie vein, was sunk in a rich body of red oxide of copper, running high in silver. The oxidized zone, however, proved to be very shallow in vertical extent, the rich oxide ore changing abruptly to chalcopyrite at less than 30 ft. in depth. (See Plate V.)

Taking a broad view of the entire copper producing area, it may be said with emphasis that there is but little, if any, evidence of a positive character to be found in the outcrops or the oxidized zones of the Butte veins to indicate the existence of copper in commercial quantities at greater depths.

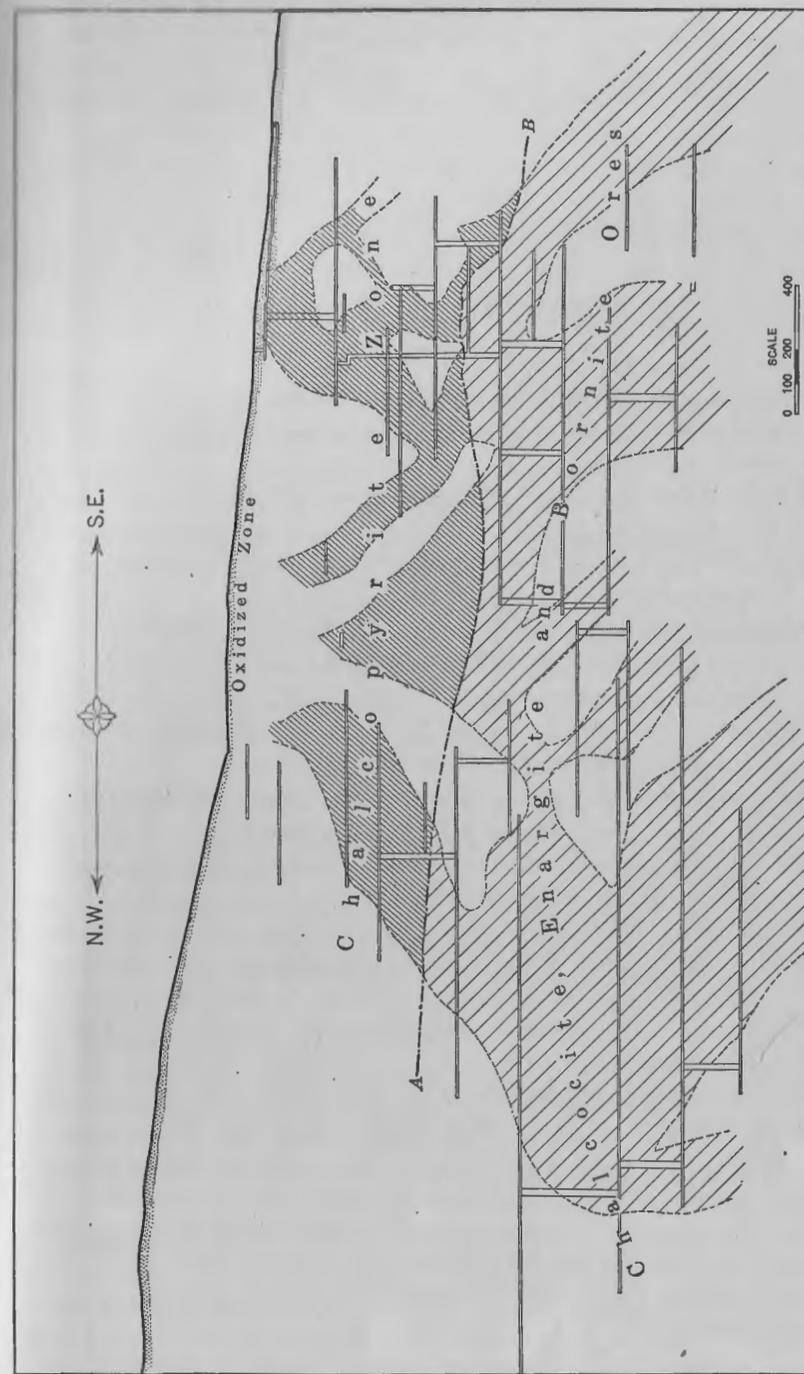


PLATE V.—LONGITUDINAL PROJECTION OF A PORTION OF THE JESSIE VEIN, SHOWING ARRANGEMENT OF ORE SHOOTS.

Line A-B marks approximately the dividing line between chalcopyrite and rich chalcocite-enargite ores below. Both above and below line A-B quartz and pyrite are abundant as gangue minerals. Above line A-B rhodochrosite is commonly present.

The following table gives the analyses of a series of samples taken from oxidized portions of producing copper veins:

TABLE I.—*Analyses.*

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.	XIII.
SiO <sub>2</sub> .....	48.0	84.2	65.5	41.1	79.2	67.4	71.7	69.3	73.3	26.6	58.4	51.9	56.2
Fe.....	4.6	3.3	15.0	30.6	5.9	12.3	8.9	10.2	5.4	19.8	12.5	16.5	17.6
Al <sub>2</sub> O <sub>3</sub> .....	25.3	5.9	4.3	5.4	5.5	7.4	4.1	6.4	11.5	25.9	45.5	8.5	4.7
Cu.....	0.05	tr.	0.12	0.13	tr.	0.15	0.05	0.05	tr.	0.05	tr.	0.05	0.20
As <sub>2</sub> O <sub>3</sub> .....	1.71	0.14	0.79	0.52	0.22	0.38	0.32	0.56	0.38	0.88	5.24	1.29	2.29
Zn.....	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.	tr.
Ag, oz. per ton.....	17.7	3.7	5.8	1.0	4.1	3.1	5.7	10.9	1.2	1.1	2.8	4.2	12.0
Au, oz. per ton.....	0.05	0.008	0.005	0.005	0.07	0.01	0.015	0.02	0.01	0.007	0.03	0.01	0.04

- I. Lloyd tunnel 250 ft. below outcrop of vein.
- II. Well-defined quartz vein 5 ft. wide; sample taken 10 ft. below outcrop.
- III. Oxidized quartz vein of Anaconda system; sample taken 15 ft. below outcrop.
- IV. Soft dark red oxides along fault clay; sample taken 15 ft. below outcrop.
- V. Sample of 4-ft. siliceous vein taken 20 ft. below outcrop.
- VI. Oxidized enargite-chalcocite ore taken 2 ft. above sulphides and 400 ft. below outcrop.
- VII. Oxidized vein; sample taken 20 ft. above sulphides, St. Lawrence mine, and 100 ft. below outcrop.
- VIII. Anaconda vein, Mountain View mine; much enargite in ore below; sample taken 500 ft. below outcrop.
- IX. Anaconda system, South vein; taken above secondary chalcocite ore, 260 ft. from outcrop.
- X. Soft oxidized clayey vein, 20 ft. below outcrop.
- XI. Blue vein system; taken above enargite ore, 360 ft. below outcrop.
- XII. From fault vein enargite ore, Mountain View mine, 450 ft. below outcrop.
- XIII. From south vein, Mountain View mine, 600 ft. below outcrop.

The above samples are from veins lying well within the alteration zone in the vicinity of the Rarus mine. The most significant feature is the high content of As<sub>2</sub>O<sub>3</sub>, indicating that not all of the arsenic is extracted from the vein in the process of oxidation. Further investigations are now under way to determine if possible the relation between the arsenic present in the oxidized to the total arsenic in the unoxidized vein below.

### Outcrops of Manganese-Silver Veins.

In marked contrast to the ill-defined copper-vein outcrops are the bold projecting outcrops of the manganese-silver veins, which may be traced for hundreds or even thousands of feet over the surface. Many of them, like the Rainbow, Silver Lick, Ancient, Emma, and numberless others, project in bold relief from 1 to 10 ft. above the ground surface. Where they do not project above the wash, their presence is generally indicated by an abundance of characteristic float rock.

The outcropping portion or the oxidized zone of a typical manganese-silver vein consists chiefly of quartz and oxides of manganese and iron. As an original mineral of the unoxidized vein, pyrite is not as abundant as in the copper veins, nor is it so universally present.

The Black Rock vein, an important producer of zinc, is a member of the manganese-silver vein series belonging, it is thought, to the Anaconda fracture system. The developments in the Black Rock vein show that many of the great sphalerite ore bodies first appear several hundred feet below the surface, and that the upper portion of the vein is composed principally of quartz and rhodochrosite. The outcrop is mainly quartz and oxide of manganese.

In the outcrops and oxidized zone of the zinc-producing veins the zinc is entirely removed in the processes of oxidation, and not more than a trace remains to indicate the presence of zinc at greater depths.

### Oxidation and Disintegration of the Granite.

In the great zones of altered granite associated with the copper veins there are but few, if any, actual outcroppings of solid granite or bed rock, the latter being effectually concealed by the covering of disintegrated rock. This surface wash, or débris, consists of iron-stained altered granite in the form of angular fragments, and finer incoherent grains, together with fragmentary oxidized vein quartz, aplite, and quartz-porphry. The clusters of rounded boulders so characteristic of the weathering of normal granite are entirely absent.

The unaltered granite is apparently more resistant to the action of atmospheric agencies than the altered granite, and owing to this fact veins or fault outcrops found within normal granite areas are conspicuous as belts or zones of finely disintegrated rock, readily traceable over the surface. Generally in the manganese-silver vein area and all of that portion of the Butte district lying to the north of the Speculator, Tuolumne, and Corra mines, there is but little alteration of the granite, excepting within and along the vein or fault fissures. Under these conditions the positions of the veins and faults are indicated by smooth surfaces, while the intervening areas of normal granite are marked by

the presence of rounded granite boulders, a feature characteristic of normal granite weathering over the whole Boulder granite area.

#### *Zone of Oxidation.*

By the expression "zone of oxidation" is meant those portions of the veins and country rock which have been oxidized through the action of descending ground-waters. It embraces in vertical extent all of the veins and country rock lying above the irregular boundary plane marking the upper limit of the sulphides. (See Plate IV.) The depth of the zone of oxidation in the Butte district is extremely variable in different localities, and in exceptional instances wide variations occur within small areas. For example, in the Mountain View mine, No. 4 vein, the first sulphide ore was met at 250 ft. below the surface, or 150 ft. above the first level, while at a point 400 ft. south of the main shaft the South vein is oxidized for a short distance along its strike to a depth of over 900 ft. below the surface. Extreme local variations of this nature, however, are not the rule. The depth of the zone of oxidation in a particular locality is largely dependent upon the character of the veins and the inclosing country rock (see Plate II), to a greater extent, in fact, than upon the topographic features. The deepest oxidation is found in the great zones of altered granite described on pages 30-31, inclusive, where it runs from 100 to 400 ft., averaging in the neighborhood of 250 ft. (See Plate IV.) Under similar conditions of granite alteration the heavily mineralized veins of the Anaconda system show deeper oxidation than the fault veins, owing to the greater permeability of the quartz vein to downward-seeping waters and to the greater abundance of pyrite, the source of the all-important oxidizers, ferric sulphate and sulphuric acid. In regions unaffected by the widespread hydro-thermal processes accompanying the early vein formation, the depth of oxidation along the veins of the Anaconda system averages about 75 ft., and that of the fault veins 20 ft., with frequent variations in both classes of veins.

Examined from the surface downward the oxidized portion of a copper vein will show but little change in physical character and mineral composition between the outcrop and the sulphide ore below. The line of separation marking the change from oxidized to sulphide ore is extremely sharp. Above this contact plane there is no mixture of oxides and sulphides, the oxidation is complete. The entire change, as shown at any single cross-section of a vein, takes place within a vertical distance of a few feet. Frequently, near the upper limits of the sulphide ore, the proximity of the zone of oxidation is indicated by slight changes in the relative abundance of certain secondary minerals,

but in the case of the oxidized vein there is seldom any change indicating nearby sulphides.

In the quartz-pyrite veins of the Anaconda system within the copper-producing area, the appearance of sulphides at the lower limit of the zone of oxidation almost always means the beginning of commercial copper ore. This feature of the heavily mineralized veins is in striking contrast to the fault veins of the Blue and Steward systems, where the ore shoots are often separated vertically by hundreds of feet of barren unoxidized vein matter which begins at the base of the shallow oxidized zone below outcrop. (See Figs. 6 and 6A.)

Unusual conditions of oxidation are found in the Bullwhacker, Butte & Duluth, and adjoining properties, situated along the line of the Continental fault outcrop east of the Pittsmont mine. It appears that the unoxidized granite of that section carries a small percentage of disseminated chalcopyrite. The shearing and crushing along the fault zone caused a rapid disintegration of the granite under the action of atmospheric agencies, during which process the copper of the chalcopyrite was oxidized and carried downward by surface waters and redeposited as chrysocolla, red oxide, or as a carbonate. The granite exhibits but slight alteration. The resulting ore is therefore a green-stained granite with the more important accumulations of copper carbonate along the cracks and joint planes. As mined the ore runs from 1.5 to 4 per cent. The absence of pyrite in the original disintegrating granite explains the formation of ore of this character. In the process of oxidation of chalcopyrite, insufficient ferric sulphate or sulphuric acid is formed to prevent the formation of the insoluble oxides, silicates, and carbonates of copper. Under such conditions copper migrates but short distances.

#### GROUND-WATER.

Extensive mine developments have disclosed many interesting facts concerning the distribution of the underground waters in the veins and rocks of the Butte district. In areas of intense rock alterations there is approximate saturation of the rocks and veins, a feature in striking contrast to areas of normal granite, where alternate wet and dry zones are the rule. In the great zones of rock alteration not only are the veins wet, but the intervening country carries water as well. The granite in one part of a cross-cut through an area of altered granite may be wetter than at other points, but no part of it will be absolutely dry. The inclosed veins and faults may or may not be wetter than the granite, the more important trunk channels not being readily recognized as in the zones of unaltered granite.

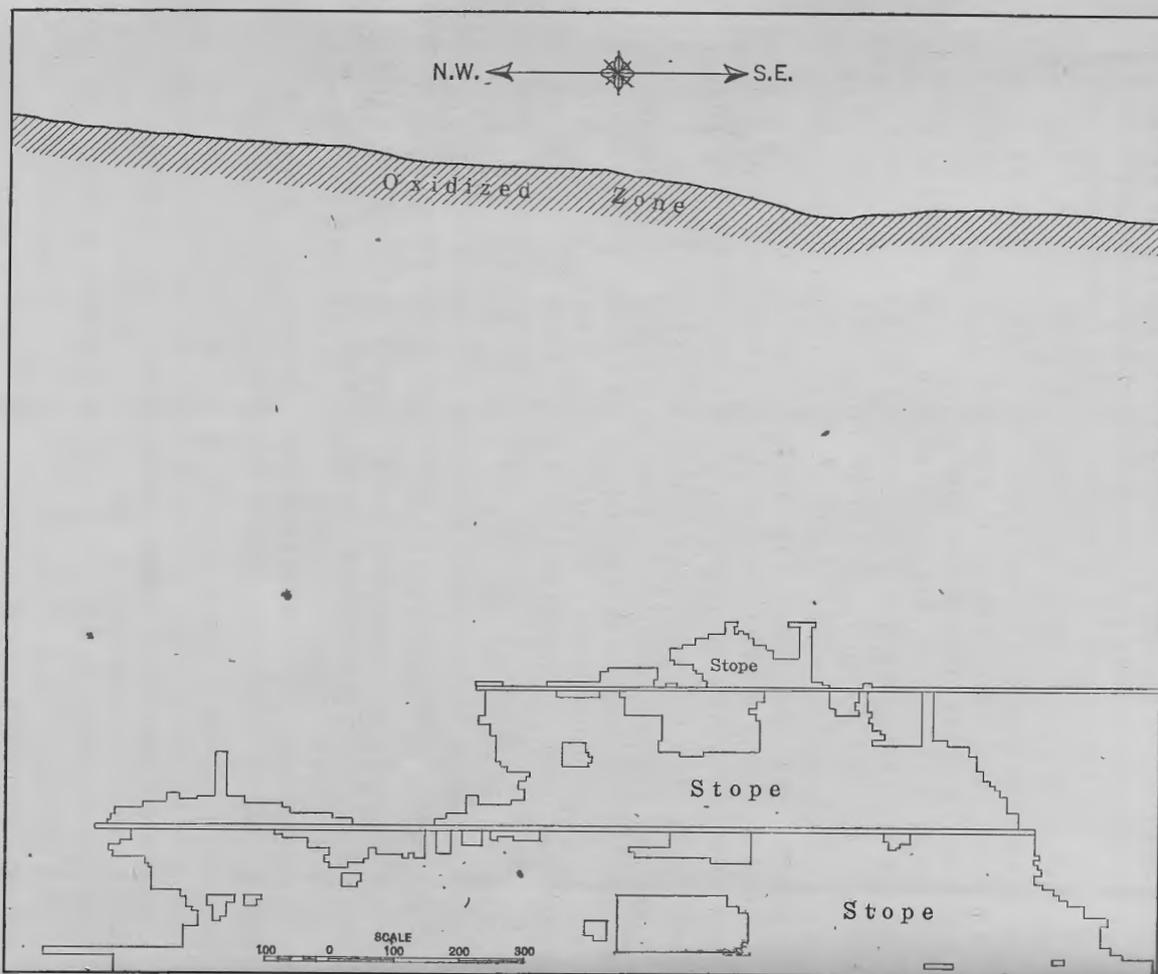


FIG. 6.—LONGITUDINAL SECTION OF THE EDITH MAY VEIN OF THE BLUE VEIN SYSTEM, SHOWING THE

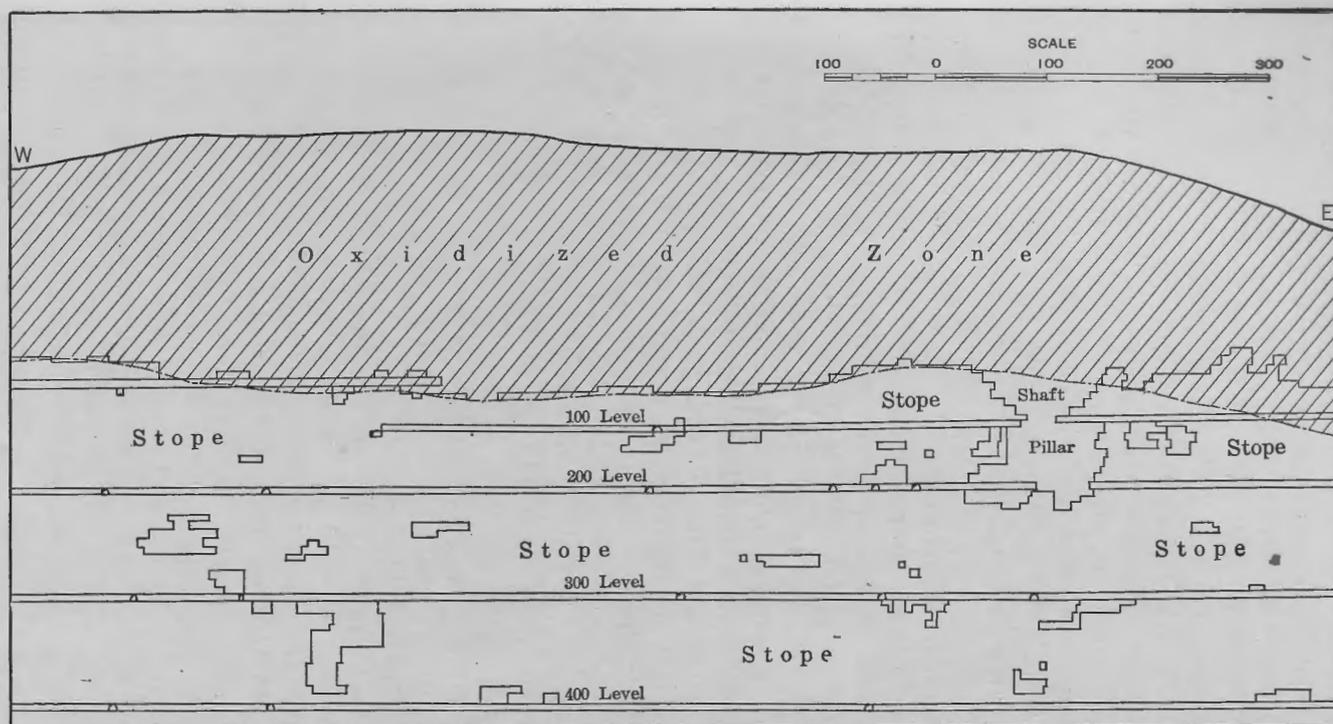


FIG. 6A.—VERTICAL PROJECTION OF A PORTION OF PENNSYLVANIA VEIN, A MEMBER OF THE ANACONDA SYSTEM, SHOWING THE RELATION BETWEEN THE OXIDIZED ZONE AND THE COMMERCIAL ORE BELOW.

In this connection it is not implied that in areas of altered granite water moves freely through the actual rock. It is believed, however, that the water does follow rather freely, comparatively speaking, the numerous joint planes, from which it spreads outward into the altered solid rock much more readily than in the case of unaltered granite. The saturated condition of the altered granite is therefore due to the ease with which the water finds its way along every insignificant joint plane or crack. The altered areas are more fractured than the areas of normal granite, because they were, in the first place, zones of the most intense early fissuring. This early fissuring being followed by marked alteration, a weakening of the rock naturally resulted. Because of this weakening, the faults of later systems commonly spread out over wider zones and were accompanied by greater crushing than in areas of normal granite.

In areas of normal or unaltered granite the ground-water is confined to the definite channels or water zones afforded by shear zones, cracks, faults, or veins. Generally the unaltered granite between the main circulation channels is dry. From these facts it appears that the unaltered granite is quite impervious to ordinary underground waters under normal conditions of temperature and pressure.

