XVI INTERNATIONAL GEOLOGICAL CONGRESS

GUIDEBOOK 23 - - - EXCURSION C–2

THE BUTTE MINING DISTRICT MONTANA

International Geological Congress
XVI session
United States, 1933

Guidebook 23—Excursion C-2

THE BUTTE MINING DISTRICT MONTANA

By
EUGENE S. PERRY
MONTANA SCHOOL OF MINES

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1932

For sale by the Superintendent of Documents, Washington, D. C. - - - - Price 10 cents

This guidebook is published under the auspices of the United States Geological Survey, but it is not a part of the Geological Survey's regular series of publications, and the opinions expressed in it and the use of nomenclature do not necessarily conform to Geological Survey usage.

CONTENTS

	Page
Abstract	1
Introduction	1
History	2
Geomorphology	3
Historical geology	4
Petrology	5
Fissure and vein systems	5
Classification of fissures	5
Anaconda vein system	6
Blue vein system	7
Steward veins and Rarus fault fissures	9
Continental fault system	10
Earlier classifications	10
"Horsetail" structure	11
Mineralogy	11
Zonal arrangement	13
Ore minerals	15
Paragenesis	18
Hypogene rock alteration	19
Supergene alteration	20
Ore bodies	21
Mining	21
Milling and smelting at Anaconda	24
Bibliography	24

ILLUSTRATIONS

	Page
PLATE 1. Map of the vein systems of the Butte district	4
2. North-south section through the Butte copper district near the Anaconda shaft	4
3. *A*, Bornite-chalcocite graphic structure, Shannon vein; *B*, Chalcopyrite replacing bornite without visible relation to fractures	20
4. Flow sheet of ore, Butte district	20
FIGURE 1. Longitudinal vertical projection of the High Ore vein	8
2. Plan of a portion of the 1,200-foot level of the Leonard mine	12
3. Plan at altitude of 4,600 feet showing general zonal arrangement of ore minerals	14

THE BUTTE MINING DISTRICT, MONTANA

By Eugene S. Perry

ABSTRACT

Although the Butte district, greatest of all copper camps, has produced more than $1,500,000,000 worth of copper, it has also yielded one-fourth of that amount in silver, zinc, gold, and lead. Development in this district began with placer-gold mining in 1864; 20 years later the oxidized silver ores were mined; since 1881 copper has been the chief product.

The ore deposits, in part fissure fillings but mainly replacement veins, are confined to granite and aplite in the Boulder batholith, which was intruded in late Cretaceous or early Tertiary time. Three main systems of fissures—early, intermediate, and late—cut the granite in three directions. The first and second are mineralized; the second and third are conspicuous fault fissures. The copper minerals are chiefly primary chalcocite and bornite, with considerable enargite. Sphalerite, galena, native gold, native silver, and silver-bearing tetrahedrite are other valuable minerals. The ores of the district show a well-marked zonal arrangement; copper minerals form a central core; copper and zinc minerals an intermediate zone; and zinc, lead, and manganese minerals a peripheral zone. Oxidized copper, zinc, and lead minerals have always been inconspicuous, but oxidized silver minerals were formerly mined. Superficial alteration has affected the deposits near the surface, resulting in thorough leaching to a depth of 100 to 500 feet (30 to 152 meters) and in the deposition of secondary "sooty chalcocite" for 100 to 500 feet below the leached zone. The main mass of ore extending from a depth of 500 feet to more than 4,000 feet (1,219 meters) is believed to be of primary origin and to have been deposited by ascending magmatic solutions under conditions of intermediate thermal intensity.

INTRODUCTION

Butte, Montana, a city of about 50,000 people, lies in an intermontane valley among a confused group of mountains in what may be termed "the heart of the Rockies," more than 500 miles (805 kilometers) from the Pacific coast. Far below its streets and buildings extend dark passageways and timbered mine stopes, level below level, to a depth of nearly 4,000 feet (1,219 meters). These mine drifts and crosscuts if connected end to end would more than extend across the continent from San Francisco to New York. The mines at Butte had produced to the end of 1930 about 10,131,000,000 pounds (5,003,551,000 kilograms) of copper, 2,630,000,000 pounds (1,193,943,000 kilograms) of zinc, 312,000,000 pounds (141,522,000 kilograms) of lead, 1,835,000 ounces (57,075,000 grams) of gold, and 466,600,000 ounces (14,512,883,700 grams) of silver. Normally 10,000 men find employment in these mines, and the monthly pay roll is approximately $2,000,000. Many other mining camps have flourished in western Montana and have been abandoned, but Butte, discovered and developed with the first of these camps, has continued for more than 65 years.