In the early days of Butte mining the water level was encountered in the shafts in the region of the contact between the oxidized and sulphide ores. This was true, however, only in areas of altered granite or where the opening was made within a vein. A shaft sunk in the normal unaltered granite between faults and veins, perchance missing a water course, might extend to great depths as a dry shaft. On the other hand, a shaft put down in the altered granite areas became a wet shaft as soon as the general water level was reached, whether a vein was encountered or not, the whole mass of the altered rock being practically saturated.

It has been repeatedly observed that the well-developed fault fissures do not serve as the most important channels for the movement of the present day ground-waters, although the influence of the fault movements in determining the distribution of these waters has been very marked. For example, the Bell, Rarus, and Middle faults seldom contain water in unusual quantities; on the contrary, they are often dry. They have broken and cracked older veins, making them quite permeable to solutions. Of much greater importance as water carriers are the veins of the Anaconda system, fissures, cracks, and shear zones of relatively slight displacement. The Anaconda veins are frequently of a porous nature and contain many cavities, vugs,

and water courses. They are especially good water carriers where cracked or broken by late fault movements.

The ore-bearing faults of the Blue and Steward systems are alternately wet and dry along the strike. It is believed that originally the uprising solutions spread out along these fissures throughout the entire length, but continued earth movements along the fissure planes developed zones of impervious clay and crushed granite, and the circulating solutions were directed along the more open zones now occupied by the ore shoots. The dry zones have remained so, and the waters now found in association with the fault veins are encountered in the more porous ore shoots, or in cracks and broken granite of the walls of the fissure. Frequently the ore shoots contain no water, and it is probable that they have been dry ever since the close of the period of thermal water activity, when the ores were deposited.

The Mountain View breccia veins are practically impervious to water. It appears that they were never connected with active uprising waters, although in part, at least, they are older than the ores of the Steward fault veins. The breccia filling of these cracks is often horizontally bedded, showing characteristic water action. It is probable, therefore, that during the period of filling, the fissures were filled with water practically stagnant.

#### *Source of the Ground-Water.*

There are two possible sources of the water now found in the rocks and veins of the Butte district: (a) uprising waters of deep-seated origin, and (b) meteoric water derived principally from atmospheric precipitation in the form of rain or snow.

*Primary or Juvenile Waters.*—The primary ores of the district were deposited from ascending waters presumably of deep-seated origin. The deposition of primary minerals and ores apparently stopped some time prior to the Rarus faulting, but it is not known how much longer ascending waters continued to traverse the channels of circulation after ore deposition ceased. It is reasonable to assume that during the period of primary ore formation the ascending waters were very active and plentiful and they constituted the bulk of the waters then occupying the veins and adjacent granite. A rapid waning in the activity of the ascending waters took place, no doubt, at the close of the period of primary ore deposition, after which time downward-seeping water of meteoric origin more and more predominated, until at the present day it is extremely doubtful whether any appreciable quantities of the mine waters found above the 3,000-ft. level have been derived directly from deep-seated sources.

*Meteoric Waters.*—The annual precipitation in the district varies from 12 to 20 in. Of this amount a certain part evaporates, some finds its way to the streams as run-off, and the remainder sinks into the earth and by means of cracks, veins, porous rocks, etc., reaches to considerable depths, forming the ordinary ground-water. On account of the extreme porosity of the surface wash covering the district, an unusually large proportion of the rainfall sinks to the contact between the wash and the solid rock below. This factor is offset in a large measure by the steepness of the slopes, permitting a proportionately large run-off.

*Underground Circulation.*—Actual underground observations of the action of water in the veins and rocks as disclosed by mine openings are not especially important in determining the immediate source of the ground-water. Where an opening such as a cross-cut or drift penetrates undrained water-bearing rocks or veins a pervasive dripping from the top or roof of the opening, due to gravity, is certain to follow, regardless of the original source of supply. Irregular cracks and water courses, of which there are many, both in veins and in the hard country rock, may appear in the top, side, or bottom of the opening, exhibiting either a downward or an upward flow of water according to whether the water channel first appears in the bottom or in the back of the opening.

The flow of water encountered in a new bottom level decreases rapidly, but does not entirely cease until additional openings are made at greater depths in the immediate vicinity. While this observed condition indicates a water-soaked condition of the rock and included veins or fissures, it does not afford a reliable clue concerning the immediate source of the water. Whether the source of supply is from above or below, the flow from the opening will be maintained until a certain rock volume surrounding the opening is drained. The rate of flow, however, will vary from a maximum when the opening is first made, to a certain minimum after the opening is made, the length of time elapsing depending on many factors, such as volume of ground to be drained, porosity of the rock, etc.

The fact that the water flow decreases rapidly from newly opened ground indicates that the normal ground-water of the district is extremely sluggish, if not practically stagnant, particularly in the deep levels. In higher levels incontrovertible proof of a certain amount of ground-water activity is afforded by the zone of oxidation and, in slightly deeper zones, by the presence of sooty chalcocite, an undoubted product of descending water action. After the altered rocks and veins of the great altered zones and the veins of the unaltered gran-

ite areas become waterladen, it is certain that a small supply only need be added to maintain saturation. The fact must be kept clearly in mind that the water flow encountered by mine openings penetrating new and undrained country in the Butte district does not represent the rate at which water is being supplied, but instead merely the rush of water into the opening caused principally by force of gravity.

*Ground-Water Largely of Meteoric Origin.*—The facts and conditions heretofore outlined seem to indicate a meteoric origin for the greater part of the present mine waters of the district. The frequent occurrence of dry ore shoots in deep levels, known to have been saturated at a former time with ascending water, indicates that the period of intense activity of uprising water has long ago ceased. In certain instances, such as in the Tramway deep levels, where unusually high water temperatures are noted, one is led to suspect a possible dying ember of a former active hot-water circulation. There are no active hot springs and no waters have been encountered in the mines to which one might ascribe with any degree of certainty a deep-seated origin. The series of temperature observations given below, however, indicate that the waters encountered in areas of intense granite alteration are slightly hotter than waters in unaltered areas at corresponding elevations. The waters of the Tramway mine traverse intensely altered granite zones, and they are, furthermore, in close proximity to certain of the high-grade primary chalcocite ore shoots of the No. 16 vein belonging to the Steward system, known to be the most recent of the primary copper ore bodies.

TABLE II.—*Temperature Observations on Butte Mine Waters.*

Mine.	Mine Level.	Elevation above Sea Level.	Temperature Degrees F.	Remarks.
Tramway.....	2,800	3,400	102	Water encountered in shaft station bottom level.
Tramway.....	2,200	3,571	100	Water in drift newly opened.
Tramway.....	2,000	3,770	104	Drift on north-south vein near No. 16 fault vein.
Tramway.....	2,000	3,770	100	Water from cross-cut.
Tramway.....	1,700	3,917	94½	Drift on vein, new work.
St. Lawrence.....	2,800	3,395	97	Average of four observations at different points bottom level.
Pennsylvania.....	1,800	3,940	92	Water from diamond-drill hole in altered granite area.
Pennsylvania.....	1,800	3,940	90	Water from diamond-drill hole partly in altered granite area.
Pennsylvania.....	1,800	3,940	87	Water from diamond-drill hole outside of altered granite area.
Pennsylvania.....	1,800	3,940	94	Water in face of drift on No. 1 vein in altered granite area.
Gagnon.....	1,900	3,955	88	Average of 8 observations in new cross-cut in normal granite area.
Original.....	2,800	3,400	99	Water in face of drift on Gagnon-Original vein.
Original.....	2,800	3,393	98	Water in face of drift on Gagnon-Original vein.
Diamond.....	2,800	3,393	95	General average of observations, bottom level.
Diamond.....	2,600	3,590	94	General average of observations.
Badger.....	1,800	4,430	76	New drift in new territory on east-west vein.
Badger.....	1,800	4,430	74	Water running from diamond-drill hole in area of normal granite.

The Tramway, St. Lawrence, and Pennsylvania mines are within the great altered zones of Anaconda hill. The Gagnon and Original are in an area of normal granite, although a prominent altered belt is associated with the main Gagnon-Original vein. (See Plate III.) The Diamond area shows a less general altered condition than the main altered zone. In the Badger mine granite alteration is prominent only within and along the veins.

#### MINERALOGY OF THE VEINS.

It is not intended in this chapter to describe in detail all of the minerals found in the district, but to note only those of importance in connection with the ore deposits.

The important copper minerals of the Butte ores, named in order of their relative abundance, are; chalcocite, enargite, bornite, chalcopyrite, tetrahedrite, tennantite, and covellite. Of the oxidized products, chrysocolla, malachite, cuprite, and native copper are the most common, but taken as a whole they have contributed but little to the total copper produced. The gangue minerals are principally quartz and pyrite, occurring in about equal amounts. Sphalerite is abundant in the border zones of the district, in some instances being the predominating constituent of the vein filling, as in the Black Rock mine, where zinc ore is the chief product.

The less common minerals found in the copper veins are hübnerite, galena, barite, rhodochrosite, fluorite, and calcite. Passing from the copper to the silver veins, minerals characteristic of the silver vein area, rhodochrosite, galena, and barite become more and more abundant, the quartz and rhodochrosite finally forming the chief constituents of the gangue, although pyrite and sphalerite are present in notable amounts.

The great bulk of waste matter in the ore as mined and sent to the reduction works is altered granite, which forms from 50 to 70 per cent. by weight of the ore. The occurrence and association of the common minerals of the veins will be described in greater detail below.

#### *Chalcocite.*

Chalcocite is the most important copper mineral of the Butte district. As a common constituent of the copper ores it has been the source of not less than 60 per cent. of the total copper produced to date. It occurs in ore-producing veins of all ages and is abundant at all levels from the upper limit of the sulphides down to the greatest depths yet reached, extending, in many instances, more than 3,000 ft. below the surface.

Broadly speaking, the chalcocite of the Butte veins occurs in three

distinct forms: (a) as "sooty" glance, so-called, in which form it appears as a dull black coating on iron pyrite or other sulphides, or frequently developing a black amorphous powdery substance resembling "soot," where it has resulted from the replacement of the precipitant sulphide; (b) as massive steel-gray chalcocite; and (c) in the form of crystals. Of the three varieties named, the first two are of great economic importance. Chalcocite crystals are of frequent occurrence but they have no commercial significance.

*Sooty Chalcocite.*—Sooty chalcocite is widely distributed as an ore-forming mineral, but it is confined particularly to those portions of the veins lying immediately below the zone of oxidation. (See Plates II. and IV.) This "sooty" glance zone, or belt, is the "chalcocitization zone" of Lindgren at Morenci. In Butte it varies in vertical extent between wide limits, depending primarily on the mineralogical and physical character of the veins and the depth of the zone of oxidation. The veins of the Anaconda system, or the quartz-pyrite series, are deeply oxidized as a rule, and in these veins the sooty chalcocite reaches its greatest development.

In the fault veins the zone of oxidation is usually of but slight vertical extent, and since the primary ores seldom extend upward to the surface, the development of sooty chalcocite is of but little importance. The barren portions of fault veins consisting of clay and crushed granite, occupying long stretches on the strike of the vein between ore shoots, do not offer an adequate source for copper to form sooty glance ores in quantity below the zone of oxidation. The majority of the big chalcocite-enargite shoots of the fault veins do not extend upward to within 500 ft. of the lower limit of the oxidized zone. Where fault-vein ore shoots reach the surface they are found to be oxidized, and they are accompanied by the development of sooty chalcocite ores within the boundaries of the primary-ore shoot similar in every respect to the corresponding secondary enrichment belt of the quartz-pyrite veins.

In the veins of the Anaconda system, particularly in the great altered granite belts, sooty chalcocite is very important commercially. It is found usually as a coating, or as a partial replacement of pyrite, and, less commonly, sphalerite, enargite, and chalcopyrite. It replaces, completely or in part, the pyrite of the veins, also the stringers, veinlets, and fine disseminations of pyrite in the altered granite, not only within and along the veins, but in the intervening altered country rock. The chalcocitization of the altered pyritized granite lying between the more important veins has resulted in the development of a low-grade material similar in general character to the disseminated porphyry

ores of the Southwest, although in the Butte district such material is seldom rich enough to mine except when adjacent to the well-defined veins.

In the veins of the Anaconda, or quartz-pyrite, series (see Plates II. and IV.) the sooty chalcocite occupies a zone from 200 to 1,200 ft. in vertical extent, measured from the bottom of the zone of oxidation. The lower limit of this chalcocitization zone is ill-defined and extremely irregular, which is in marked contrast to the sharply defined lower limit of the zone of oxidation. The mineral is most abundant in the highest levels of the sulphide zone. As depth is gained it becomes less prominent, finally disappearing. On the accompanying maps, Plates II. and IV., the lines marking the lower limit of the sooty chalcocite zone are intended to mark approximately the elevation below which but little, if any, sooty chalcocite has been observed.

*Massive Chalcocite.*—Chalcocite in massive form is of wide distribution in the Butte veins, occurring in veins and masses of great purity. In color it is steel gray, exhibiting the usual conchoidal fracture. In the veins of the Anaconda system it is found in great abundance at all levels from the bottom of the oxidized zone to the greatest depth reached by underground workings. In the ore shoots of the Blue vein system chalcocite ores seldom extend upward to within 500 ft. of the surface. In the later Steward fault veins the rich chalcocite ore bodies were first encountered at a depth of from 1,000 to 1,200 ft.

As an ore mineral chalcocite is found filling fractures in quartz, pyrite, or other older vein minerals, and in irregular veinlets, seams, and stringers in altered granite within or along the veins. Chalcocite plays an important part in the formation of the great stock-work ore bodies of the Mountain View, West Colusa, and Leonard mines. In these properties the granite has been highly altered and much fissured. (See Plate I.) The shattering and alteration was followed by mineralization of the fissures and joint planes, chiefly by pyrite, quartz, chalcocite, and enargite, with occasional covellite. In the massive quartz-pyrite veins, such as the Anaconda and Syndicate veins, chalcocite is commonly found associated with quartz, pyrite, bornite, and enargite-filling fractures or vugs in the earlier vein filling. Both in the older quartz-pyrite veins and in the later fault veins massive chalcocite is found in close association with pyrite, bornite, enargite, and quartz, forming an extremely complex mineral aggregate.

In the ore shoots of the Blue vein and Steward vein series, chalcocite frequently occurs as fine disseminations, seams, and splotchy masses mixed with iron pyrite, quartz, enargite, and bornite. It

commonly replaces the attrition clay and altered granite of these veins, often retaining the grooves, striations, and other markings characteristic of the original clay. Bodies of massive chalcocite are found in the ore shoots of No. 16 vein in the Rarus and Tramway mines. In these high-grade shoots, which are regarded as primary, enargite, pyrite, and quartz are also present intimately associated with the chalcocite. The massive chalcocite of the Blue and Steward veins and the major part of the chalcocite lying below the zone of sooty chalcocite in the Anaconda veins are believed to be of primary origin.

#### *Enargite.*

Enargite is of wide distribution both vertically and laterally in the Butte veins. It has been the source of from 25 to 40 per cent. of the copper output of the district. It is particularly abundant in the eastern portion of the district in the region of the Pennsylvania, Rarus, West Colusa, and Leonard mines. In the deep levels of the Gagnon and Original mines enargite is the predominating copper mineral and forms wonderfully rich and persistent ore bodies. Enargite is largely a product of a comparatively old mineralization period. It is found in copper-producing veins of all ages from the earliest up to and including the No. 16 fault veins of the Rarus and Tramway mines. Enargite is found in great abundance in the higher as well as in the lower levels of the Anaconda vein and other important veins of the oldest vein system, contrary to a former published statement<sup>7</sup> that it did not appear in the Anaconda vein higher than the 2,000-ft. level.

As a mineral of the veins, enargite usually occurs in interlocking aggregates of imperfectly outlined crystals in size from 0.25 to 1 in. across forming a solid mass, the individual growths always exhibiting characteristic cleavage surfaces. Beautifully formed crystals are frequently found from  $\frac{1}{4}$  to 1 in. in length, but the larger sizes are usually less perfect than the smaller ones.

The more massive enargite is found occupying fractures in older quartz-pyrite veins, or replacing the altered granite of the vein in the form of veins and stringers and as splotchy masses along the cracks and joint planes of the granite. It is often intimately mixed with either pyrite, quartz, chalcocite, or bornite, and less commonly with covellite. Intimate mixtures of enargite, pyrite, and barite crystals contemporaneous in origin are frequently seen lining vein cavities.

Enargite is chiefly a product of primary ore deposition. In the

<sup>7</sup> Weed, W. H., *Geology and Ore Deposits of the Butte District, Montana, Professional Paper No. 74, U. S. Geological Survey*, pp. 77 and 107 (1912).

Shannon, Windlass, Enargite, South, and other veins of the eastern district it is found in great abundance in the upper mine levels, the greatest development occurring immediately below the lower limit of the oxidized zone and extending downward for from 400 to 600 ft. Chemical analyses show appreciable amounts of arsenic (see Table I. p. 38) in the oxidized portions of these rich enargite veins, but no marked development of chalcocite occurs in the sulphide zone immediately underlying these gossans. It seems not unreasonable under such conditions to assume that a part, at least, of the enargite is of secondary origin.

#### *Bornite.*

Bornite is one of the commonest of the copper sulphide minerals. It is almost universally present in the copper ores, associated with chalcocite, enargite, chalcopyrite, and other sulphides, but usually in subordinate amounts. As a source of copper it is especially important in the Steward and Original mines and in the mines of the North Butte section. The bornite occurrence in Butte is particularly interesting from the fact that while it seldom forms the chief copper mineral of the ore, it is rarely absent even in hand specimens.

In physical character the bornite of the Butte vein exhibits on fresh surface the characteristic horse-flesh color, tarnishing rapidly on exposure to a blue or green color. It is a frequent associate of chalcocite, chalcopyrite, enargite, and other sulphides.

Bornite occurs in copper veins of all ages at all levels from the oxidized zone to the greatest depths yet reached. It is largely a product of primary ore deposition along with enargite, chalcocite, and other associated primary minerals.

#### *Chalcopyrite.*

Although described in former years as the chief copper mineral of the primary ores of the Butte copper veins, chalcopyrite has proved to be of comparatively small importance as a source of copper. It is characteristically a mineral of the border zone of the central copper area. Chalcopyrite is practically unknown in the Anaconda, Mountain View, and other mines of the eastern part of the district. It is common in the extreme west end of the Gagnon mine, in the Lexington, West Gray Rock and in the veins of the Speculator mine. It is of frequent occurrence in the Elm Orlu mine, Alice, and other silver properties. Chalcopyrite is commonly a product of late vein-forming action, being frequently found in cracks, vugs, and cavities within older vein filling or as a thin coating or replacement of older sulphide minerals, particularly sphalerite, pyrite, enargite, and covellite. It has been noted in the form of small imperfect crystals in rare in-

stances, occurring in cracks in older vein filling and finely disseminated throughout the unaltered granite, particularly in the Altona and Amazon shafts in the eastern part of the district. The unusual occurrence in the Jessie vein of chalcopyrite-pyrite vein filling capping rich chalcocite-enargite ores at greater depths is of special interest and will be further described in the discussion of the formation of chalcocite. (See p. 100.)

In vertical distribution chalcopyrite is found at all levels. In certain localities, as in the Gagnon and Steward mines, it is more abundant in the deep levels than in the upper levels, in marked contrast to the chalcopyrite ores of the Jessie above mentioned.

Chalcopyrite in the Butte veins is largely a product of primary mineralization, although in certain instances it is believed to be possibly of secondary origin. Frequently it is the most recent mineral of the vein in which it is found, occurring as fine crystals in cracks or as a replacement of enargite, covellite, or chalcocite.

#### *Covellite.*

Covellite occurs as massive mineral and more rarely as crystals of the characteristic indigo-blue color in certain veins of the northern and eastern parts of the district. It was found in abundance in the Gray Rock and Edith May veins, particularly at comparatively shallow depths from the 700 to the 1,200 ft. levels. It occurs in considerable amounts in the Leonard vein from the 1,200 to the 2,000 ft. levels. The covellite of the Leonard vein frequently shows a partial alteration to chalcopyrite. An interesting occurrence of covellite was noted in the Skyrme vein of the High Ore mine, where on the 2,400-ft. level a large ore boulder broken open was found to be composed principally of covellite intimately associated with enargite, some bornite and large amounts of later chalcocite. This entire mass was in large part inclosed by a 0.5-in. covering of pyrite. At several points on the surface of the boulder the pyrite, enargite, chalcocite, and covellite alike were being altered and replaced by chalcopyrite as the latest mineral.

In the Butte veins covellite is believed to be largely of primary origin, if not entirely so. Its occurrence bears no relation to the surface or to the zone of oxidation, and the intimate association with enargite, bornite, and pyrite lends strong support to the primary view.

#### *Tetrahedrite.*

Tetrahedrite is unimportant as an ore of copper, although it has been found in small quantities in nearly every mine in Butte. It

varies in physical appearance from a dull gray to a bronzy metallic luster. The latter form occurs in considerable amounts in the Leonard mine, where it is remarkable for its high gold content. Lots of 50 tons have been known to run as high as \$20 a ton. It is especially abundant in the stopes of the Gem vein above the 900-ft. level. The common variety has a characteristic cherry-red streak, which immediately distinguishes it from chalcocite.