In the following description of the Butte district the writer has preferred wherever possible to use the available published literature, a more thorough understanding of which has been obtained by his residence of five years in the district. The principal papers on the geology of the district are listed in the accompanying bibliography. Of these the papers by Weed (22) [1] and Sales (20) are particularly recommended to those desiring a more complete description. The writer gratefully acknowledges the assistance of Messrs. Murl Gidel and Chester Steele in furnishing descriptions of various features of the fissures and ores, and takes this opportunity to thank Messrs. Sales, Linforth, Gidel, and Steele for their critical reading of the manuscript.

HISTORY

Mining in Butte began in 1864, when placer gold was washed from gravel in what is now the main part of the city. During the first three years $1,500,000 in gold is estimated to have been washed from the stream beds of creeks draining the famous Anaconda Hill.

Many lode locations were made during these first three years on the conspicuous black-stained quartz outcrops. However, at that time free-milling gold ores were sought, and little interest was excited by the discovery of rich oxidized bodies of silver ore. In 1866 an attempt was made to work these silver ores, but treatment was not successful until 1875, and the climax of Butte's silver period was reached in 1887. The low price of the metal resulted in a decline in silver mining in 1892, and since then mining for silver alone has been sporadic.

Copper mining began as early as 1865, when a 40-foot shaft disclosed 6 or 7 feet (1.8 to 2.1 meters) of copper ore in the Parrot (Anaconda) lode. In the early seventies copper ore was hauled 400 miles (644 kilometers) by wagon to the railroad at Corinne, Utah, and thence shipped to smelters in Colorado and elsewhere. Some went to the Atlantic seaboard, in part for shipment to Swansea, Wales. Freight rates were so high that a shipment of ore containing $50 in gold and silver to the ton and 35 per cent of copper, worth 18⅝ cents a pound, gave no profit. In 1881 the Utah Northern Railroad was extended northward into Butte from the main lines of the Union Pacific Railroad at

[1] Numbers in parentheses refer to bibliography, pp. 24–25.

Ogden, Utah, and during the next year or two copper matte was shipped to eastern markets. Active development of the ore deposits followed the advent of the railroads.

From 1880 to 1910 many mining and smelting companies were organized, several of which operated with enormous profit. Bonanza after bonanza was exploited. In the wild rush for rich ore bodies distributed across an area of about 15 square miles (39 square kilometers), apex rights [2] became involved, and an extremely complicated system of faulted and intersecting veins, some of which had subsurface apexes, led to heated disputes, which generally ended in prolonged and costly litigation.

By 1915 six major companies were actively mining ore at Butte—the Anaconda Copper Mining Co., Elm Orlu Mining & Milling Co. (W. A. Clark interests), East Butte Copper Mining Co. (Pittsmont Copper Co.), North Butte Mining Co., Butte & Superior Mining Co., and Davis-Daly Copper Co. The present Anaconda Copper Mining Co. resulted from a consolidation of several independent companies in 1910. Their interests included most of the copper mines, together with many surrounding properties. The Anaconda Co. purchased the Davis-Daly Co. in 1923 and the Elm Orlu Co. and other Clark interests in 1928.

GEOMORPHOLOGY (2)

Western Montana, now rough and mountainous, gives evidence of having been comparatively level as late as Oligocene time (middle Tertiary). Peneplanation was well on its way when uplift rejuvenated the rivers, causing them to cut deep valleys and gorges into an upland plain. The dissection is so complete in most of the mountain area that travelers little suspect the existence of perched remnants of the old surface. Downcutting of the upland plain has been effected by stages, and a detailed study shows more than one level of erosion. The uplift was accompanied and followed by faulting and volcanic activity, which dammed many of the broad valleys and developed extensive lakes, into which streams carried alluvium and

---

[2] In order to encourage prospecting in the Rocky Mountain region in the early development of the western United States, the mining law of May 10, 1872, which is still in force, provided that locators of mining claims "shall have the exclusive right of possession and enjoyment of all of the surface included within the lines of their locations and of all veins, lodes, and ledges throughout their entire depth, the top or apex of which lies inside of such surface lines extended downward vertically, although such veins, lodes, or ledges may so far depart from a perpendicular in their course downward as to extend outside the vertical side lines of such surface locations." (See Morrison, R. S., Mining rights, p. 508, Denver, Colorado, 1908.) This law has been the basis for most of the western mining litigation, some of which was dishonest in intent.

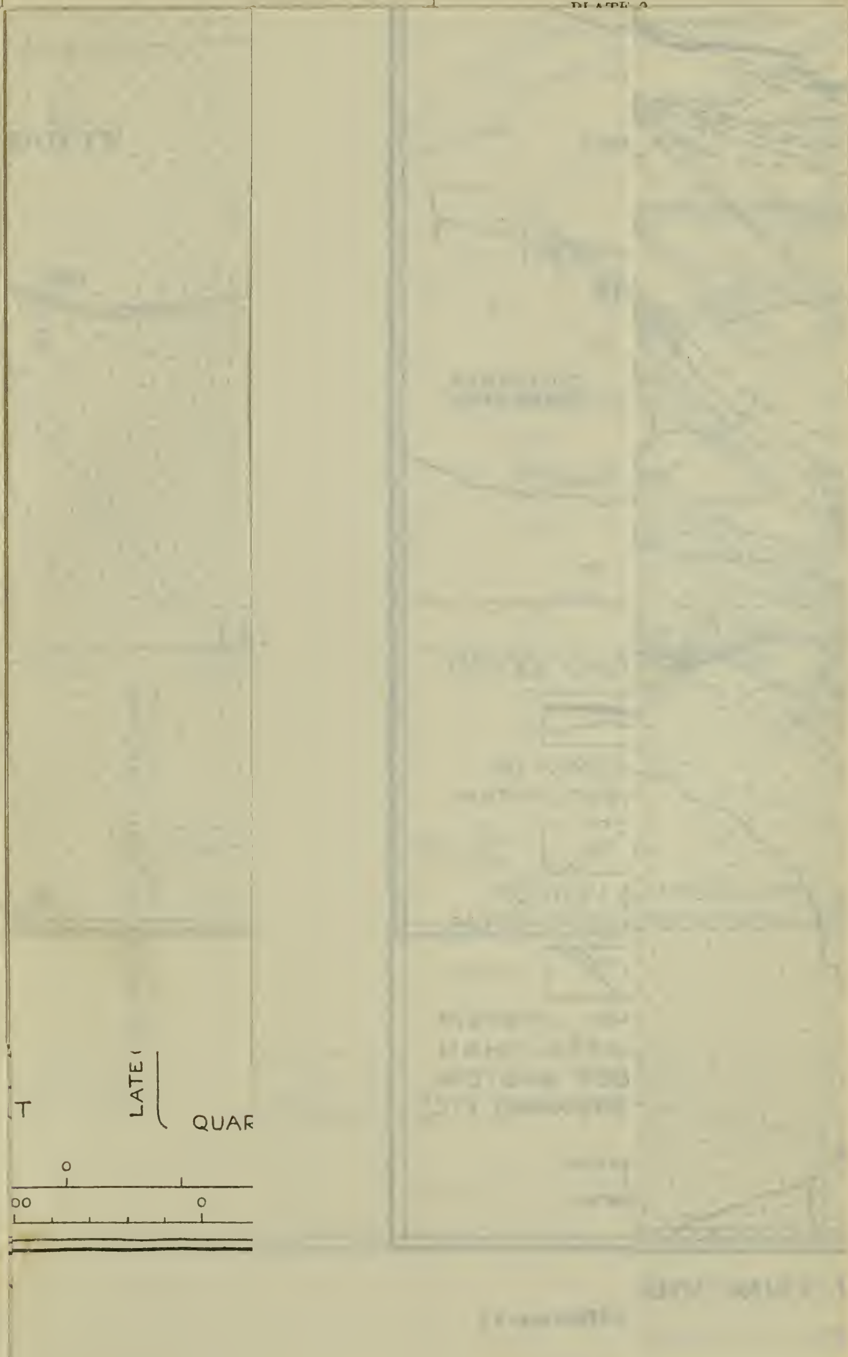
volcanic ash. Eventually the lakes were drained, and intermontane valleys, broad and flat as a result of the lake-bed filling, became a common feature in western Montana.

The uplands to the north and south of Butte are a portion of the old erosion plain. The high "ridge" east of Butte, along which the Continental Divide passes, is believed to be an eroded fault scarp. Much of the surface east of this ridge is similar to that of the low upland south of Butte. That part of Silver Bow Valley called The Flat has been considered a lake bed, but it may be the result of normal valley fill due to wash. The crest of Anaconda Hill (the "copper hill") is a part of the old land surface. It was subjected to prolonged erosion and likewise to oxidation and leaching in late Tertiary time, and these processes, which have continued until the present time, have affected the ore deposits to depths ranging from 500 to 1,000 feet (152 to 305 meters).