#### *Tennantite.*

Tennantite is of frequent occurrence in the veins of the northeastern part of the district in the Badger, Speculator, and Gem mines, but is not of great importance as a source of copper. In massive form it is of a deep gray-black color, having a faint reddish tint. It is of more common occurrence as minute gray glistening crystals of a steel-gray color, filling or coating the walls of fractures in older vein filling. These crystals are believed to have formed during the alteration of enargite to chalcopyrite, marking possibly the regeneration of the mineral from the copper and arsenic lost in the transformation of enargite into chalcopyrite.

#### *Sphalerite.*

Sphalerite is a common mineral of the Butte veins. It is of wide distribution in all of the veins of the district except in that part of the copper-producing area extending easterly from the Never Sweat to the Leonard, Berkeley, and Silver Bow mines. (See Fig. 7.) Sphalerite is especially abundant in the Colorado, Gagnon, Poulin, Lexington, West Gray Rock, and Corra mines, and to the north in the veins of the old silver-producing area. Large bodies of sphalerite have been developed in the Elm Orlu and Black Rock mines, where it occurs chiefly in veins belonging to the Anaconda system. It is here found in unusual purity, the principal gangue minerals being quartz, rhodonite, and rhodochrosite. In marked contrast to the veins of the copper area, pyrite occurs but sparingly in the zinc ores of the Black Rock mine, running generally less than 2 per cent.

Sphalerite is found in abundance in veins and faults of the Anaconda, Blue, and Steward systems. It occurs at all levels from the oxidized zone to the greatest depths yet reached by mine workings. It is a primary vein mineral deposited contemporaneously with pyrite, quartz, galena, enargite, chalcocite, bornite, and other copper minerals, in veins of all ages. As is the habit with other sulphide minerals in the Butte veins, it is more abundant in higher levels in certain parts of the district, and relatively more abundant in deep levels of other localities. The relative proportion of sphalerite to copper content is

widely variable in different veins or at different sections within the same vein. In some instances veins have been found to contain an ore rich in sphalerite and low in copper in the higher levels with increasing proportions of copper as depth is gained. On the other hand, many veins with much zinc in the upper levels show no marked improvement in copper contents down to great depths.

Sphalerite is frequently found in intimate association with pyrite, bornite, chalcocite, galena, and quartz, and but rarely with enargite. Like enargite, sphalerite is often corroded or eaten away, the dissolving action being followed in many cases by the deposition of chalcopyrite, bornite, or chalcocite. The age relations of the sphalerite have not been worked out. It probably began to deposit at an early period of vein formation, and undoubtedly appeared in large quantities in certain parts of the Anaconda fissures long before the advent of the Blue system of fissures.

#### *Galena.*

Galena is found sparingly in the intermediate zone surrounding the central copper area. It is particularly abundant in the region immediately north of the Mountain Con mine in the Old Glory, Lexington, and Gray Rock veins. It has been noted in the Anaconda, Blue, and Steward fissures in the intermediate and peripheral zones. Galena is a common, but not necessarily plentiful, constituent of the manganese-silver veins and generally of the veins of the outer zones.

#### *Silver.*

Silver is universally present in the Butte veins. In the copper area silver is more plentiful in the veins carrying zinc. The enargite veins of the Rarus, Berkeley, and Silver Bow mines have the lowest silver content of any in the district. Silver increases toward the border area, where the proportionate amounts of bornite, chalcocite, and sphalerite become greater. The mineralogical nature of the silver occurrence has not been definitely determined. It is frequently seen in native form associated with chalcocite and bornite. Argentite has been noted in the veins of the silver area.

#### *Gangue Minerals.*

*Quartz.*—Quartz is the most abundant vein mineral of the district. It forms the chief constituent of the gangue of the copper and zinc veins, occurring in both massive and crystal form. Quartz is a product of vein-forming activity of all ages from the earliest known veins following the appearance of the quartz-porphry dikes up to the close of the primary ore-forming period marked by the Steward-vein ores.

Several generations of quartz are readily observed in the vein filling of Anaconda veins, all of which are of primary origin. Secondary quartz as a product of meteoric water circulation has not been observed, excepting possibly within or near the lower limit of the zone of oxidation. Quartz probably forms 70 per cent. by volume of the vein filling of the Butte veins.

#### *Pyrite.*

Pyrite is the most widely distributed of the sulphide minerals. It occurs both massive and crystalline in veins and fissures of the Anaconda, Blue, and Steward systems. Pyrite occurs sparingly as a primary constituent of the Butte granite, and abundantly in a finely disseminated condition in altered granite resulting from the attack of thermal waters upon the dark silicates of the original rock. In the veins of the district pyrite is more abundant in the early copper veins belonging to the Anaconda system than in later fault veins, and much more abundant in the veins of the central copper area than in the manganese-silver veins of the border areas. In vertical distribution it is doubtful if there has been a measurable change in the total pyrite present between the higher and the deep levels of the mines. In the regions of sooty chalcocite pyrite has been to some extent replaced by secondary chalcocite. Below the zone of sooty chalcocite no marked change has been noted.

#### *Manganese Minerals.*

Rhodonite and rhodochrosite are found in great quantities in the veins of the peripheral zone surrounding the copper-producing area of the district, but rarely in the important copper-producing veins. These minerals are also abundantly associated with the sphalerite of the Black Rock veins.

#### *Other Minerals.*

Hübnerite, fluorite, barite, and calcite are of frequent occurrence in the copper area. *Hübnerite* has been noted in the Steward, Leonard, Mountain View, and many other mines, where it appears as one of the earliest-formed minerals. It is found in considerable quantities in certain veins, 2 miles east of the Pittsmtont mine. In the Mountain View mine blade-like enargite after hübnerite has been noted from the High Ore vein, a northwest-southeast fault of the Blue system.

*Barite* in characteristic tabular crystals is occasionally seen projecting into cavities in the veins. It is pale brown in color. Excellent crystals have been found in the Parrot mine.

*Calcite* is rarely seen in the copper veins, but it is commonly formed in veinlets along joint planes of the granite in areas of fractured or crushed character, where alteration processes have but slightly affected the rock. It is unknown in areas or zones of altered granite. Where found in copper veins it has always proved to be the most recent mineral, often filling cracks through chalcocite, chalcopyrite, and other copper minerals.

*Fluorite* has been found in the Parrot vein, in the Blue and Steward veins, and in considerable quantities in the Black Rock vein on the 1,200-ft. level of the Black Rock mine. In the Parrot mine on the 1,200-ft. level fluorite and enargite were intimately associated and apparently contemporaneous. Later chalcopyrite was observed replacing the enargite.

#### THE ORE DEPOSITS.

The ore deposits of Butte are essentially of the fissure-vein type. They have resulted from the mineralization of fissures accompanied by replacement of the country rock. The fissure systems, as previously described, belong to at least six, or possibly seven, distinct periods of fracturing, and many examples of extreme complexity are presented. The oldest or first-formed fractures, composing the Anaconda system, have been continuously mineralized and are remarkably free from sudden changes in vein filling, a feature which presents a marked contrast to the later mineralized fault fissures of the Blue and Steward systems. In the latter the ore occurs in great lenses, or shoots, with intervening stretches of barren vein characterized by crushed country rock and fault gouge. The fissure-vein structure is the rule throughout the district. The ore-bodies display rather well-defined boundaries, when broadly considered. Important exceptions, however, are found in the Leonard, West Colusa, Rarus, and Tramway mines, where the largest ore bodies are more in the nature of mineralized highly fissured granite, having boundaries which are often commercial rather than geological. The mineralization of the early complex fracture systems, followed by later faulting, has resulted in a most complicated arrangement of ore bodies. Reference to Plates I. and II. will convey to the reader a more comprehensive understanding of these structural relations than can be conveyed by detailed description.

The valuable metal content of the ores is chiefly copper, with subordinate but important amounts of silver, gold, and zinc. As mined, 60 to 80 per cent. by weight of the ore is altered granite, which usually, though not always, carries sufficient quantities of valuable minerals in seams, impregnations, or disseminations to constitute ore.

Irregularities in the vein boundaries, horses, pinches, and included granite, necessitate stoping widths often in excess of the actual thickness of ore streaks. The copper ores invariably carry commercially important quantities of silver. The typical manganese-silver ores contain only traces of copper; and the newly developed zinc ores of Elm Orlu and Black Rock mines carry considerable silver, but rarely appreciable amounts of copper.

#### *Distribution of Ore Types.*

An interesting geological condition is found in the unmistakable concentric zonal arrangement of certain ore types, based on mineral composition, around a central copper zone. It was observed in the

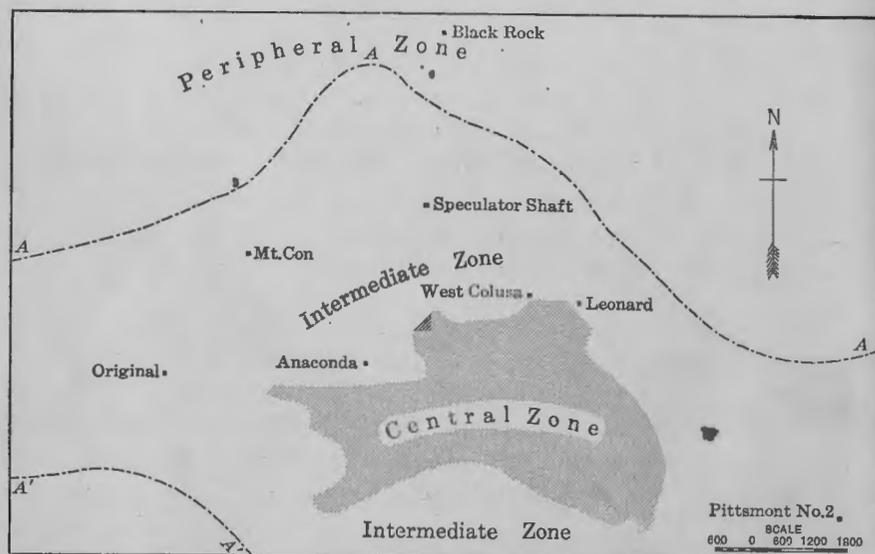


FIG. 7.—PLAN MAP AT ELEVATION 4,600 FT. ILLUSTRATING GENERAL DISTRIBUTION OF ORE TYPES WITH REFERENCE TO THE CENTRAL COPPER ZONE.

early days of mining that ores from different mines exhibited considerable variation in mineralogical composition, but it has been only in the more recent years that underground developments have progressed to such an extent that the apparent orderly arrangement of the various types can be approximately outlined. From the information now available, the writer has formulated certain generalizations concerning these features, and on the accompanying map, Fig. 7, an attempt has been made to indicate as accurately as possible the zones or belts which are typified by characteristic mineral associations.

In brief, these zones may be grouped as follows:

1. A main or central copper zone occupying largely the great area

of altered granite in the vicinity of the Mountain View mine, in which the ores are characteristically free from sphalerite and manganese minerals. This zone is represented by the shaded area in Fig. 7.

2. An indeterminate zone of irregular width nearly surrounding the central copper zone, in which the ores are predominantly copper, but are seldom free from the mineral sphalerite, and near the outward boundaries, *A-A-A* and *A'-A'*, the manganese minerals rhodonite and rhodochrosite are of frequent occurrence.

3. An outer or peripheral zone of undetermined width bordering the intermediate zone, in which copper has not been found in commercial quantities. The vein filling is chiefly quartz, rhodonite, sphalerite, pyrite, and rhodochrosite. In this zone are included the manganese-silver veins of the Alice, Moulton, and Magna Charta mines on the north and the Emma, Ophir, Travonia, etc., on the south.

It should be kept in mind that the dividing lines between these three zones shown on the map are from necessity of an arbitrary nature. The passing of one zone into another is gradual, and cannot, as a matter of fact, be correctly represented by a mere line. Underground developments will never be of sufficient extent to permit of this extreme refinement.

*The Central Copper Zone.*—Within the central zone represented by the shaded area in Fig. 7 are found the typical copper ores in which the copper minerals are predominantly chalcocite and enargite in a gangue of pyrite and quartz. Bornite is also present, but in proportionately small amounts. Covellite is uncommon, having been found only in the Leonard and Mountain View mines associated with chalcocite, enargite, and later chalcopyrite. Chalcopyrite and sphalerite are extremely rare, having been noted in but few instances. The manganese minerals rhodonite and rhodochrosite are unknown, as is galena. Silver is a universal constituent of the veins of this area, but in less quantity than in the ores of the intermediate zone. The ratio between the silver and the copper is approximately  $\frac{1}{3}$  oz. of silver to per cent. of copper.

It is of special interest to note that the central copper zone coincides in part with the great zone of rock alteration, and again a feature of interest is found in the fact that within the area there is no essential difference in mineralogical composition of the vein filling in veins of different ages, although there may be great variations in the relative amounts present. In one locality a vein of the Anaconda system may contain proportionately more enargite than a nearby vein of the Blue system, while in other localities the reverse is true. As a general con-

dition, however, it is believed that the later veins of the Blue system have more chalcocite and bornite, and less enargite proportionately than the veins of the Anaconda system. In the ores of the Steward veins the chalcocite ratio is especially high.

*The Intermediate Zone.*—In the intermediate zone surrounding the central copper area there is a noticeable change in the mineralogical composition of the veins. This change consists chiefly in the addition of the mineral sphalerite to the general type of vein filling of the copper zone above described. Outwardly from the central copper area the sphalerite does not appear suddenly in great quantity, but it comes in rather gradually. This feature is variable in different localities; for example, in the Moonlight mine there is but little sphalerite in the veins of the east end of the mine, but westerly even in the same veins, within a distance along the strike of 1,000 ft., the ores become very rich in zinc. In the Anaconda vein westerly from the Never Sweat mine sphalerite increases in amount slowly and gradually, and unusual quantities of zinc are found only at distances of 3,000 ft or more from the general outside limit of the central copper zone.

In addition to the changes noted in zinc content, other mineral variations take place that are of considerable interest. The manganese minerals rhodonite and rhodochrosite begin to appear in small quantities toward the borders of the intermediate zone, and increase perceptibly toward its outer limits. Among the copper minerals, as compared with the central copper zone, there is less enargite in proportion to the total copper present, but proportionately greater quantities of bornite, chalcopyrite, tetrahedrite, and tennantite. Chalcocite apparently remains about the same relative to the total copper present as in the central copper zone. The silver content increases materially, the ratio to copper content being 1 oz. of silver to 1 per cent. of copper as a general average. It should be remembered that the facts above outlined are generalized conditions and that locally extreme variations occur. The net result, however, is a decrease in copper content with an increase in silver, zinc, lead, and manganese. Quartz as a gangue mineral does not vary perceptibly, but pyrite is less abundant toward the outside limits of the intermediate zone than in the central copper zone and certainly much less common in the peripheral zone than in the intermediate and central zones. In the intermediate zone the veins of different systems carry the same variety of minerals, but in widely different proportions. The veins are more zincky in some localities than in others. Those of the Anaconda system are exceptionally high in pyrite and quartz in certain localities, and at

other places sphalerite is unusually abundant. There are certain areas in the Mountain Con and Diamond mines where the ores closely resemble those of the central copper zone, and, curiously enough, these areas are closely associated with the earliest vein development which had attended intense rock alteration.

*The Peripheral Zone.*—As with the central and intermediate zones, the line of division between the intermediate and the outer zones is largely an arbitrary one. It marks the general outside limit of present known commercial copper deposits, and therefore it is in nowise intended to be construed as an attempt to mark the possible limit of copper ores. Up to the present time the ores of this zone have been valuable principally for silver, gold, and zinc. The vein filling is characterized by the abundance of the manganese minerals rhodochrosite and rhodonite. Sphalerite is present in great abundance, forming in some instances ore bodies of value. Copper is sparingly present, chiefly as chalcopyrite, tetrahedrite, tennantite, and rarely chalcocite and bornite. Pyrite is common, but in relatively much less quantities than in the two zones above described. Quartz is the most abundant gangue mineral. Galena is also present in considerable quantities intimately associated with sphalerite and of the same age. The width of this zone is indefinite and irregular and there is a noticeable change in the mineralogical character of the vein filling at greater distances from the central copper zone. Extending outward from the peripheral zone the fissures appear to become less mineralized; the manganese, pyrite, zinc, and other sulphides largely disappear, the vein filling consisting principally of quartz with scattered pyrite; and, curiously enough, arsenopyrite is noted at extreme distances, 2 miles or more from the central copper zone.

The zonal arrangement of ore types above described is repeated on a smaller scale in certain ore shoots of the Blue veins in the north-eastern part of the district. In the shoots of the Jessie and Edith May veins, for example, the mineral composition differs in the central part of the shoot from that at the ends and along its walls. High-grade chalcocite-enargite-bornite ores form the central part of the ore shoot with but little sphalerite and chalcopyrite and shade almost imperceptibly into zincky ore with chalcopyrite toward the ends of the shoots.

#### VEIN SYSTEMS.

Of the seven distinct periods of fissuring in the district only three are known to be ore producing: namely, the Anaconda system, the Blue system, and the Steward system. The Anaconda system is the

most extensively mineralized, the Blue system is less so, but is extremely important as an ore producer, while the Steward fissures seldom contain workable ore bodies, although in many instances they appear to have exerted an important influence on older veins. The mineral composition of the ores of the various vein systems is of marked similarity. A suite of hand specimens typifying the ores of the Anaconda veins does not differ materially from a similar suite collected from the later fault veins. The distinctions where recognizable are in the relative quantities of minerals present, or in matters pertaining to physical character. The variation in mineral composition of the veins is a matter of geographic position, rather than of geologic age as above outlined.

#### *The Anaconda Vein System.*

The Anaconda system of veins is the oldest geologically and the most important commercially of any in the district. It comprises a great series of veins having a general east and west strike, which have resulted from the mineralization of the Anaconda system of fractures previously described. The largest and most important of these veins is the Anaconda, variously called the Gagnon, Original, Parrot, Anaconda, Mountain View South, etc., named from the many adjoining shafts through which it has been worked. Another important member of this system is the Syndicate vein, or lode, of the Mountain Con mine, one of the big producers. Other highly productive veins belonging to the Anaconda system are the O'Neill, Moonlight, Berkeley, Windlass, Shannon-Colusa, Modoc, Bell-Speculator, Middle, West Gray Rock, Chief Joseph, Badger, and many others of less importance, but having the same general geological characteristics. It is believed that the silver veins of the Alice, Moulton, Lexington, and other mines of the north district are also mineralized fractures belonging primarily to the Anaconda system. In mineralogical character, however, they differ materially from the copper veins above named.

*Structure.*—The veins of the Anaconda system are remarkably continuous. The ore seldom shows sudden changes in width or general mineralogical character. Many of the important members of this system have been stoped continuously on strike for thousands of feet. As a replacement of relatively firm rock the ore is usually hard and massive, at times exhibiting imperfect banding due to replacement of sheared granite, or deposition of mineral along closely spaced fractures.

The veins often split or branch, both on strike and dip. Where

continuously stoped they are frequently composed of two or more closely spaced ore streaks, called the "foot-wall streak" and the "hanging-wall streak." It is not unusual to find a stope face showing four or five roughly parallel ore streaks varying in width from an inch up to several feet. The included granite and wall rock are highly altered and commonly netted with smaller seams of mineral similar in a general way to the large ore streaks. The variable mineralogical nature of the many ore seams, veinlets, etc., is a notable feature not only of the veins of the Anaconda system, but of all of the veins in the district. For example, a drift face may show a well-defined foot-wall streak 2 ft. wide composed almost entirely of quartz and pyrite assaying less than 2 per cent. of copper. The hanging-wall vein, separated from the foot-wall streak by perhaps 2 ft. of highly altered granite, may be very rich, consisting largely of chalcocite, enargite, bornite, and pyrite, assaying 25 per cent. of copper. However, as stopes are made above the drift, the rich streak may show only enargite and pyrite or only chalcocite, while the lean foot-wall vein in the stopes may become richer by the appearance of enargite, chalcocite, or bornite. These extreme local variations in veinlets and ore streaks are extraordinarily common to veins of all systems, although the general average valuable metal content of the ore as mined in a particular locality may not show much general longitudinal or vertical variation over hundreds of feet. It is a notable fact that while the variety of minerals present in a given vein seldom suffers marked changes within short distances, the relative proportions of minerals reach extremes.

The component ore or vein streaks may or may not be included within fairly well-defined boundaries. Usually one of the ore bands is wider, more prominent, and more persistent than the rest, the smaller streaks maintaining a rough parallelism separated by vein granite from the main fissure. The most important variation from the common type of vein above described is found in the Shannon-Colusa vein. The stoping width of the Anaconda veins varies from 5 up to 100 ft., with a general average of 20 ft. The Anaconda and Syndicate veins average 30 ft. or more. The stopes of the Leonard mine within the big stock-work ore bodies often run as high as 400 ft. from north to south. Within this extreme width, however, there are many bands or ribs of waste, and as a rule the actual stope is not solid ore, from 10 to 30 per cent. of the ground broken being sorted out and rejected. Among the less important veins 10 ft. is a common stoping width. In most cases the actual vein filling represents only

a fractional width of the stoped material, the remainder being mineral-bearing altered granite.

*Minerals of the Anaconda Veins.*—The veins of the Anaconda system carry more quartz and pyrite than the later veins, though the term "quartz-pyrite," formerly much used to designate the veins of this system, is, in the strict sense, a misnomer. Quartz and pyrite are present in great quantities in the Blue veins and form the chief gangue minerals, but in less quantities in proportion to the copper minerals present than in the earlier veins. The greater continuity and uniformity of the hard vein filling, its freedom from fault clay and crushed granite, together with the proportionately greater amounts of quartz and pyrite, gave rise to the early usage of the name "quartz-pyrite" veins as distinguished from the typical fault fissure not known to contain ore bodies. That "quartz-pyrite vein system" is not, strictly speaking, a proper designation, but often misleading, may also be readily understood by a casual inspection of representative ores from the different veins of the district.

The general mineralogical character may be best illustrated by a more detailed description of some of the more prominent veins belonging to the Anaconda system. Of those described below the Anaconda is typical of the important well-defined continuous compound fissures. The Shannon-Colusa illustrates fissuring of remarkable complexity and ore bodies of an unusual type. The Syndicate vein illustrates certain structural features of interest, while the Gray Rock vein is of interest as a copper vein well toward the border of the copper-producing area.

*The Anaconda Vein.*—Beginning in the Gagnon mine on the extreme west, the principal copper minerals are chalcocite, enargite, bornite, and chalcopyrite, named in order of their abundance. The gangue minerals are quartz, sphalerite, and pyrite, with occasional occurrences of rhodochrosite and hübnerite. In vertical arrangement there is possibly more chalcocite and less enargite and bornite in the upper levels than in the lower levels of the Gagnon mine. The sphalerite is only slightly variable as between the higher and lower levels, probably less in the latter. The most notable change in depth is the remarkable development of enargite in the bottom levels, accompanied by unusual quantities of later chalcopyrite, largely a replacement of enargite. In the Gagnon mine the silver tenor of the ore has decreased in depth. The oxidized zone here is from 100 to 200 ft. deep, accompanied by a considerable development of sooty or secondary chalcocite whose vertical extent is in the neighborhood of 400 ft.

Easterly from the Gagnon mine, in the Original and Steward, the oxidized zone with the accompanying zone of sooty chalcocite shows no marked change from that just described. Of the copper minerals, enargite and chalcopyrite decrease, while chalcocite and bornite increase in amount. Quartz and pyrite increase, especially the latter, but sphalerite shows a marked decrease. The silver content is slightly lower than further west. Rhodochrosite and fluorite have been noted in the Steward and Parrot mines.

Taking the next step eastward into the Never Sweat, Anaconda, and St. Lawrence mines, the enargite and bornite have continued to increase slightly, chalcocite increases, silver content becomes lower, sphalerite and chalcopyrite disappear completely, while on the whole, the vein becomes much more massive. The gangue, instead of being granitic, is hard, composed chiefly of quartz and pyrite. Hübnerite is noted occasionally; rhodochrosite and fluorite are unknown. In the Never Sweat-St. Lawrence section the oxidized zone is of unusual depth, averaging 300 ft. Below, the secondary chalcocite zone shows extensive development, having a vertical extent of from 600 to 800 ft.

Easterly from the St. Lawrence the Anaconda is faulted north by the High Ore vein into the Mountain View mine, where the mineralogical character does not differ materially from that shown in the Never Sweat-St. Lawrence region. The copper minerals are enargite and chalcocite, with unusually small amounts of bornite in a quartz-pyrite gangue. Southeasterly, where the main Anaconda vein apparently forks and in a large measure loses its identity, there is no noticeable change in mineral content, except as to relative quantities present, until the region of the Pittsmont or East Butte property is reached, where the only change is in the reappearance of sphalerite in considerable quantities. Chalcopyrite does not again appear except in rare cases, chalcocite and enargite forming the chief source of the copper. The silver content decreases slightly southeasterly from the Mountain View. The rarer minerals noted are fluorite in the Parrot mine, barite occasionally at different points in the vein, and hübnerite in the Mountain View mine.

On the whole, the veins of the Mountain View, Rarus, and Pennsylvania mines have more enargite but very much less bornite in proportion to the total copper present, than those of the Steward, Anaconda, Moonlight, and St. Lawrence mines.

*The Shannon-Colusa Vein.*—The Shannon-Colusa vein is a strongly mineralized fissure forming the north boundary of the complex Anaconda fracture zone previously described. In the Mountain View mine it has been developed as a compound fissure striking

slightly north of east, composed usually of a single vein in the upper levels, but of two or more branches at greater depths. The vein dips from  $80^{\circ}$  to  $85^{\circ}$  north. There are, occasionally, nearly north and south veins branching toward the south, but the north wall is generally clean cut and well defined. This comparatively simple vein structure is maintained eastward into the West Colusa mine, where it suddenly becomes exceedingly complex. Great mineralized fissure zones forming remarkable ore bodies break suddenly to the south nearly at right angles to the main foot-wall fissure. The granite between and forming the country rock of the complex fissure aggregates is richly mineralized with chalcocite and enargite as disseminations or veinlets following the joint planes of the granite.

In the Leonard mine the development of the north-south vein structure does not appear higher than the 600-ft. level. Figs. 1 and 2 illustrate the relation between the veins of the Leonard 300-ft. level and the fracture complex of the 1,200-ft. level. On the 300 there are four well-defined veins having approximate east-west strikes. The Colusa, the most northerly one, is a large well-defined vein, averaging 40 ft. in width, having an  $85^{\circ}$  dip to the south. At a depth of 600 ft. it experiences a sudden change to a flatter dip, due in part to faulting by the Rarus fault, causing it to appear on the 700-ft. level, 320 ft. south of its position on the 600-ft. level. From the 700-ft. level downward it meets the vertically dipping Gambetta veins, and it is below this level that the development of the north-south fissuring begins. The north-south veins are often well defined and carry wonderfully rich bodies of chalcocite-enargite ore, with occasional admixture of covellite associated with later chalcopyrite.

The Gambetta veins are intersected between the 300-ft. and 500-ft. levels and are displaced northward by the Rarus fault. Above the fault they carry but little commercial ore except near the Gambetta shaft. Below they are notably rich in enargite, often showing from 2 to 5 ft. of nearly pure enargite, with numerous veinlets of coarse enargite penetrating the vein walls. Where intersected by a cross-cut on the 800-ft. level the Gambetta vein showed more than 6 ft. of solid, coarsely crystalline enargite, with little or no chalcocite, quartz, or pyrite. The oxidized zone of the Gambetta veins is slight, being not more than 60 ft. and usually much less. There is but a slight development of sooty chalcocite below; in fact, not enough to make the vein filling of commercial grade. The zone of oxidation in the Colusa vein, which varies from 100 to 150 ft. in depth, is accompanied by a marked enrichment of the veins below by sooty chalcocite. This enrichment zone, however, barely reaches the 600-ft. level. In the big

flat stopes connecting the 700-ft. and 600-ft. levels and in the big ore zones of deeper levels, the valuable copper minerals are chalcocite and enargite, with occasional bunches of covellite associated with chalcopyrite.

*The Syndicate Vein.*—The Syndicate vein of the Mountain Con group of mines is a massive quartz-pyrite vein with a curving strike from N.  $70^{\circ}$  E. in the Buffalo mine to a more easterly and southeasterly strike eastward from the Mountain Con mine. (See Plate I.) In general habit it does not differ materially from the main Anaconda vein above described. There are the common splits, or branches, on strike and dip, including horses of granite. The granite of the walls is highly altered and contains the usual minor mineralized fissures roughly parallel to the main vein. The Syndicate is cut and displaced by the Nappa, Dernier, Midnight, and other fault veins belonging to the Blue system. The Bell, a strong northeast fault, crosses the Syndicate vein at an acute angle, at times following it as a strike fault for several hundred feet.

In mineralogical character there is a notable difference between the Syndicate and the main Anaconda vein. The former is more massive, with a larger proportion of pyrite as a gangue mineral. There is more bornite and less enargite in proportion to total copper present than in the Anaconda. Chalcocite is abundant. There is the usual oxidized zone of from 150 to 250 ft. thick, accompanied by important secondary enrichment below. There is less chalcopyrite than in the Gagnon mine, but more than in the neighborhood of the Mountain View mine. The Syndicate vein contains large amounts of sphalerite in the Poulin, slightly less in the Buffalo, Mountain Con, and eastward. In the immediate vicinity of the Mountain Con shaft for a short distance on strike sphalerite is almost entirely absent. There is a tendency on the west to develop minerals characteristic of the manganese-silver vein area to the north. Barite, galena, tetrahedrite, and tennantite are frequently seen in the ores of the Poulin mine. The Old Glory vein of the Buffalo carries unusual amounts of galena.

*West Gray Rock Vein.*—The West Gray Rock vein has been worked only in the Gray Rock mine. It is a well-defined vein of the Anaconda system, exhibiting the usual characteristics as to general strike, continuity of mineralization, etc. It appears to split into several branches, dying out quickly both east and west. It is a typical hard quartz-pyrite vein having more quartz and less pyrite than the Syndicate. Sphalerite is always present. Galena, chalcopyrite, and barite are occasionally noted. Chalcocite and bornite are the chief copper

minerals. Engarite is less important than in most of the copper veins.

It is faulted by the High Ore, the South Bell of the Blue system, and the La Plata of the Steward system, and the Corra fault, a north-dipping fissure possibly of the same age as the Rarus.

*Physical Changes Effected in Anaconda Veins by Faults.*—Where in contact with the intersecting fissures of the Blue vein system the Anaconda veins are usually shattered and broken, often exhibiting step faulting with a disturbance of orientation of the vein as the fault is approached. There is frequent strike faulting locally along the intersected vein, due to the general disturbance of the hanging- and foot-wall country-rock near the fault. Blue vein fault fissures often split where passing through older veins and develop the phenomena of step faulting.

The physical changes caused by faults meeting the Anaconda veins at acute angles or strike faults is more marked than that caused by faults like the Blue and Rarus crossing at obtuse angles. With strike faults along other veins, of which the Gagnon, Moonlight, and Bell-Speculator are notable examples, the movement may take place along the foot or the hanging wall of the vein or both. If the movement is extensive the older vein filling becomes more or less broken. If ore-bearing solutions are introduced by the later faulting, or if ore-forming waters are traversing the older vein, the new fractures and cracks in the old vein filling may become filled with mineral again forming in solid veins. This process of breaking and re-cementing of older veins by new primary ores is a common feature of the Butte veins, and where the process is many times repeated the chronological sequence of mineral formation cannot be satisfactorily determined.

Often where a strike fault crosses older vein filling diagonally from hanging-wall to foot-wall, the displacement along the fault causes the two segments of the vein to become separated on strike by a barren stretch of the fault fissure, giving the general effect of separate ore shoots, a feature early described by R. G. Brown.<sup>8</sup>

*Mineralogical Changes Due to Appearance of Faults.*—The changes in mineral composition of the Anaconda veins effected by later fault influence cannot be fully determined. It is certain that the Anaconda veins were well formed and existed as solid quartz-pyrite veins containing unknown quantities of copper minerals at the time the Blue fault fissures appeared, as shown by included blocks of drag ore found at intersections with Blue veins. The extensive mineralization of the

<sup>8</sup> Brown, R. G., *The Ore-Deposits of Butte City, Trans.*, xxiv., 555 (1894).

Blue fissures, identical in character with that of the Anaconda veins, indicates that there was no substantial period of quiescence separating the two vein series. With an overlapping of these periods, marked possibly by a slight change only in the character of minerals deposited, the problem concerning the influence of the Blue veins on earlier-formed veins becomes a complex one and difficult of solution.

Certain facts have been observed which tend to throw some light on this question. It is found that the crossing of older veins by fault veins of the Blue and Steward is not always accompanied by undoubted enrichment of the former. In fact, the stope and assay records show that as a general rule there has been no marked local enrichment at these intersections. There are many exceptions, however, where, at certain elevations along the line of intersection, between veins of the Anaconda system and later fault veins, both the old vein and the later fault fissure contain unusually rich ores. Careful observations of a number of such examples of enrichment show that they mark not merely the intersection of the two fissures, but the intersection of the older vein and an ore shoot lying within the plane of the fault fissure. The enrichment, therefore, bears no relation to the surface or secondary influence, but it occurs where the ore shoot happens to cross the older vein segments. A good example is found in the Parrot mine where a Blue vein ore shoot meets the Parrot vein between the 1,200-ft. and the 1,500-ft. levels.

It has been suggested that the Blue veins have been prominent zinc ore channels and that the Black Rock and other sphalerite veins probably of Anaconda age, of the north district, owe their unusual zinc content to the Blue vein fissures. The Black Rock vein appears to be of Anaconda vein age, as it is cut and displaced by northwest fissures of the Blue system, and no doubt its mineral content has been influenced by these intersecting veins. But it might be said with just as good reason that since these same northwest faults of the Blue system contain copper ore farther south, they were responsible for the copper in the earliest copper veins. The fact is, the Blue veins in the zinc regions contain sphalerite, quartz, and manganese minerals just the same as the other veins of that particular section. In the central copper area, however, the Blue veins carry no sphalerite, neither do the Anaconda or Steward veins; they all contain the ore and gangue minerals common to that locality. Intermediate between the copper and zinc areas, the Blue veins, which extend directly and continuously from one area to the other, contain ores of intermediate mineralogical composition, getting more zincky with less copper toward the zinc area, and less zincky with more copper toward the

copper area. Finally toward the north the copper minerals fail with increased sphalerite, manganese, and quartz, and less pyrite, while toward the copper area, sphalerite and the manganese minerals drop out completely, while pyrite and the copper minerals, chalcocite, enargite, and bornite, increase.

The above general statements apply with equal force to the fault-veins of the Steward system or any faults or fissures which have served as channels for uprising primary ore solutions. The Steward veins, like the Blue, exhibit the same variations in mineralogical composition which are believed to be functions of geographical position. (See pp. 58-61, inclusive, *Distribution of Ore Types*.) The direct effect of the Steward faults on the mineral composition of the Anaconda veins is a more obscure problem than in the case of the Blue veins, because the Steward fissures are so scantily mineralized that, even where in direct contact with older veins for long distances on strike, there are logical reasons for doubting that any primary enrichment whatsoever has resulted directly from these faults. In certain instances, however, it is believed that older veins have been enormously enriched by faults of the Steward system. Important examples may be cited, such as the Moonlight vein in the Anaconda mine, the Gagnon vein in the Original and Gagnon mines, the Bell-Speculator, and others. The No. 16 vein in the Rarus and Tramway mines contains remarkably rich primary chalcocite ore where it possibly acted in part as a feeder, exercising a marked influence on the mineral content of the big ore bodies of the Leonard, Tramway, and Rarus mines.

Since fault-vein ore occurs in separated shoots along the strike of the fissures, it is not improbable in the case of strike faulting that the crackled and reopened older vein filling has supplied important new channels connecting the widely separated ore channels of the fault veins, in which case the enriching influence upon the old vein filling might be very great.

*Influence of Faults on Secondary Enrichment.*—The influence of faulting on the secondary enrichment processes which have been active in the Anaconda veins is not easily determined. The breaking and shattering, by faults, of the old massive vein filling has undoubtedly permitted a more rapid and extensive oxidation of the vein and a correspondingly greater enrichment below. As in the case of primary minerals, the strike faults have exerted more influence on the older veins than the cross faults; that is, where the coincidence of the old vein and the strike fault occurs in levels relatively near the surface. In the St. Lawrence and Mountain View mines secondary enrichment

has reached unusual depths, owing to intense fissuring and a highly altered and mineralizing condition of the granite, and to faulting of Anaconda veins.

Weed's statement<sup>9</sup> that the early quartz-pyrite veins belonging to the Anaconda system were too low grade and unworkable except where fractured and enriched through the action of descending sulphate waters, has not been corroborated by the writer's own observations. The assertion that workable ores in the veins of the Anaconda system are localized and occur only at or near intersections with later fissures is entirely disproved by mining operations.

The Rarus fault has not influenced the mineral content of the ores of older veins, either in regions near the surface or at greater depths. The segments or blocks of ore included within the walls of the Rarus fault are no richer than the original vein. There has been no primary enrichment traceable to Rarus fault influence and it is believed that this fault has exerted but slight influence even in the case of the sooty chalcocite enrichment.

*Vertical Distribution of Ore Minerals in Veins of the Anaconda System.*—The upper parts of the Anaconda veins are oxidized to depths varying from 50 to 400 ft. The mineralogical composition of the oxidized portions of the veins is fully described under the subject of superficial vein alteration on preceding pages of this paper. Without exception in the copper district there is a development of sooty chalcocite immediately below the zone of oxidation in the Anaconda veins, which is found to be of variable vertical extent, depending primarily upon many factors, such as depth of the zone of oxidation, physical character of the vein, copper content of the primary ore, etc. Since the Anaconda veins were, in many instances, rich with primary copper minerals such as enargite, bornite, and chalcocite, apparently before being subjected to secondary influences of importance, the addition of a large amount of copper in the form of secondary chalcocite resulted in marvelously rich ores extending many hundreds of feet below the zone of oxidation. In the large quartz-pyrite veins, such as the Anaconda, Colusa, and Syndicate, the wonderful bonanzas of the upper levels were examples of the secondary enrichment of already rich primary vein filling. Below the zone of secondary enrichment there are no great variations in the mineralogical composition of the veins on the dip at any particular vertical section taken through the vein, but no general rule holds good for all veins. For

<sup>9</sup> Weed, W. H., *Geology and Ore Deposits of the Butte District, Montana*, Professional Paper No. 74, U. S. Geological Survey, p. 95 (1912).

example, in certain veins, such as the Johnstown, Shannon, Enargite, Windlass, and many others of the Mountain View mine, the predominant copper mineral in the higher levels is enargite, while in the Gagnon and possibly numerous other veins enargite is much more abundant in the deep levels than near the surface. Analogous conditions hold in the case of primary chalcocite, bornite, and sphalerite. In the "stock-work" ore bodies of the Leonard mine primary chalcocite is vastly more abundant at great depths than above the 800-ft. level. The same is true of the Moonlight, Original, and other veins.

Concerning the presence of the gangue minerals, quartz and pyrite, much difficulty is encountered in an endeavor to arrive at definite conclusions as to increase or decrease with depths. As indicated by the uneven distribution of these minerals along the veins, it is not improbable that they are principally deposited in irregular zones or shoots within the plane of the vein, so that observation on a single vertical cross-section through a vein does not accurately determine the general vertical distribution of either mineral. As a general observation on this point, however, it is believed by the writer that proportionately to the total gangue present, there is more quartz and less pyrite in the higher levels in the Anaconda veins than at great depths. Not enough data have been collected, however, from which reliable deductions can be made.

In the manganese-silver veins belonging to the Anaconda system but little information can be had on the matter of vertical distribution of minerals, owing to the inaccessibility of the mine workings.

#### *Blue Vein System.*

The veins belonging to this system have resulted from the mineralization of the Blue fissure system previously described. (See pp. 18-20.) The veins known to be of greater or less importance as ore producers are the No. 1, Clear Grit, Blue, Diamond South, High Ore, South Bell, Skyrme, Adirondaek, Edith May, Jessie, Gem, and Cræsus. In the earlier days of copper mining in Butte the presence of these well-defined copper-bearing fault veins was not recognized. Even for a long time after they were known as faults, their importance as ore carriers was not known. Their tardy development was due to two facts, later determined: (a) the ore bodies rarely reach the surface so as to come within the observation of the prospector, and (b) the early copper vein developments were along quartz-pyrite veins of the Anaconda system, little attention being paid to cross fissures, known to the miners as breaks, pinches, etc., which, as a

matter of fact, were usually barren where in contact with the older veins. (See Plate I.) But little encouragement was therefore offered by these veins, either to the surface prospector or to the miner underground. Many valuable mining claims of the district covering certain veins of this system remained idle and were considered as having but little value until they were cross-cut at deep levels from adjoining properties.

*Structure of the Veins.*—The Blue veins are typical fault fissures of marked displacement, with variable dips, but fairly uniform strike. (See Plates I. and II.) There is frequent splitting, or branching, on strike, the branches commonly re-uniting along the course of the vein after inclosing horses of granite. (See High Ore vein, Plate I.) In certain localities the branches are diverging and remain separate, as far as known from present developments. In closer detail the fault zone, which may be entirely included within a width of from 5 to 25 ft., is often composed of two or more well-defined movement planes characterized by seams of fault clay from 0.25 to 2 in. thick. The clay seams are usually accompanied by crushed granite of variable thickness, often occupying the entire width of the fault zone. The so-called crushed granite does not as a rule represent a cracked condition of granite adjacent to the movement planes, but more precisely, it is a distinct zone of finely comminuted granite, sharply separated from the fairly solid country rock by a wall or a clay seam marking a plane of movement.

*Mineralogy of the Blue Veins.*—The principal copper minerals are chalcocite, enargite, and bornite, together with small amounts of chalcopyrite, covellite, tetrahedrite, and tennantite, named in order of their importance. The gangue minerals are quartz and pyrite, with widely variable amounts of sphalerite and rhodochrosite, the latter minerals being present in certain localities only. Variations in the mineralogical composition of the ores of the Blue veins are common; in fact, are the rule. In certain ore shoots chalcocite predominates, in others enargite is the chief source of copper. Both are usually present, and bornite always but in less important quantities. Covellite is of small importance in the Gray Rock and Skyrme veins, but generally absent from the other veins of the Blue system. Chalcopyrite is of widespread occurrence, but in insignificant amounts, excepting in the Jessie vein, where it formed the chief ore mineral in the upper levels of the Jessie and Mountain Chief mines. Tetrahedrite and tennantite have been of little commercial importance, although of frequent occurrence, particularly in the northeast section. The gangue minerals are chiefly quartz and pyrite, with large

amounts of sphalerite in certain localities and minor amounts of galena, rhodochrosite, fluorite, etc.

Like the Anaconda veins, the mineral variations are matters pertaining largely to locality. As far as the primary copper minerals are concerned there is no possible mineralogical distinction between the ores of the Blue veins and those of the Anaconda system. The Blue veins lack the zone of sooty chalcocite, so common to the older veins. The minerals composing the ore bodies are believed to be almost universally of primary origin. Where shoots of primary ore reach the surface they are oxidized and secondarily enriched below the zone of oxidation in a manner similar to the Anaconda veins.

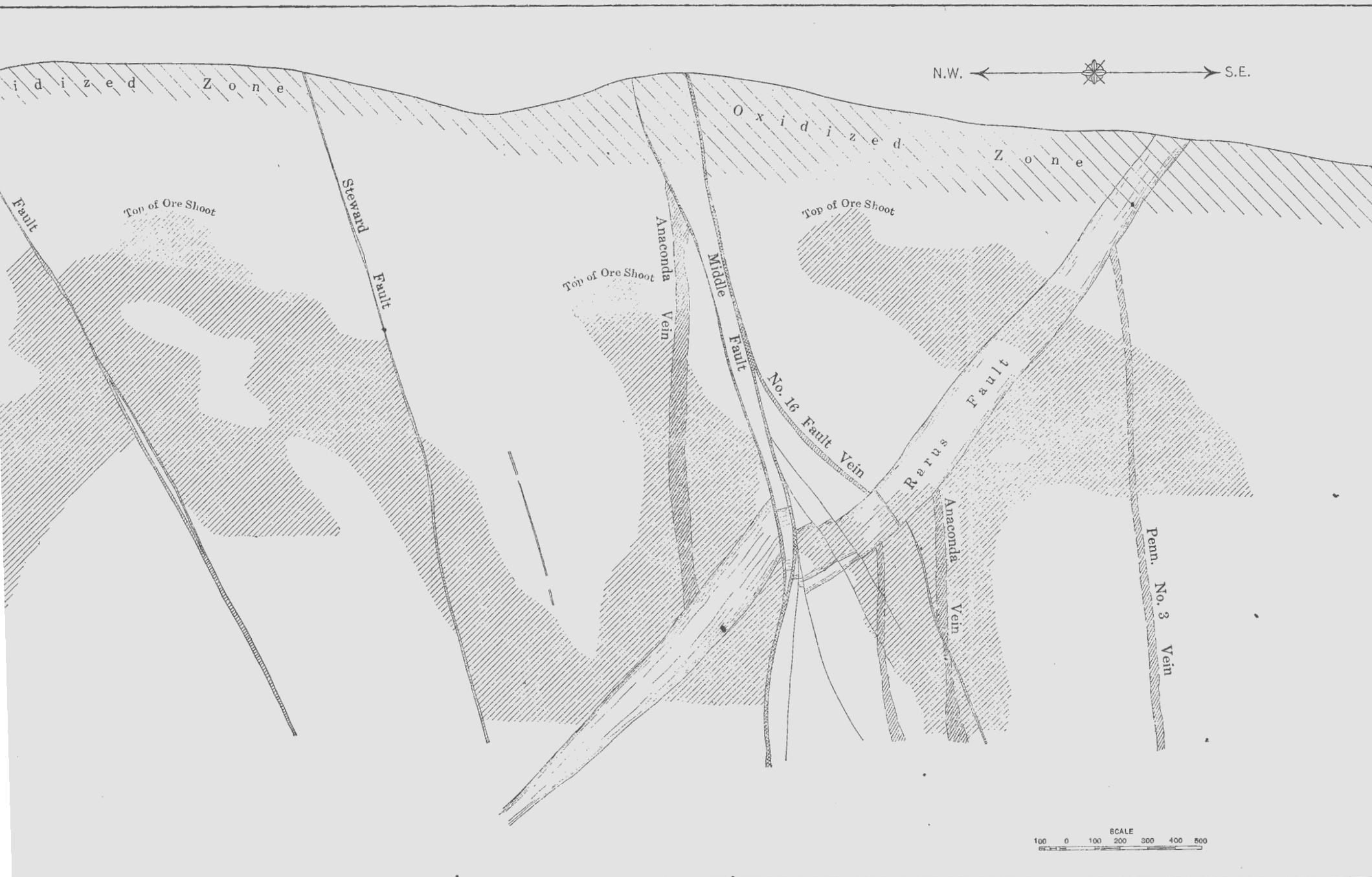
*Ore Bodies.*—The ore occurs in irregular shoots, either along the main fissure or along the various branches comprising the fault zone. On the strike of the fissure the ore shoots are separated by barren stretches of typical fault material consisting of crushed granite intensely altered and one or more clay seams. The altered granite usually carries abundant disseminated pyrite and frequently small wavy quartz-pyrite veinlets of small lateral extent.

The general distribution of the ore shoots is shown in plan on the accompanying map. (See Plate I.) It will be seen that they are irregularly spaced along the fissures, and, at this particular elevation at least, they appear to be arranged wholly without regard to Anaconda or other vein intersections. Typical examples of ore shoot occurrences are shown in Plates V. and VI., longitudinal projections of the Jessie and High Ore veins, respectively, upon which have been outlined the ore shoots (shaded areas) as far as known from present developments. The pitch of the ore shoots is usually to the southeast, but not uniformly so. The stope length of the shoots varies from 100 to 2,000 ft. The width of the ore runs from nothing up to 30 ft. or more. Stopping widths of from 10 to 20 ft. are common.

*Structure of the Ore.*—As a rule the vein filling of the Blue vein ore shoots is less massive than that of the Anaconda veins. A certain amount, however, of mineralization and replacement of firm wall rock has taken place along the Blue vein fissures, as well as in the older veins, resulting in hard, massive, complex aggregates of ore and gangue minerals similar to the typical "quartz-pyrite" ore of the Anaconda veins. Where, as is commonly the case, the ore is a complete or partial replacement of crushed granite, by quartz, pyrite, and copper minerals, it may be readily distinguished from ore formed by replacement of hard granite by reason of retaining the brecciated structure. Blue vein ore frequently consists of crushed and altered granite netted by stringers, bands, and tiny seams of the copper



PLATE I  
 THE BLUE VEIN SYSTEM, SHOWING INTERSECTIONS AND ORE SHOOTS.  
 (The fault and intersected older veins.)



VERTICAL PROJECTION OF THE HIGH ORE VEIN, A MEMBER OF THE BLUE VEIN SYSTEM, SHOWING DISTRIBUTION OF ORE SHOOTS.

(Note that the shoots appear to be independent of later cross faults and intersected older veins.)

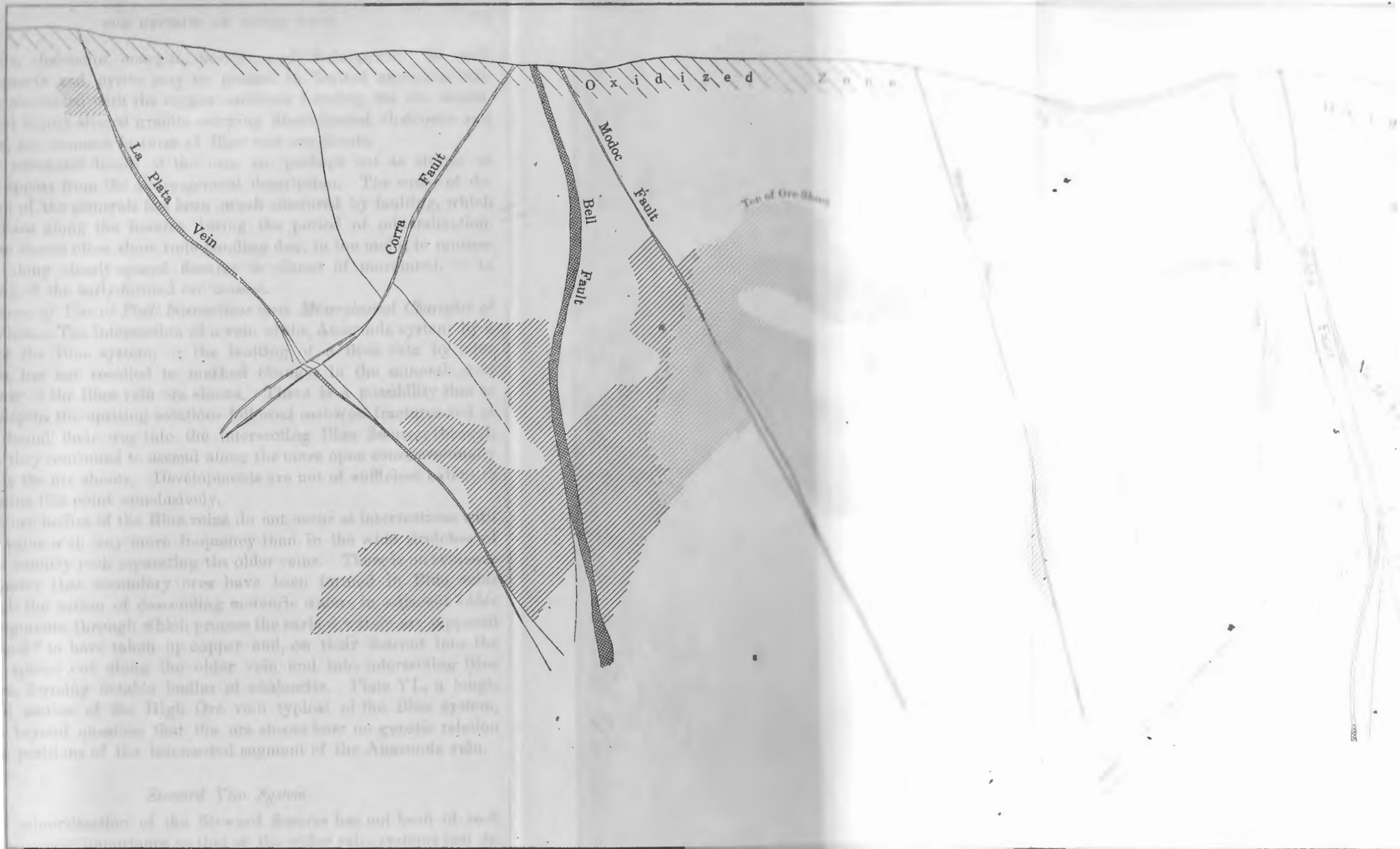
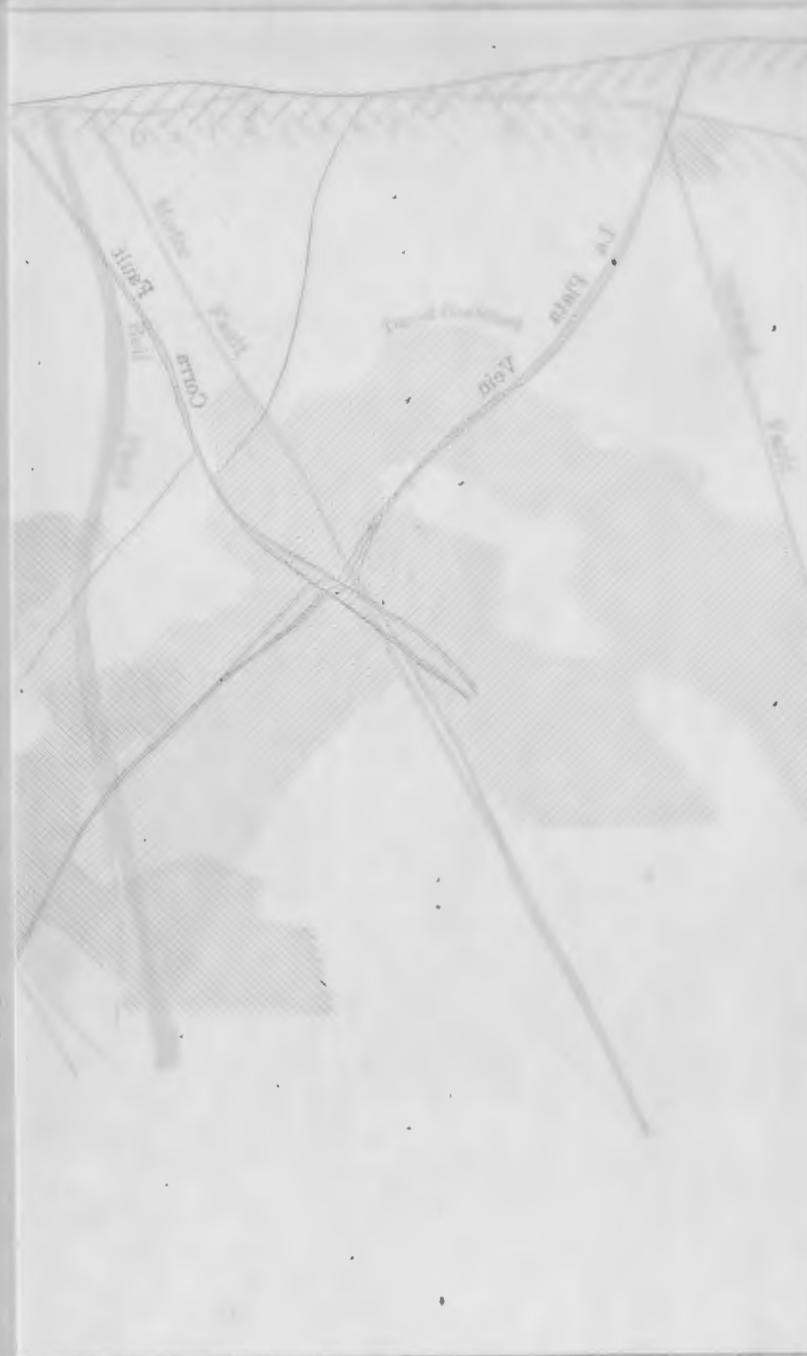


PLATE VI.—LONGITUDINAL VERTICAL PROJECTION OF THE BELL VEIN SYSTEM, SHOWING DISTRIBUTION OF ORE SHEETS.  
 (Note that the sheet dips to the eastward at each cross fault and intersected older veins.)



minerals, chalcocite, enargite, bornite, and chalcopyrite. In such cases quartz and pyrite may be present in limited amounts, intimately associated with the copper minerals forming the ore seams. Crushed highly altered granite carrying disseminated chalcocite and bornite, are common features of Blue vein ore shoots.

The structural details of the ores are perhaps not as simple as might appear from the above general description. The order of deposition of the minerals has been much obscured by faulting, which took place along the fissures during the period of mineralization. The ore shoots often show rude banding due, in the main, to replacements along closely spaced fissures or planes of movement, or to shearing of the early-formed ore masses.

*Influence of Vein or Fault Intersections upon Mineralogical Character of Blue Veins.*—The intersection of a vein of the Anaconda system by a vein of the Blue system, or the faulting of a Blue vein by later fissures, has not resulted in marked changes in the mineralogical character of the Blue vein ore shoots. There is a possibility that at great depths the uprising solutions followed east-west fractures and at times found their way into the intersecting Blue fissures, through which they continued to ascend along the more open zones eventually forming the ore shoots. Developments are not of sufficient extent to determine this point conclusively.

The ore bodies of the Blue veins do not occur at intersections with older veins with any more frequency than in the wide stretches of barren country rock separating the older veins. There is no evidence whatsoever that secondary ores have been formed in Blue veins through the action of descending meteoric waters in adjacent older vein segments, through which process the surface waters are supposed by Weed<sup>10</sup> to have taken up copper and, on their descent into the earth, spread out along the older vein and into intersecting Blue fissures, forming notable bodies of chalcocite. Plate VI., a longitudinal section of the High Ore vein typical of the Blue system, shows beyond question that the ore shoots bear no genetic relation to the positions of the intersected segment of the Anaconda vein.

#### *Steward Vein System.*

The mineralization of the Steward fissures has not been of such great economic importance as that of the older vein systems just described. The ore bodies of the No. 16 vein of the Rarus and Leonard mines are the largest yet found in this system of fissures. The La

<sup>10</sup> Weed, W. H., *Geology and Ore Deposits of the Butte District, Montana, Professional Paper No. 74, U. S. Geological Survey, p. 103 (1912).*

Plata vein north of the Syndicate vein in the Mountain Con mine yielded a small amount of silver ore from shallow workings. In depth two small shoots in the Buffalo mine were worked for copper; however, they have thus far proved to be of little commercial importance. In the Gagnon mine the Gagnon South vein, apparently belonging to the Steward system, has yielded a considerable tonnage of copper-silver ore. This vein may possibly be the western extension of the No. 6 fault of the Parrot mine.

*Occurrence of the Ore Bodies.*—The ore of the Steward fault veins occurs in shoots similar in form and general character to those of the Blue vein system. There are many instances where Steward fissures are strike faults along veins of the Anaconda system, forming what might be properly termed compound veins. In examples of this class it is next to impossible to determine with any degree of certainty the influence of the fault fissure on the mineralogy of the older veins. Usually the fault fissure follows along the vein for a time on one wall, then crosses diagonally to the opposite wall. If the vein filling of the old vein is wide there may be but little breaking or crushing. As a general rule, the old vein itself is stronger than the adjoining altered wall rock, so that the strike fault occupies the plane of least resistance, which is usually the contact between the vein filling and wall rock. Further movement crushes the weaker altered granite, forming a zone of fault material following the solid ore. Where a small ore vein is overtaken by a strong strike fault both walls of the older vein may form planes of movement. The older vein filling thus inclosed within fault zones has the appearance of the usual fault vein ore and it is generally impossible to correctly classify such mineral masses without additional corroborative evidence. Even where the evidence proves conclusively that the major part of the vein filling belongs to a geologically older vein system, the influence of the strike fault on the mineral composition may be determined with difficulty, if at all. The mineral mass may exhibit later-filled fractures in primary vein filling, or replacements of the first-formed minerals, etc., but the phenomena of successive periods of mineral deposition are so frequently met with in veins of all ages that such evidence cannot be given great weight. The existence of minerals indigenous to the fault fissure itself in the vicinity of the mineral mass in question, identical with that found filling fractures in the older vein filling, offers satisfactory evidence of the fault influence.

The most important ore shoots found in fissures of Steward age and known positively to be indigenous are those of the No. 16 vein in the Rarus and Leonard mines. Although existing as a single well-defined

ore-bearing fault fissure in the Rarus mine, in the Leonard mine the No. 16 vein fissure splits into two or more branches, both of which contain important ore bodies. The ore is especially high grade, often showing from 1 to 4 ft. of reasonably clean chalcocite ore, containing also enargite, quartz, and pyrite, with little or no sphalerite, chalcopryite, or bornite.

*Depth of Ore Shoots.*—No ore was found in the No. 16 vein higher than the 1,000-ft. level of the Rarus mine, or more than 1,100 ft. from the surface. In the Leonard mine the first ore was encountered at more than 1,200 ft. below the surface. These ore shoots have persisted to the greatest depths yet reached by mine workings.

*Influence of Later Faults.*—There is no evidence that the quality or mineralogical character of the Steward ores has been influenced by later faulting. The high-grade chalcocite-enargite shoot of the No. 16 vein in the Rarus mine is cut sharply by the Rarus fault unaccompanied by enrichment. (See Fig. 5.) Where the ores occur at great depth, as in No. 16 vein below the oxidized zone, it is doubtful if any appreciable amount of secondary enrichment has taken place. The chalcocite and other copper minerals of these deep ore bodies are believed to be universally of primary origin.

*Minerals of Steward Vein Ores.*—The mineral composition of the Steward ore bodies corresponds to that of the Anaconda and Blue veins, but depends on the particular locality in question. In the Rarus and Tramway mines the copper mineral comes principally from chalcocite, which occurs in great purity. There are usually present in small quantities enargite and bornite, but no sphalerite. There are also less quartz and pyrite than in the older veins. In the Gagnon district the ore shoots contain a large amount of sphalerite similar to older vein ores. The same is true of the La Plata ore shoots, where the ore contains sphalerite and rhodochrosite, both characteristic of the border zones.

In structural appearance the Steward ore shoots are similar to the previously described Blue vein shoots. They are, however, less complex both mineralogically and structurally, and it does not appear that the faulting movement continued to any great extent during the period of ore deposition.

#### CONTRASTING FEATURES OF VEIN SYSTEMS.

##### *General Summary.*

*Forms of Ore Bodies.*—The Anaconda fissures are solidly and continuously mineralized, forming ore bodies which may be continuously stopped over thousands of feet without showing any great variations

in valuable metal content. Anaconda veins seldom exhibit evidences of extensive fault movement so characteristic of the Blue and Steward veins.

The ore of the Blue and Steward fissures occurs in the form of "shoots" which vary greatly in size and extent. These ore shoots are irregular in outline and are separated on the strike of the fissure by hundreds or even thousands of feet of barren crushed granite and fault clay composing the fissure zone. The walls of the ore are seldom free from fault gouge or other evidences of extensive movement.

*Oxidation and Enrichment.*—The vein filling of the Anaconda fissures within the copper area extends with great strength upward to the oxidized zone. It is deeply oxidized and invariably shows a marked development of secondary chalcocite below the zone of oxidation, which has proved in most instances to be of immense commercial importance. (See Fig. 6A.)

In the Blue and Steward fissures the ore shoots seldom extend upward to within 500 ft. or more of the zone of oxidation. Except in the zones of highly altered granite the zone of oxidation in fault veins is shallow, the vertical extent being not more than from 20 to 40 ft., and often as low as 10 ft. The disseminated pyrite so universally present in the crushed granite of the fault fissure may show slight secondary chalcocite enrichment immediately below the zone of oxidation, but it is of no commercial importance. (See Fig. 6.)

*Physical Character of the Ores.*—As regards physical character, the ore of the Anaconda veins is usually harder, more massive, and it seldom exhibits the breccia structure so often characteristic of replacement of fault breccia of the fault veins. The solid ore streaks of the Anaconda veins are wider, and the metasomatic action has been sharper and more complete than in fault veins where vein-forming processes were often disturbed by fault movements.

*Mineralogical Differences.*—There are no notable differences in the mineralogy of the veins of the three systems in any given area. As noted on a previous page, the veins of a certain limited area contain minerals characteristic of that particular area, regardless of geological age. The Blue veins are later than the Anaconda veins and they have less pyrite but more quartz in proportion to the total vein filling present. There is also the same general order of sequence in mineral deposition in the various veins. The earliest minerals are quartz and pyrite, followed by enargite, bornite, and chalcocite in the central zone. In the intermediate zone the order is quartz and pyrite, enargite, sphalerite, bornite, and chalcocite, with chalcopyrite probably forming contemporaneously but under different conditions in

border zones. In the peripheral zone, the order among quartz, pyrite, galena, and sphalerite has not been worked out owing to inaccessibility of mine workings.

#### GENESIS OF THE ORE DEPOSITS.

##### *Source of the Ores.*

The evidence points directly to the conclusion that the ores have been derived primarily from rocks of igneous origin. The veins are found entirely within igneous rocks, with no sedimentary rocks in quantity within 15 miles of the district. Formerly sedimentaries may have covered the granite of the Boulder batholith, but there is no evidence indicating that such rocks played any part whatever in the formation of the Butte ores. The ore deposits of the district are so centered or concentrated within a relatively small area that causes which led to their formation must be sought within, or in close proximity to, the area in which the ores are found.

Compared with other mining districts situated within the borders of the Boulder granite batholith, the chief point of difference in the geologic structure is the presence in Butte of the quartz-porphry dikes in close association with the veins. In the Corbin, Wickes, Rimini, Basin, Clancy, and Alhambra mining districts no quartz-porphry has been found, although rhyolite intrusions are common, corresponding, no doubt, to the rhyolite intrusion forming Big Butte at Butte. The districts above named, however, have developed no important copper deposits, and it is believed, therefore, that the many rhyolite eruptions occurring at a comparatively recent date within the Boulder granite area, played a minor part in the deposition of the copper ores at Butte and elsewhere. The rhyolite at Butte is not directly associated with the ores in any way. The copper veins become poor going westerly, and the earlier vein systems are known to be older than the rhyolite.

There are three or more well-defined quartz-porphry dikes traversing the Butte district in close association with the copper ores of the main central zone. Those dikes extend in an easterly and westerly direction, coinciding in a significant manner with the general habit of the veins of the Anaconda system. (See Plate I.) It will be observed that in going easterly from the Anaconda mine the Anaconda veins bend to the southeast toward the Silver Bow mine, while a similar bend may be noted in the quartz-porphry dikes. Farther to the east a change in strike from southeast to northeast in the dikes is accompanied by a similar variation in the course of the Anaconda veins. These last changes in strike in both the dikes and the veins

are accompanied by corresponding changes in dips from south to north.

Another feature of interest in this connection is found in the fact that the areal extent of the quartz-porphry appears to be increasing in depth. Where the upper levels of the Mountain View mine show but one small dike of an average width of 30 ft., the 2,200-ft. level discloses three dikes, having a combined width of 150 ft. The main St. Lawrence dike, found no farther west than the Nipper shaft on the surface, has been cut in the Gagnon, 1,900 ft. level, 2,500 ft. west of the Nipper. Again, in the Mountain View, West Colusa, and Leonard mines, areas of the most intense fissuring of Anaconda age are associated with quartz-porphry dikes, and dikes wholly unsuspected at the surface are appearing in deep levels.

A certain significance might also be attached to the marked zonal arrangements of ore types about the central copper zone in which the more important quartz-porphry dikes occur. This fact tends to support the belief that the Butte ores were derived from a demonstrable centralized source.

Notwithstanding these apparent close genetic relations between the copper veins of the central zone and the quartz-porphry, it does not follow necessarily that the quartz-porphry magma was the immediate and direct source of the ore minerals now found in the veins. The association of the quartz-porphry dikes and the Anaconda veins seems to have greater significance when considered in connection with the origin of these early fissures than when referred to the source of the vein-forming waters. There is no evidence indicating a direct transfer of vein-forming waters from the quartz-porphry dikes into the adjacent granite, nor does it appear that any notable alteration of the granite took place prior to the appearance of the Anaconda system of fractures. The dikes are altered only in areas where the granite is altered in connection with the veins. The Modoc dike extends northwesterly from the East Colusa mine through a long stretch of unaltered granite, in which the dike itself shows no alteration whatever. Other similar instances have been noted.

It is a reasonable assumption that the quartz-porphry was derived primarily from the parent granite magma; and also that the ultimate source of the ore minerals was the granite magma. The principal part played by the quartz-porphry has apparently been the opening of the way for vein-forming waters of deep-seated origin to reach the higher regions where the ore deposits are now found. While the ultimate source of the metals of the ores was probably the original

granite magma, the direct source may have been the same magma locally which furnished the quartz-porphry, the latter rock following the earliest fracturing and at the same time stimulating an upward movement of the ore-bearing waters.

#### *Ore Deposition.*

*Ore-Forming Agents.*—There is little doubt that the chief transporting agent at work in the formation of the primary Butte ores was water. Vein-forming waters are believed to have been derived from the same fluid magma which earlier produced the quartz-porphry dikes, and possibly also, at a much later period, the rhyolites. Such waters, of deep-seated origin, either contained primarily the elements which now go to make up the minerals forming the ores, or they gathered them from the wall rocks in the course of their upward journey. In regions open to observation the almost entire absence from the normal granite of many of the most abundant elements of the ore-forming minerals, such as copper, arsenic, sulphur, zinc, etc., points to the conclusion that these elements could not have been derived from the rocks adjacent to the avenues of travel, but that they were probably constituent parts of the solution when the upward journey began.

*Composition of Vein-Forming Waters.*—Certain general conclusions may be drawn as to the probable composition of these uprising waters when they reached the regions in which the ore deposits are now found, through a study of the character of the vein minerals known to be of primary origin, and the altered condition of the rocks directly associated with the veins. In the Butte district enormous quantities of copper, sulphur, arsenic, zinc, and manganese have been added, together with notable quantities of lead, antimony, silver, tungsten, barium, fluorine, etc.; most of which are very minor constituents of the normal granite rock and some of them have not been detected in the original granite by chemical analyses of fresh rock. In addition, the abundance of pyrite and quartz in the veins indicates the presence in the solutions of large quantities of iron and silica, both of which, however, are essential constituents of the original granite. Although purely a matter of speculation, it seems unnecessary to assume that the uprising solutions originally contained notable quantities of either iron or silica, both of which could have been readily derived from the granite wall rock at great depths through chemical processes.

The variable mineralogical nature of the ores of different veins presumes, apparently, many changes in the composition of the vein-forming waters from time to time. However, such a statement re-

quires some modification. It is conceivable that from uprising waters carrying constant proportions of ore-forming elements, varying quantities of certain minerals might deposit at different localities within the same vein, or at different periods in the same locality, due to changes in temperature, pressure, or other controlling factors. Analyses of the altered granite in association with the veins show that large amounts of sodium and calcium have been extracted from the granite. These elements were undoubtedly present in the vein-forming waters in varying quantities along with the metallic elements which were later deposited as minerals in the vein.

The probable high temperature and vigorous chemical activity of the earliest solutions passing upward through the fissures of the Anaconda system is indicated by the intensely altered condition of the wall rock in the region of such fissuring. The composition of these solutions can be judged in a general way only from a study of their effects. The widespread development of pyrite both in veins and as disseminated pyrite in granite, in the absence of sulphur as a constituent of the original granite, requires the addition of sulphur in large quantities. The extraction of the sodium and calcium in this process with addition of sulphur, forming pyrite, may be accounted for by the presence originally of an abundance of  $H_2S$ . Since this activity was probably more intense at great depths, it is reasonable to assume that the ascending waters in the upper regions now open to observation carried not only hydrogen sulphide but alkaline sulphides as well.

*Processes Involved.*—The ore-forming minerals gathered at great depths, were transported upward and deposited largely through metasomatic replacement of the country rock along fissures so as to yield the ores now being mined. The factors which influenced mineral deposition at certain horizons are believed to be mainly those of temperature and pressure. However, another important factor entered into the vein-forming processes which is believed to account in no small way for the variable nature of the ore minerals in different localities and at different points in the same vein. The association of the great areas of altered and pyritized granite with the massive quartz-pyrite veins belonging to the oldest vein system indicates that the early solutions were extremely active chemically, and it is not improbable that the first processes were in certain measure solfataric in their action. These solutions or gases readily attacked the granite wall rock to which there was free access along the fissures, and they also found passage by means of cracks, joint planes, etc., outward for considerable distances from the main chan-

nels into the granite. While the alteration was in progress the oldest vein filling, largely quartz and pyrite, was being deposited along the fractures. In these early processes of granite alteration the attacking solution carried sulphur in some form. It is believed that at great depths it was, in part at least, in the form of hydrogen sulphide. Analyses of normal and altered pyritized granite show that, as a result of vein-forming action, the normal granite has lost sodium and calcium, but that in regions open to observation in the Butte mines, iron, although readily attacked, has remained fairly constant in quantity. The formation of pyrite in the process, accompanied by the extraction of sodium and calcium, would seem to indicate the presence of hydrogen sulphide. The action of the attacking vein-forming waters finally resulted in the formation of pyrite, largely *in situ*, from the iron of the original granite, and the soluble alkaline sulphide,  $Na_2S$ , which was not again deposited in the fissures, but migrated far beyond the zone of ore deposition, probably reaching the surface through hot springs. The presence of soluble alkaline sulphides in the vein-forming waters is believed to have exerted a marked influence in the deposition of the Butte ores, as will be later seen.

The above line of reasoning suggests the possibility that a large part of the pyrite, and possibly the quartz of the Butte veins, were not primary constituents of the vein-forming waters as they began their ascent from great depths. The presence of veinlets of pyrite in the altered granite in connection with the Anaconda veins indicates that some of the pyrite formed through the action of deep-seated waters on the iron of the granite, migrated for short distances at least, to be re-deposited as vein pyrite. It is doubtful, however, whether appreciable amounts of the pyrite of the veins originated in this manner from nearby wall rock. Since, however, it is evident that the vein-forming solutions did attack the iron of the granite, it is not unreasonable to suppose that at greater depths conditions were such that the iron thus attacked did not immediately combine with sulphur to form pyrite *in situ*, but that the iron was taken into solution and remained so until more favorable conditions for deposition as pyrite were found. Such favorable conditions may have been encountered in the fissures at higher regions, now occupied by the ore deposits. The same method of reasoning may also be employed to account for the quartz of the Butte veins. The possible origin of the pyrite in the above manner has much significance when considered in connection with the variable mineralogical nature of the ores, as will be later set forth.

Further consideration of the possible chemical action between the uprising waters and the granite wall rock is of interest when viewed

in connection with the variations in mineralogical character of the ores deposited during different periods in the same locality, and also variations in ore types zonally arranged around the central copper zone previously described.

As already stated, it is believed that the earliest ascending waters vigorously attacked the wall rocks on their upward journey through the newly formed Anaconda fractures. Sodium and calcium were extracted from the normal granite, and since they were not again deposited, the attacking solution necessarily became more and more alkaline toward the surface. The chemical activity in the early stages was more intense because (1) the solutions were probably at a higher temperature than during later periods, and (2) when the fissures were first formed the solutions had direct access not only to the unaltered wall rocks of the fissures, but to much sheared and easily attackable, crushed, unaltered granite within and along the fissures. Under these conditions, if it be assumed that the original solutions contained certain proportions of hydrogen sulphide and alkaline sulphides, or alkaline carbonates, it is evident that the solutions would become more alkaline with a less preponderance of  $H_2S$  as they moved upward toward the surface.

From the state of maximum alkalinity, which is believed to have occurred when the early high-temperature waters had only unaltered granite to work upon, there was probably a gradual return to conditions wherein a higher ratio of hydrogen sulphide was established. Observed facts show that the alteration of the granite took place outward from the fissures, cracks, and joint planes through which the solutions passed. It is reasonable to infer that after a certain length of time the solutions no longer reacted chemically with the already altered granite adjacent to the avenues of travel; in other words, a partial chemical equilibrium was established between solution and the fringe of altered granite contiguous to the fissure, as far as the process concerned the extraction of alkalis or the attack of the iron of the granite. Metasomatic replacement of altered rock adjacent to the fissures by vein minerals, principally quartz and pyrite, was probably taking place during this time as a part of the general process. In the later stages, therefore, the ascending waters were unable to take into solution such large proportions of sodium, calcium, iron, and silica per unit volume of solution passing, owing to the presence of the protecting layer of already altered granite bordering the fissures, upon which the solutions had but a slight effect. Assuming then a fairly constant  $H_2S$  content of the original deep-seated solutions, there must have been at first an increase in the proportion of the alkalis and a

corresponding decrease in  $H_2S$  as the solutions moved upward, until a certain maximum degree of alkalinity was reached, after which time there was a gradual decrease in alkalinity, due to the protective effect exerted upon the normal granite by the altered granite barrier from which the available sodium and calcium had been extracted. A further decrease in the alkalinity of the solutions would be effected at later periods because of the development of solid veins, for subsequent fracturing of the vein filling (a common phenomenon) would permit a ready passage for the vein-forming waters along and in contact with vein minerals. The  $H_2S$  solution would thus be afforded a double protection against the influence of normal granite (1) by the vein filling, and (2) by the altered granite belt forming the vein wall rock.

If, as has been already suggested, the vein pyrite was derived from the granite through the action of uprising alkaline sulphide or  $H_2S$  solutions on the iron of the normal granite, the decrease in alkalinity would be accompanied by a corresponding decrease in the pyrite content of the later vein-forming waters, for the same reasons as above outlined. The latest vein filling in a given vein should contain less pyrite than the earliest concentrations of vein minerals.

Regarding the above discussion of the probable effect of the chemical action between the uprising vein-forming waters and the granite, as affecting the deposition of certain ore types, the writer does not assume that such reactions have been the sole influence in the determination of the vertical and lateral distribution of the minerals and ore types in the Butte deposits. In fact, this discussion has been undertaken largely for the purpose of bringing out more forcibly the possible genetic relations between certain ore types and the more important areas of altered granite. The elements Na, Ca, and Fe were chosen for discussion because comparative chemical analyses of normal and altered granite show clearly that these elements have entered prominently into the reactions between the vein-forming waters and the granite, and therefore, if such reactions were to any degree influential in the formation of ores, the above-named elements were, no doubt, the most directly concerned. To the variations in temperature and pressure, to changes in the composition of the original solutions from time to time, and to the mingling of unlike solutions must also be assigned important rôles in the distribution of the primary ores throughout the veins of the district.

Concerning the possible influence of these various factors as affecting the distribution of ore types, many facts have been observed that are of particular interest. For example, primary chalcocite and enargite occur only in association with the intensely altered granite of

the district. In the central copper zone, or in veins where alteration has reached an advanced stage, these two minerals are commonly found in intimate association with other vein minerals forming the ores, and, in addition, small veins or stringers, largely chalcocite and enargite, may be found extending outward into and replacing the wall rock, the granite being in actual contact with the copper minerals. In areas of unaltered granite, chalcocite and enargite are confined to highly altered zones within or along the veins, and never as stringers or disseminations inclosed by unaltered granite. It is improbable that solutions bearing these minerals did not find passage outward into the normal granite during the active vein-forming period, when chalcocite, bornite, and enargite were being deposited in abundance in the veins. The frequent occurrence of stringers of pyrite, quartz and sphalerite extending into wall rock of normal granite in the intermediate zone, with addition of manganese minerals in the peripheral zone, indicates that the mineral-bearing waters did to some extent find their way into the wall rock, but only where alteration was marked were chalcocite and enargite deposited contemporaneously in the veins proper and in the altered granite wall rock.

Applying a similar method of reasoning to the remaining important minerals of the veins, it is observed that quartz and pyrite are found abundantly in association with all stages of rock alteration and with all periods of primary ore deposition, although there is a noticeable decrease in the proportionate amount of pyrite in the intermediate and peripheral zones as compared to the central zone. It is true also that there is proportionately less pyrite in the Blue vein ores than in the Anaconda veins, and markedly less in the Steward ore shoots than in the Blue veins, an indication that the later vein-forming waters either contained less pyrite or that conditions were less favorable for deposition. These later ores are quite certainly less rich in pyrite for reasons previously stated. Quartz and pyrite are thus found to have been deposited under widely varying conditions of the solutions, such as composition, temperature, and pressure. Sphalerite is rarely found in zones of most intense alteration. It is sparingly developed in the slightly less altered areas of the Mountain Con and Diamond mines, and is very abundant in veins occurring in regions of relatively unaltered rock. It is believed to have been deposited under conditions of alkalinity similar to those under which enargite was formed, but generally at lower temperatures. Being more soluble, it would tend to migrate in solution before deposition through greater distances than would enargite.

Galena is a relatively uncommon mineral, associated usually with sphalerite. It is not found in the central copper zone. The manganese mineral, rhodochrosite, is an abundant constituent of the veins of the peripheral zone, and is not uncommon toward the outward limiting boundaries of the intermediate zone. It is entirely unknown in the central zone. Chalcopyrite is not an uncommon mineral associated with sphalerite, quartz, and galena in the manganese-silver veins.

In an endeavor to explain these general relationships between the various vein minerals and altered granite areas, certain assumptions must be made in order to form a working hypothesis. It is believed by the writer that the ores of Butte in their entirety have been derived from one general centralized source at great depths. There is no evidence in support of, and much evidence contradicting, the hypothesis that the so-called manganese-silver or zinc veins belong to a vein-forming epoch separate and distinct from that in which the copper veins were formed. Going outward from the central area (see Fig. 7) of typical zinc-free copper ores, there are no instances of early copper veins being cut by later veins of different mineralogical character, which would naturally be the case if, for example, the Blue fissures were of a distinctly later period than the copper veins of the east-west system. It has been suggested also that the manganese-silver ores represent an invasion of an older copper area, or *vice versa*; this is also untenable, for the reason that it is an unlikely assumption that a later mineralization period could almost completely surround a central core, depositing new mineral in fissures identically the same age as those of the central area, without some of the later ore types appearing within the inclosed zone. It has been shown that the mineral composition of the different vein systems is not a result of separate periods of mineralization, but rather of geographic position. The structural relations point strongly to the conclusion that the east-west fractures of the manganese-silver area are of the same age as the Anaconda fractures of the copper area, and that they were well mineralized by quartz, pyrite, rhodochrosite, and sphalerite at the time they were cut by fissures of the Blue series. The Blue veins, furthermore, with their typical silver mineralization of the peripheral zone, continue southward into the copper area, cutting the oldest copper veins, and there contain valuable copper ores and are characteristic copper veins. Fissures of the Steward system are also found in both the copper and the silver areas, cutting copper ores in the former case and zinc ores in the latter. Therefore, while some copper ore bodies are found in these fissures, and zinc mineral-

ization is also found in them, the bulk of the vein filling in both areas is prior to this system of fissures. These structural relations between mineral deposition and the faulting periods point to the conclusion that the primary ores of the whole district are products of one great vein-forming period beginning immediately after the appearance of the Anaconda fractures, and ending with the completion of the ore bodies of the Steward vein system. It is not improbable that during this period there were some interruptions and possibly at times ore deposition practically ceased, or that vein-forming action was more vigorous in some portions of the district than in others. The fracturing of early-formed ore with subsequent filling of such fractures with new minerals is not believed to mark distinct periods of vein-forming action, but rather to indicate faulting movement during the active deposition processes. It is reasonable also to infer that the older fissures became partly or wholly plugged or sealed by minerals, at certain places. The result of subsequent fracturing by faulting might merely divert ore-bearing waters from localities where they were yet active into new fractures in the formerly plugged portion of the veins.

Proceeding on the assumption that the primary vein minerals were derived from a common source at relatively great depths below where they are now found, it is believed that the broad, general, orderly arrangement of the ore types both vertically and laterally is due in a large measure to the variable temperature and pressure conditions encountered by the vein-forming waters along the lines of travel toward the surface, and to changes effected in the chemical composition of these transporting waters through their action on the granite wall rock. Moreover, there were, no doubt, wide variations in the metal content of the vein-forming waters from time to time. It is believed that the minerals of the veins were more soluble in strongly alkaline sulphide solutions than in hydrogen sulphide solutions under conditions of constant temperature and pressure, but in either alkaline sulphide or hydrogen sulphide solutions they were more soluble in hot than in cold waters.

The areal distribution of the mineral types found in the oldest vein system (the Anaconda) is believed to be due, in part, to the relative solubility of these various minerals in the original uprising waters from which they were deposited. It has been previously pointed out that these early solutions were carriers of alkaline sulphides due in part to the extraction of sodium and calcium from the granite. Under conditions of high alkalinity and elevated temperature, quartz and pyrite were deposited in abundance, forming the massive quartz-

pyrite veins of the central and intermediate zones. Under high temperature conditions, the minerals, sphalerite, rhodochrosite, galena, and chalcopyrite were more readily soluble and migrated outward to the intermediate and peripheral zones, where they were deposited along with quartz and pyrite, forming the primary vein filling of the so-called manganese-silver veins. During the period of migration of these solutions from the hotter zones the solutions lost none of their alkalinity, but the temperature was greatly reduced. These conclusions are drawn from the fact that there is no evidence to indicate that calcium and sodium were precipitated; in fact, slight alteration of the normal granite along the veins indicates a further addition of these elements to the vein-forming waters; and furthermore, the probable occurrence of alkaline carbonates is shown by the abundance of rhodochrosite in the border zones. The lower temperature conditions and comparative inactivity of the solutions toward the granite in the outer regions are well shown by the slight alteration of the wall rock adjacent to the fissures. In great veins a hundred feet or more in width in the manganese-silver district, alteration of the granite extends for only a few feet outward from the general vein boundaries.

These early solutions contained some copper, as shown by its almost universal presence in the oldest known quartz-pyrite vein material and in the disseminated pyrite of the altered granite. Apparently no copper minerals were deposited in quantity in the earliest stages of vein formation, except possibly the chalcopyrite of the manganese-silver veins, but enargite is known to have formed in considerable abundance in the Anaconda veins prior to the appearance of the Blue fracture system, not, however, until the old veins were well formed. Enargite is therefore regarded as a relatively high-temperature mineral, but it probably formed under less alkaline conditions than existed in the early stages of the process, when quartz and pyrite were first deposited. The absence of notable quantities of other minerals containing copper or arsenic associated with this early enargite vein filling implies that these two elements were present approximately in the necessary proportions to form enargite. Copper was probably in excess, otherwise arsenopyrite would have been formed in cooler regions. Chalcocite did not form from the copper excess owing to the alkalinity of the solutions. It is probable that some bornite was formed at this early period, as was chalcopyrite in the outer zones of lower temperatures.

During the later stages when the Blue and Steward fault vein ores were formed, enargite, bornite, and chalcocite were deposited in large quantities in veins of all ages within the central and intermedi-

ate zones. In all of these veins the same order of deposition is noted; that is, pyrite and quartz are the oldest minerals, followed by enargite, sphalerite, bornite, and chalcocite, in the order named, chalcocite being associated with the older vein minerals only where the granite is intensely altered.

The general relationships above noted between the various ore types and conditions of granite alteration tend to show that under conditions of high alkalinity and high temperature and pressure, the vein minerals first deposited were principally pyrite and quartz. That this condition prevailed in the early stages of mineralization in fractures of all ages, except where the later fractures passed through areas of granite previously altered, is shown by the universal priority of a portion of the quartz and pyrite. As previously stated, the solutions became less alkaline, with a corresponding increase in the proportion of hydrogen sulphide present. It is known that the metals common to Butte, such as iron, copper, zinc, and manganese, are soluble in sodic sulphide solutions, but less so in hydrogen sulphide solutions; in fact, when present in sufficient proportions, hydrogen sulphide acts as a precipitant for these metals. The change of solution from a highly alkaline condition to one in which hydrogen sulphide predominates is brought about through conditions approaching chemical equilibrium between the uprising solutions and the granite wall rock. That chalcocite is a late mineral in the ores is well known. The explanation may be found in the suggestion here offered that it was deposited in the Butte veins only when the amount of hydrogen sulphide present in the vein-forming waters was large in proportion to the alkaline sulphides present. Observed conditions in the veins tend to support this view. Regardless of the geologic age of the fissure, quartz and pyrite are found to be the first minerals to form, chalcocite was one of the latest, and enargite, sphalerite, and bornite were found in intermediate stages. Quartz and pyrite, however, are formed under all conditions and, therefore, are intimately associated with minerals of the later stages, including chalcocite.

The deposition of chalcocite, the cuprous sulphide of copper ( $\text{Cu}_2\text{S}$ ), directly from ascending waters, seems well within the range of possibility, considering that it is well known, or at least it has been frequently stated,<sup>11</sup> that the minerals enargite<sup>12</sup> and bornite, admittedly primary<sup>13</sup>, contain the cuprous sulphide molecule  $\text{Cu}_2\text{S}$ .

<sup>11</sup> Dana's *System of Mineralogy*, pp. 76 and 147 (6th ed., 1892).

<sup>12</sup> Kirk, C. T., *Conditions of Mineralization in the Copper Veins at Butte, Mont., Economic Geology*, vol. vii., No. 1, p. 82 (Jan., 1912).

<sup>13</sup> Graton, L. C., *The Sulphide Ores of Copper, Trans.*, xlv., 26 (1913).

With an excess of copper present in the cuprous form, over and above that required to satisfy the enargite molecule, it would seem reasonable to look for the deposition of chalcocite or bornite under favorable conditions.

Many minerals have undergone alteration, particularly the copper minerals, enargite and chalcocite. These alterations have been effected by primary processes. Enargite frequently alters to or is replaced by chalcopyrite and bornite, and chalcocite commonly exhibits slight alterations to bornite and rarely to chalcopyrite. Such alterations are believed to be due to the instability of the minerals under changing conditions in the solutions.

#### *Summary of Ore Genesis.*

The original source of the ores at Butte was the granite magma. Quartz-porphry dikes formed a local closing phase of the igneous activity connected with the intrusion of the parent rock, and these dikes structurally and areally are in such close association with the ore deposits that they appear to be a direct factor in the localization of the ores. Heated waters and gases escaping from the cooling magma were the carriers of the metals to their place of deposition. The elements thus transported and deposited in the veins were silicon and oxygen as  $\text{SiO}_2$ , sulphur, iron, copper, zinc, manganese, arsenic, lead, calcium, tungsten, antimony, silver, gold, tellurium, bismuth, and potassium. Small quantities of potassium are believed to be added to the granite in the sericitization process.<sup>14</sup> Other elements, as sodium, calcium, and manganese, were undoubtedly carried by these solutions, but, as shown by analyses, they were extracted from the granite in the alteration process instead of being added as in the case of the first-named elements.

The chemical composition of these ascending waters varied in significant particulars as the process progressed. The granite wall rock was decomposed, furnishing much sodium, calcium, and possibly magnesium to the solution. Iron was also freed from the iron minerals of the granite to form pyrite with the sulphur of the invading waters. These interchanges affected the solvent capacity and character of the ore-bearing waters by the subtraction of the acid radical sulphur and the addition of alkaline radicals. While hydrogen sulphide and acidic conditions may have prevailed at the initial stages of ascent, the waters would tend to become alkaline through interaction with the wall rock. Along circulation channels, however, this

<sup>14</sup> Kirk, C. T., *Conditions of Mineralization in the Copper Veins at Butte, Mont., Economic Geology*, vol. vii., No. 1, p. 67 (Jan., 1912).

action would gradually become less pronounced after a barrier built of sericitized granite had been formed bordering the fissures, thus protecting the solutions from further reaction with the fresh granite, and permitting the acidic conditions to ascend to higher horizons. Also, the earliest vein minerals, chiefly quartz and pyrite, would tend to insulate the solution from the granite. And finally, increasing alkalinity of the solutions and lower temperature would lessen action on the granite at points further removed from the central source.

Applying the above reasoning to the facts of ore occurrence, it is found that chalcocite as a primary mineral is the latest important copper sulphide of the ores; it is, moreover, found only in association with the highly altered phases of the granite. From these facts the conclusion may be drawn that under the geologic conditions existing in Butte, the more acidic conditions were necessary for the deposition of this mineral. Similarly, enargite is associated with highly sericitized granite, and is therefore believed to have been deposited only under certain conditions pertaining to the temperature and relative alkalinity of the solution.

Sphalerite, rhodochrosite, and galena are increasingly abundant toward the intermediate and peripheral zones, suggesting their formation under lower temperature conditions with relative high alkalinity. Quartz and pyrite are everywhere present, and evidently are formed under all conditions. Pyrite is more abundant in the central and intermediate zones than in the peripheral zone. Quartz is more prominent as a gangue mineral in the peripheral zone than elsewhere.

Structurally there is no good evidence for distinct periods of mineralization in the Butte veins. It is here held that there was but one period of mineralization, varying in intensity, possibly, from time to time, with important changes in chemical character of solutions. But the mineralogical difference in vein material of the central, intermediate, and peripheral zones can be adequately explained, it is believed, by the reasoning herein set forth, which assumes that the copper mineralization indicates high temperature and acidic conditions versus lower temperature and alkaline conditions as the solutions migrated toward the peripheral fractures now represented by the manganese-silver veins.

Concerning the formation of chalcocite there is much geologic evidence, mainly structural, to support the theory above outlined, which assigns to this mineral a primary origin from deep-seated waters. The subject of chalcocite formation is of exceptional interest and well deserves special treatment in connection with the geology of the Butte

copper deposits. The evidence which tends to support the primary chalcocite theory held by the writer is briefly outlined in the chapter which follows.

#### *Origin of the Butte Chalcocite.*

Owing to the persistence to great depths of the mineral chalcocite in the Butte copper veins much interest has been aroused among geologists concerning the manner in which it was formed. In recent years the opinion has been quite generally held that chalcocite is largely, if not wholly, a product of descending sulphide enrichment. This view arose naturally through the discovery of the so-called "black sulphurets" (later proved to be sooty chalcocite) of Ducktown, Bisbee, and similar pyritic ore bodies. These belts of black amorphous chalcocite were found separating the oxidized zone from the lean pyritic ore below and they were early believed to have resulted from the reaction between the descending copper sulphate waters and the unchanged primary ores below. That this view was the correct one for the sooty chalcocite of this class of deposits has been abundantly proved by recent investigations.

The discovery of similar chalcocite ores in the early mining operations at Butte led many observers to the opinion that these remarkably rich ores were likewise of secondary origin and of limited vertical extent. When the zone of sooty chalcocite was penetrated, however, the predicted lean cupriferous pyrite ore was not found, but chalcocite-bornite-enargite ores were encountered, which have persisted to great depths. The chalcocite of the deeper levels does not occur in the sooty form, but instead, it is the gray massive mineral more or less intimately mixed or intergrown with bornite, enargite or other ore minerals replacing directly altered granite. It is not necessarily a replacement of pyrite or any other sulphide mineral, being deposited directly from solution as chalcocite in veins along with bornite and other copper sulphides.

The problem of the formation of the chalcocite in the Butte veins was studied recently by C. T. Kirk,<sup>15</sup> who endeavored to work out a definite relation between the chalcocite deposition and certain stages of granite alteration. He concludes that such a relation exists, and that the chalcocite formation is, in the main, associated with a certain phase of granite alteration which has developed through the action of descending meteoric waters. Weed,<sup>16</sup> in his recent report on Butte,

<sup>15</sup> Kirk, C. T., Conditions of Mineralization in the Copper Veins at Butte, Mont., *Economic Geology*, vol. vii., No. 1, pp. 35 to 82 (January, 1912).

<sup>16</sup> Weed, W. H., Geology and Ore Deposits of the Butte District, Montana, *Professional Paper No. 74, U. S. Geological Survey*, p. 76 (1912).

likewise declares that most of the chalcocite has resulted from descending waters, although primary chalcocite also occurs, but just how and where he fails to state. Many other writers familiar with these ore deposits, notably H. V. Winchell and the late S. F. Emmons, regarded the chalcocite as chiefly of secondary origin, at the same time holding the view that some of it might be primary. Recently, however, Winchell<sup>17</sup> has expressed the view that the deep chalcocite is largely primary.]

An intimate acquaintance with these ore deposits extending over a period of years has led the writer to the conclusion that most of the massive chalcocite is of primary origin, in the sense that it was deposited in its present position directly from deep-seated ascending solutions. Secondary chalcocite exists in large quantities also, but it is believed to be of limited vertical extent, being confined principally to the well-known sooty chalcocite zone extending from the bottom of the oxidized zone to depths ranging from 100 to 1,200 ft. It should be clearly understood, as previously stated, that the sooty glance zone has no well-marked lower limit, and furthermore, in the generation of sooty glance by descending waters, massive chalcocite is frequently developed, especially where the replacement of pyrite or other sulphide has reached an advanced stage. It is impossible to differentiate in hand specimens between primary and secondary chalcocite when both appear in massive form. There is of necessity in many cases an overlapping of primary and secondary chalcocite in the veins, inasmuch as primary chalcocite is believed to have originally extended to an elevation higher than the present ground surface. It follows, therefore, that to some extent primary chalcocite has been subjected to the action of atmospheric agencies along with the associated primary vein minerals. The result has been a sooty glance enrichment of the primary minerals of the ore, among which there existed massive chalcocite.

*Formation of Primary Chalcocite.*—The observed facts which have led the writer to the conclusion that primary chalcocite exists in large quantities in the Butte veins may be briefly stated as follows:

1. The occurrence of chalcocite in great abundance at levels 3,000 ft. or more from the surface.
2. The intimate association of chalcocite with bornite, pyrite, and enargite in such a manner that all must be regarded as having been deposited at the same time and under similar conditions.
3. Chalcocite is found at all depths without regard to surface to-

<sup>17</sup> Winchell, H. V., Discussion of L. C. Graton's Paper, The Sulphide Ores of Copper, *Trans.*, xlv., 84 (1913).

pography, which fact tends to show that no relation exists between the occurrence of chalcocite and present-day downward-seeping waters.

4. Chalcocite occurs in absolutely dry veins and ore-shoots at deep levels, and in many instances large bodies are cut by older faults, a fact further tending to show that this copper mineral is an old one and in no way genetically related to the present-day or a former similar underground water circulation.

5. Chalcocite directly replaces altered granite at deep levels. The power of cold meteoric waters to effect direct replacement of granite in quantity is seriously questioned by the writer.

6. No evidence is available tending to show that chalcocite is now being deposited in the veins, except within the sooty chalcocite zone. On the other hand, where positive evidence on this point is obtainable, it indicates a tendency of the massive chalcocite to alter to bornite and chalcopyrite under present ground-water conditions.

As outlined in the discussion of the formation of sooty chalcocite, the facts plainly show that secondary chalcocite has resulted from downward-seeping sulphate waters, and there can be no doubt that this mineral was in the active process of formation at the time the first mine openings were made in the copper veins. Concerning massive chalcocite of the deeper levels, however, there are important reasons for believing that it is in no way related genetically to the present existing meteoric ground-water circulation, or with any water circulation system of meteoric origin, but that, whatever the source, its time of formation must be referred to a relatively old mineralization period. Reference to Plate II will assist in making this point clear. It will be seen that the Rarus fault sharply cuts all the important ore veins, displacing them hundreds of feet, so that in the intersected veins the possibility of surface waters effecting an enrichment of the truncated portion of the veins lying beneath the fault is extremely remote. The upper displaced segment of the O'Neill vein, for example, is no richer in chalcocite than the sub-fault segment, excepting within the chalcocitization zone directly beneath the oxidized zone. It is evident that the descending sulphate waters moving down the upper segment could not possibly reach the lower segment, and there is no indication of an enrichment of the upper segment where it meets the Rarus fault. The moving waters did not enrich the fault, as it carries no ore, neither did these solutions spread out to other veins cut by the fault. What is said here regarding the O'Neill vein is equally true of all the veins intersected by the Rarus fault. In examples of this character where the possible source of the supply of

the sulphate waters has been effectually cut off from the lower parts of the veins by intervening faults, it becomes evident that the chalcocite of the lower segments either had its source in uprising solutions or else it was deposited from a descending water circulation existing long prior to the appearance of the fault, and possibly far removed from the conditions as we now know them.

Following this line of reasoning, it is possible, as will be later shown, to prove that chalcocite, other than the sooty variety, is a comparatively old mineral, and that it was deposited in great quantities prior even to the faults of the Steward system, which in themselves carry important bodies of ore composed of enargite, bornite, sphalerite, barite, galena, and other well-known primary minerals.

In the No. 16 vein, a mineralized fault of the Steward system of the Rarus and Tramway mines, extensive bodies of chalcocite-enargite ore are sharply cut by the Rarus fault. (See Fig. 5.) These ore bodies are in the form of the characteristic fault-vein ore shoots and actual development proves that they do not extend upward to within 1,100 ft. of the surface, the higher portions of the fissure being absolutely barren of ore or gangue minerals. Like the chalcocite ores of the O'Neill vein above noted, the No. 16 vein ore shoots were formed long prior to the Rarus fault. The altered condition of the crushed zone of the Rarus fault, the presence of much disseminated pyrite and quartz, together with the fact that a later fault (Middle) cuts and displaces the Rarus fissures, tend to show that geologically the Rarus is not a recent fissure, therefore the water circulation responsible for the chalcocite older than the Rarus fault must be far removed from the meteoric ground-waters of to-day.

Going further into the history of chalcocite, certain facts seem to indicate, if not definitely prove, that chalcocite existed as a vein mineral prior to the Steward fault period. In the ore breccia of the Gagnon mine fragments of older vein matter containing chalcocite are of common occurrence. The Steward fault fissure is of later origin than the breccia and the breccia is much squeezed and faulted where they come in contact. These angular ore fragments are within and form a part of the original breccia and they are plainly not of secondary origin. They are not breccias resulting from Steward faulting or any other fault movements, but they were formed in the same manner as the Mountain View breccias and probably at the same time. These ore fragments represent a period of mineralization of an earlier date, and they are not drag ore, but pieces of older vein which have fallen into open cracks.

In tracing the formation of earlier chalcocite, attention must be

given to the remarkable ore shoots of the Blue vein fissures, of which the great ore bodies of the Jessie, Edith May, High Ore, Skyrme, and Blue veins are examples. It is a significant fact that many of the largest and most important rich chalcocite-enargite ore shoots in these veins do not extend upward to within from 500 to 800 ft. of the surface. (See Plate VI.) Not only do the copper minerals fail, but the common gangue minerals, quartz and pyrite, drop out, so that the ore shoots are capped by hundreds of feet of barren crushed granite and fault clay marking the plane of movement. In two instances, notably in the Jessie and Blue veins, ore shoots reach the surface, but in these cases the upper 500 ft. of the shoots differ materially in mineralogical composition from the richer ores at greater depths.

A study of the composition and structure of these remarkable ore shoots indicates that the minerals forming them have had a common origin. They are not connected or related in any manner with cross-faulting or later faulting. A glance at Plate I. will be convincing on this point, that the Blue vein ore shoots do not occur at the intersections with older quartz-pyrite veins, but on the contrary, curiously enough, they are almost universally found in the intervals between the important older veins. A marked uniformity in alignment may be noted in the shoots in a northeast-southwest direction. No apparent relation exists between the Blue vein shoots and the later Steward faults; in fact, repeated observations of such intersections show beyond question that the ore shoots were in existence prior to the appearance of the Steward faults. It is next to impossible, however, if not entirely so, to determine what amounts, if any, of the minerals composing the Blue vein ore shoots were added at a period immediately following the appearance of the Steward fissures. Ore-bearing solutions traversing the Blue fissures, after the Steward faulting began, did not necessarily originate through the later fractures, nor did solutions passing along Steward fractures necessarily find their way into the Blue veins. In both cases the circulation was confined largely to irregular zones within the fissures themselves, which are now marked by the positions of the ore shoots. The intersections of Blue vein ore shoots rich in chalcocite by Steward fissures are numerous, and, from the evident lack of influence on the mineralogical character of the ore, the writer is led directly to the conclusion that chalcocite did exist in large quantities in the Blue vein prior to the Steward faults.

Assuming for the moment that the above inference is the correct one, the difficulties met with in an attempt to ascribe a secondary origin to this early chalcocite are numerous and of vital import. At the close of the Blue vein period (which period is assumed to be the

time elapsing between the beginning of Blue vein movements and the beginning of Steward faulting), it is fair to assume that the ground surface was much higher than at present, necessitating, therefore, a former extremely deep meteoric ground-water circulation to reach chalcocite ore bodies of the Blue veins now found more than 3,000 ft. from the surface. When one considers the rate of the downward invasion of the oxidized zone, it is almost inconceivable that down-seeping sulphate waters could have formed the extensive chalcocite ore bodies found at these depths. The time required would be enormous, and, furthermore, the fact must not be lost sight of that under conditions favorable for sooty chalcocite formations, as we know them, a very large part indeed, if not all, of the copper of the descending sulphate waters is deposited as secondary chalcocite before a maximum depth of 1,200 ft. below the zone of oxidation is reached.

There is another important point inviting attention, relative to the probable condition of the underground circulation existing during the time of formation of the Blue vein ores and during subsequent periods extending to the present time. It is a self-evident fact that meteoric waters could not have descended to great depths along veins, faults, or fissures at a time when appreciable quantities of waters, presumably deep-seated, were ascending through such channels. It is a reasonable assumption, then, that no important downward movement of meteoric waters took place in the Butte fissures until after the cessation of movement of the uprising solutions from which were deposited the primary ores. It is not unreasonable to believe that some surface waters did reach these channels of uprising waters at comparatively shallow depths, not, however, by direct descent along fissures through which deep-seated waters were ascending, but by a downward-lateral movement through neighboring fissures adjacent to the main trunk channels. As has been formerly pointed out, however, the movement of cold surface waters through normal granite is scarcely appreciable, and it is therefore extremely improbable that such waters could have influenced chemically, physically or in any way whatsoever the action of the deep-seated waters as they moved upward through the fissures depositing minerals undoubtedly derived from deep-seated sources. The occurrence of undoubted primary ores, or quartz, pyrite, sphalerite, galena, and rhodocrosite, together with enargite, bornite, and chalcocite, in faults of the Steward system which are known to cut and displace chalcocite ore bodies in the Blue and older vein systems, is conclusive proof that ascending solutions depositing primary ore continued in action long after the formation of the Blue vein chalcocite. It is probable that ascending waters

continued to traverse the Steward and older fissures for a considerable length of time after the primary Steward ores had formed; in fact, it is not at all improbable that the alteration of the granite and deposition of pyrite in the Rarus fault resulted from ascending waters.

If an early circulatory system existed similar to that above assumed, it is difficult to understand how meteoric waters could have been active enough to transport large quantities of mineral from the oxidized zone to great depths at any period prior to the complete cessation of the upward movement of the primary ore solution. The time of cessation must have been as late as the end of the ore-forming period of the Steward fault veins, and possibly as late as the Rarus fault, both of which are known to be later than much of the chalcocite of the Blue and Anaconda veins.

The chalcocite of the deeper levels, or in a general way the massive chalcocite of all the veins, bears no definite relation to the present surface topography. This is in marked contrast to the occurrence of sooty chalcocite known to be of secondary origin. The tops or apices of many rich, massive, chalcocite ore bodies or shoots are found at depths ranging from 100 to 1,500 ft. from the surface. The size and richness of the ore body are in no way indicated by the depth of the zone of oxidation; in fact, many of the largest ore shoots of the fault veins are capped by from 500 to 800 ft. of barren crushed granite and fault clay having an oxidized zone of less than 25 ft. in vertical extent. In the quartz-pyrite veins of the Anaconda system where the development of secondary glance is greatest, there is an apparent close relation between the depth of oxidation and the quantity of sooty chalcocite found below. A deep zone of secondary chalcocite is certain to be found below a deep zone of oxidation, while a shallow zone of oxidation is accompanied by an unimportant development of sooty chalcocite below. If a secondary origin is assumed for the chalcocite ore bodies whose tops or apices are separated from an extremely shallow oxidized zone by hundreds of feet of barren crushed granite, the question as to the source of the copper to form the chalcocite becomes of vital interest.

Where the ore shoots do not extend upward to the oxidized zone it does not appear possible that the source of the chalcocite could have been at a point higher than the top of the ore shoot, for there is no evidence, direct or otherwise, that copper-bearing mineral of any character ever existed in the eroded and oxidized portions of the vein. The marked absence, in the upper portions of many veins, of an adequate source of supply for the copper found at great depths in the form of chalcocite is a common feature of these ore deposits. This

is true not only of the fault veins, but in many of the veins of the Anaconda system. In the Tramway and Leonard mines, for example, immense chalcocite-enargite ore bodies from 50 to 200 ft. in thickness, belonging to the Anaconda vein system, have been developed between the 1,200 ft. and 2,000-ft. levels. From the 1,200-ft. level to the surface these ore bodies are represented only by small veins from 2 to 6 ft. in thickness, carrying but small amounts of copper. Indeed, in many instances the identity of the vein is entirely lost as the higher levels are approached. In nearly every case the oxidized zone capping the big ore bodies of this section is shallow, and even if it be assumed that hundreds of feet of vein have been eroded, such eroded portions represent a source entirely inadequate to account for the chalcocite found below.

In the Shannon vein (belonging to the Anaconda system) of the West Colusa mine, the ore bodies of the upper levels were of tremendous size, particularly in the region immediately underlying the oxidized zone, where there occurred a big development of sooty chalcocite. It is significant that although the vein continued big and strong in depth, with every condition favorable for secondary enrichment, the vein became poor rapidly in depth, portions of it at the 900-ft. level being too low grade to mine. Many other examples might be mentioned where old quartz-pyrite veins have been broken by later faults, and all conditions seem ideal for the formation of chalcocite ores in depth, but, other than the sooty glance enrichment, no notable addition of chalcocite has taken place.

An interesting occurrence of chalcocite is found in the Mountain Chief ore shoot of the Jessie vein, belonging to the Blue fault system. Plate V., a longitudinal projection of the vein, has been prepared to show the forms and positions of the various ore shoots. As will be noted, the oxidized zone is extremely shallow, being not more than 25 ft. deep at any point in the vein. The ore shoots have been opened by continuous workings from the surface to the 2,200-ft. level.

There is a marked difference in mineralogical composition of these ore shoots between their upper and lower portions. The change is found to take place at a depth of from 500 to 800 ft. from the surface. Some of the shoots do not extend entirely to the oxidized zones. The line *A-B* is drawn to mark approximately the elevation at which the change takes place. Above *A-B* the ore is an intimate mixture of quartz, pyrite, and chalcopyrite, the latter mineral occurring in abundance. Sphalerite and rhodochrosite are also present in considerable amounts. In the Mountain Chief mine one shoot extends entirely to the surface, where it is oxidized to a rich ore com-

posed of cuprite and iron oxides. Immediately below these rich oxides there is but a slight development of secondary chalcocite, occurring as thin films coating the chalcopyrite and pyrite. At about the line *A-B*, within a vertical distance of from 50 to 75 ft., there is almost a complete transitional change from chalcopyrite ore to an ore consisting of chalcocite, bornite, enargite, pyrite, and quartz, with only small amounts of chalcopyrite. This character of mineralization has continued to the deepest levels yet opened, although there are some variations in the relative amounts of the minerals present. The development of chalcopyrite seems to take place only in the high levels or at the waning ends of the ore shoots, indicating possibly that under certain conditions it is a lower-temperature mineral than either enargite or chalcocite, assuming for the moment that all three are here of primary origin.

In this particular example it is impossible to conceive of a surface water origin for the chalcocite lying below the chalcopyrite capping. There certainly is no apparent adequate source for the copper. Where the chalcopyrite ore suffers oxidation the larger part of the copper is held in the oxidized zone as an oxide or carbonate, and, even assuming that a part of the copper was carried downward, it is quite impossible for the writer to believe that it could have remained in solution while passing downward over the chalcopyrite-pyrite ore, to be later deposited as chalcocite from 800 to 2,200 ft. below the surface.

As already stated, many of the Butte veins have but slight oxidized zones, accompanied by sooty chalcocite zones of small vertical extent separated by hundreds of feet of barren vein from the chalcocite ores below. In such instances it is impossible to trace any genetic relation between the meteoric water circulation and the chalcocite commonly occurring at depths greater than 1,000 ft. Where, however, as in the case of most of the quartz-pyrite veins of the Anaconda system, an important chalcocitization zone exists associated with massive chalcocite ores, and is underlain at greater depths by large quantities of chalcocite not associated with sooty chalcocite, it is, perhaps, reasonable upon first thought to suppose that all the chalcocite of both higher and lower levels has had a common origin. The early prominence of the copper veins of this class has been largely responsible for the former general belief in a secondary origin for the chalcocite in the Butte veins.

The changes which occur in the oxidized zone of the old copper-bearing quartz-pyrite veins in Butte are due to processes which act slowly. The invasion of the oxidized zone downward into the sulphides took place at an extremely slow rate, and in view of this fact it

must be admitted that the sulphate solutions originating at the sharp contact between the oxides and sulphides were extremely dilute. The chemicals added to these downward-seeping surface waters through the oxidation of the sulphides are chiefly copper and iron sulphates, and possibly small amounts of free sulphuric acid. These cold surface waters, after taking up their burden at the oxide-sulphide contact, pass immediately downward along the vein, or partly through country rock, moving more or less constantly in direct contact with the pyrite and other vein sulphides. As is well known, the reaction between the sulphides and sulphate waters results in the formation of sooty chalcocite as a direct replacement of the sulphide attacked. These sulphate waters also attack the altered granite, resulting in greater porosity and in the formation of abundant kaolin. There is also a chalcocitization of the disseminated pyrite so common in the altered granite. In meeting already existing ground-waters below, a large proportion of which, although of meteoric origin, did not take copper into solution on their downward journey, the descending waters along the veins must become more and more dilute and certainly less active chemically as greater depths are reached. As a matter of fact, actual comparisons of the veins and granite of the upper and lower mine levels show conclusively that the downward-seeping waters actually become weak and inactive at not great depths below the surface, and it was due to this fact, in part at least, that C. T. Kirk was able to differentiate so clearly between the chloritic, sericitic, and kaolinitic alteration phases in the Butte granite.

It is extremely important to understand clearly this feature, because, apparently much more vigorous chemical processes have been active in the formation of the massive chalcocite of the deeper levels than were necessary for the formation of the secondary chalcocite of the higher levels. In the sooty chalcocite zone only sulphides are attacked and replaced by the chalcocite, while at greater depths massive chalcocite alone, or intimate mixtures of chalcocite, pyrite, bornite, and enargite, directly replace altered granite in quantities within and along the fault veins and veins of the oldest system. The writer believes that such replacements could not have been effected by dilute meteoric waters, which, in the act of reaching great depths, not only became extremely dilute and of doubtful activity, but they have been deprived wholly or in part of their copper in the regions of sooty chalcocite formation.

The observed facts which have led primarily to the belief that the chalcocite of the Butte copper deposit is of secondary origin may be briefly stated as follows:

1. The chalcocite is often of a later age than the vein minerals with which it is associated.

2. In some instances the proportionate amounts of chalcocite in the veins have decreased rapidly with depth.

3. It has been abundantly proved at Ducktown, Morenci, Bingham, and in many other instances, that under certain conditions chalcocite is a product of descending sulphate waters.

4. The depth of the chalcocite enrichment in many of the Butte veins bears a definite relation to the depth of the zone of oxidation in the respective veins.

In an endeavor to solve the problem of the chalcocite formation, some investigations have been made. H. V. Winchell<sup>18</sup> succeeded in producing artificially, under normal conditions of temperature and pressure, chalcocite identical in chemical composition and physical character with the sooty chalcocite of the Butte veins. His experiments seem to prove conclusively that the formation of secondary chalcocite is easily possible under the conditions of temperature and pressure found in the upper levels of the Butte mines. Similar conclusions have been reached by Stokes and others in the laboratories of the U. S. Geological Survey.

Perhaps the most elaborate investigation of this subject was undertaken by Charles T. Kirk<sup>19</sup> who made careful chemical and petrographic analyses of the altered granite occurring in and along the Butte copper veins. He found that during the vein-forming processes the granite suffered great changes in chemical and physical character. These changes took place more or less gradually. He separated them into three general alteration phases, namely: (1) the chloritic phase, which marks the earliest stage of alteration; (2) the sericitic phase, marked by the development of great quantities of sericite through the further action of heated waters in (1); and (3) the kaolinitic phase, a change from the sericitic phase brought about through the action of descending sulphate waters of sericitized granite.

Phases (1) and (2), therefore, result from the action of deep-seated ascending waters; (3) is effected by the action of descending cold meteoric waters on phases (1) and (2). With these three alteration phases Kirk links certain generalized groups of minerals. He believes the early quartz-pyrite ores began to form with the early chloritic phases; that the copper mineralization during this and the succeeding

<sup>18</sup> Winchell, H. V., The Synthesis of Chalcocite and Its Genesis at Butte, *Engineering and Mining Journal*, vol. lxxv., No. 21, pp. 783 to 784 (May 23, 1903).

<sup>19</sup> Kirk, C. T., Conditions of Mineralization in the Copper Veins at Butte, Montana, *Economic Geology*, vol. vii., No. 1, pp. 35 to 82 (Jan., 1912).

sericitic stage was principally enargite, bornite, and chalcocite; and lastly, that the chalcocite formation belongs entirely to the third or kaolinitic phase. He holds that kaolinite is wholly a product of cold meteoric water action and therefore the presence of it in deep levels indicates the presence of waters of meteoric origin. Many geologists, notably Gregory, dissent from this view and hold to the opinion that kaolinite may also be a product of ascending water alteration.

It is to be regretted that Kirk did not give a series of direct comparisons between samples of altered granite taken both from the sooty chalcocite zone and the deep levels. Certainly there is much yet to be learned concerning the relation between the altered granite and chalcocite formation. Even assuming for the moment that meteoric waters have sunk to great depth in the Butte veins, accompanied by the formation of kaolinite at all levels, it does not necessarily follow that the chalcocite was deposited from such descending waters. It cannot be doubted that the sulphate waters descended to depths greater than the lower limit of the sooty chalcocite zone, but it is evident that while the chemical effect of these waters upon the granite at greater depths may have been of the same general nature as in higher levels, that is, kaolinization, the chemical action toward copper mineralization was entirely different. The chalcocite of deeper levels is not necessarily a replacement of a sulphide mineral as in the upper levels. Since the replacement of the pyrite by chalcocite in the higher zones is accompanied by the formation of ferrous sulphate, the descending waters passing below the sooty chalcocite zone still retain an abundance of dissolved iron sulphates and possibly sulphuric acid to act on the sericitized granite, forming kaolin, as in the higher levels, but it is more than probable that the descending waters were entirely robbed of copper in the secondary chalcocite zone. The small amount of kaolinite present in the deeper levels as compared with the great abundance in the oxidized and sooty chalcocite zones indicates less activity, due either to dilution or to change in chemical composition of the solution.

From these considerations it is readily seen that the association of chalcocite with minor amounts of kaolin below the chalcocitization zone does not necessarily imply that both have resulted from the same solutions. The descending sulphate waters may still continue to form kaolin in regions of primary chalcocite after having deposited all of the copper burden in the region immediately below the zone of oxidation. It may not be difficult to understand meteoric waters reaching to unusual depths in the Butte veins, but the writer seriously doubts that such waters could retain copper in appreciable

quantities after moving downward for hundreds of feet in direct contact with newly formed chalcocite and an abundance of pyrite.

It is unfortunate that most of the granite samples used by Kirk in his investigations were collected from the Pittsmont vein, for the reason that this property is peculiarly situated with respect to the general topography of the district, and it is also in close proximity to the Continental fault, a fracture of comparatively recent occurrence. The effect of this fault upon the water level and oxidized zone may be readily understood by reference to Plate IV. It will be seen that the immediate effect has been to drop the former erosional surface and oxidized zone to a depth considerably below their former positions. The collar of the Pittsmont shaft at the present ground surface is about 400 ft. above the old erosional surface. In the mine workings the oxidized zone is from 250 to 300 ft. thick, measured downward from the former surface, and the sooty chalcocite belt is known to extend at least 500 ft. deeper. Summing up these figures, the result is reached that the deepest general working level of this mine (the 1,200 ft.) is not more than 600 ft. below the zone of oxidation, or, as a matter of fact, scarcely below the zone of sooty chalcocite. When it is remembered that in the Mountain View mine the sooty chalcocite zone is from 800 to 1,200 ft. thick, one is forced to the conclusion that Kirk's samples do not represent conditions far removed from the direct influence of copper-bearing surface waters. The results of his work are extremely interesting and of value, especially his investigations concerning the alteration of the granite, but in the opinion of the writer he has erred in attempting to apply his method of reasoning to the chalcocite of deep ore bodies of the Butte veins with which he is evidently unfamiliar. His results are valuable inasmuch as they further corroborate and establish, from a new point of attack, the conclusions already reached by others that the sooty chalcocite, and massive chalcocite to a limited extent, of the Butte deposits, have resulted from the work of downward-seeping sulphate waters whose copper was derived from the oxidized zone.

W. H. Weed<sup>20</sup> has set forth some facts which, in his opinion, tend to prove the secondary origin of the Butte chalcocite. He observes generally that the old quartz-pyrite veins were originally of very low grade and they became commercially valuable through the later addition of enargite, bornite, chalcocite, and other copper minerals. He believes that this copper mineralization followed various periods of faulting, the enargite and bornite being the first to appear, probably

<sup>20</sup> Weed, W. H., *Geology and Ore Deposits of the Butte District, Montana, Professional Paper No. 74, U. S. Geological Survey, p. 152 (1912).*

contemporaneous in a general way with the Blue and Steward fault system. Chalcocite, which forms the bonanza ores of the district, is thought by him to have been almost entirely a product of descending sulphide enrichment processes, acting at great depths, however, only where the older quartz-pyrite veins were crackled and broken by faults, thus permitting a ready passage for the downward-seeping waters. He cites many examples of such intersections of faults and older veins in support of this view, and maintains that the old quartz-pyrite veins are workable only where thus fractured.

The writer's own observations do not confirm Weed's conclusions as above outlined. Actual examination of a great many intersections of old quartz-pyrite veins by later faults has shown conclusively that as a general proposition the east-west veins are no richer at or near intersections with Blue vein faults than at other points along the vein except in cases where the fault vein ore shoots cross the older vein. It is extremely difficult to form even an approximate idea as to the extent of primary enrichment in the older veins due to the late faults of the Steward system. Mineralization processes were active in the early veins prior and subsequent to the Blue vein period, so that it is impossible to determine, in the absence of any characteristic minerals, what influence was exerted by the later faults upon the older veins. As might be expected, the fault vein intersections are usually accompanied by a breaking and shattering of both the older vein and the country rock in the immediate vicinity, thus developing favorable factors tending to greatly influence ore deposition at such points. In any case, where a chalcocite enrichment of a vein of the Anaconda system is shown to have resulted from the influence of an intersecting fissure of the Blue or Steward system there remains the strong probability that such enrichment is due to primary waters, if, as believed by the writer, the primary chalcocite was deposited in great quantities, after the appearance of these faults, not only within the faults themselves, but in the fractured older veins.

#### DISCUSSION.

L. C. GRATON, Cambridge, Mass.:—It has been my privilege to read with some care Mr. Sales's paper, and I feel it a sense of duty and a pleasure to discuss it briefly. After two months spent underground in the Butte mines by my associates—Messrs. Augustus Locke, A. M. Bateman, and E. H. Perry—and myself, it seems only fair to record our appreciation of the almost baffling structural complexity of the Butte veins, of the remarkable accuracy with which their mechanical details have been worked out, and of the unusually

effective and intelligent use of geologic conceptions in interpreting their subtler characters and significance. During this period, under the courteous and helpful guidance of either Mr. Sales, the members of his staff, or the geologists of other companies, we have been afforded opportunity to test many of the conclusions embodied in the present paper, and it is but just to state that as our observations have accumulated sufficiently the great majority of these conclusions have received unquestioned confirmation in our minds.

The pleasure consists in realization that the science of mining geology, to which so many of us have devoted ourselves, actually embraces the possibilities that this paper exhibits. The science of geology has been favored by many brilliant contributions of general nature, and by a smaller number of studies remarkable because of their detail and precision. I know, however, of no other piece of work like this, which, including Mr. Winchell's administration, virtually represents the combined results of over 15 years of work by a staff of trained geologists in a district which measures not much more from end to end than it now does from top to bottom. That this concentration of effort and observation has been required, and that it has been repaid by the results attained, are plentifully evident in Mr. Sales's paper. If one were inclined to doubt this after perusal of the text, surely he would be convinced by the maps and sections, several of which, I venture to say, are unapproached in detail and accuracy by anything attempted before.

Among the features of more general geologic significance mentioned by Mr. Sales that we have had opportunity to confirm to our own satisfaction may be noted the peculiar character of the Mountain View fault breccia; the essential unity of the period of primary mineralization in the district, regardless of the trend or age of the fractures; and the rudely concentric zoning exhibited both by intensity of alteration and by character of ore minerals deposited.

The subject upon which Mr. Sales places most emphasis, viz., the origin of the deep-level chalcocite, is one that possesses far more than ordinary interest for the four of us who are beginning here a country-wide study of secondary enrichment of copper deposits. I may say that Mr. Sales and I are not wholly in accord regarding some features of chalcocite occurrence and significance at Butte, but as my own views are not fully shared by my associates, it would seem the better part of valor to postpone any statement upon this subject until more thorough study can be given to it. That this problem is extremely complex will probably be admitted by all acquainted with it. In any event, after microscopic study of nearly a thousand specimens

of Butte ores, we are fully agreed with Mr. Sales that there are great quantities of original or primary chalcocite in these ores, and that several other rich copper minerals so plentiful here, notably enargite and bornite, are predominantly primary and not due in any important degree to influences active at or near the surface.

It appears, therefore, as pointed out elsewhere,<sup>21</sup> that the history of this greatest of the world's copper camps is not soon to be ingloriously terminated by a giving out of downward enrichment, but instead that, regardless of whatever alterations may have affected the deeper ores now known, profitable mining will probably be able to continue as far as the physical limitations of depth and vagaries of primary ore deposition will permit.

One might have wished that Mr. Sales had not confined himself so strictly to Butte. Comparisons in various respects with other mining districts might serve as tying-in points to those not fortunate enough to see this camp for themselves; and it would seem that the statement regarding genesis, particularly the nature of the depositing solutions, might have been strengthened if citations had been made to other mining regions for which similar ideas have been held. It is, however, a sufficient task to record the geology of a single district so complex as Butte, and those who would combat Mr. Sales's hypotheses should remember that these have been devised to accord with an enormous store of hard facts gathered through 13 years of close personal observation. I feel greatly indebted to Mr. Sales for his contribution.

W. C. RALSTON, San Francisco, Cal.:—When you speak of the acidity of the inclosing granite—that is, the primary granite—what is meant? Do you refer to the per cent. of acid present, and also how does the acidity of the altered granite adjoining the veins compare with the normal unaltered granite? To me the line of demarcation would be rather indefinite, and this dividing line does not appear to be clearly defined.

MR. SALES:—“Acidity” when applied to rocks is a comparative term only and it refers to the relative amounts of silica present. The quartz-porphry of Butte is more “acid” than the granite because it contains 4 or 5 per cent. more silica. The silica content of the altered granite associated with the vein is a widely variable constituent. Sometimes it is more siliceous and often less siliceous than the unaltered granite, depending upon the degree of alteration and many other factors. In general terms, the line of demarcation between

unaltered and unaltered granite is well defined, though there may be a slow gradation between slightly altered and highly altered material.

MR. RALSTON:—Is it a highly acid rock?

MR. SALES:—The Butte granite runs about 64 per cent. silica.

MR. RALSTON:—Now, as to the altered granite, what percentage has it?

MR. SALES:—It is variable, sometimes higher, but often lower in silica than the normal rock.

J. W. RICHARDS, South Bethlehem, Pa.:—May I call attention to the fact that where chemistry touches the field of geology a knowledge of physical chemistry will greatly aid the geologist in solving his questions. It is a great thing to have a thousand million dollars' worth of copper, but to the real geologist there is more satisfaction in knowing how the copper got there. We are now possibly groping in the dark because of a lack of knowledge of the reactions of copper-bearing solutions under high pressures. I think that is one of the weak points of the paper, especially where it enters upon theory and speculation as to how the primary chalcocite was produced. I think we should go to the laboratory and get more experimental information as a preliminary and guide to our theory and speculation.

<sup>21</sup> The Sulphide Ores of Copper, *Trans.*, xlv., 67 (1913).