HISTORICAL GEOLOGY

That part of the geologic history of the Butte district which has a direct bearing on the ore deposits begins with the intrusion of the Boulder batholith, a large irregular granitic mass whose surface exposures now measure 25 by 75 miles (40 by 121 kilometers). The host rocks for the intrusive were pre-Cambrian, Paleozoic, and Mesozoic sediments and a thick series of andesitic lavas, probably of late Cretaceous age. The structural features of the host rocks are complex, but in general the region appears to be geosynclinal. After the partial cooling and solidification of the granite the first notable event was an intrusion into the granite of many irregular-shaped, dikelike and sill-like bodies of aplite, which locally is pegmatitic. Earth stress next affected the area, resulting in zones of shear and fracturing, which in subsequent times were enlarged, multiplied, and mineralized. A third set of intrusives, consisting of fine to coarse grained quartz porphyry, were injected as dikelike masses before the mineralization and most of the faulting. These masses were probably later than the normal aplite, and they are localized mainly in the area now bearing copper.

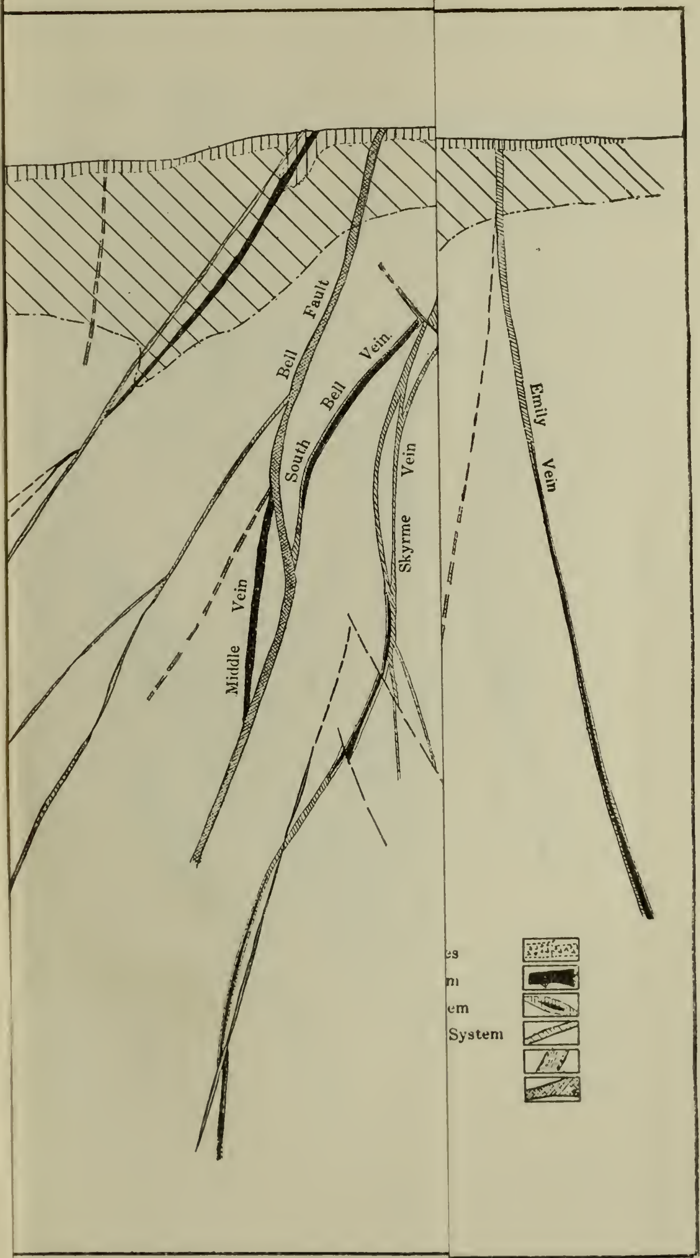
The mineralization occurred in early Tertiary time. It accompanied faulting and was followed by faulting and later by extensive erosion. The last manifestation of igneous activity, other than hot springs, which are still plentiful over the region, was the extrusion of extensive masses of rhyolite, probably about middle Tertiary time, onto the old erosion surface.


LATE
QUAR
0
00
0

GEOLOGIC MAP OF THE BUTTE DISTRICT, MONTANA, SHOWING PRINCIPAL VEINS AND FAULTS

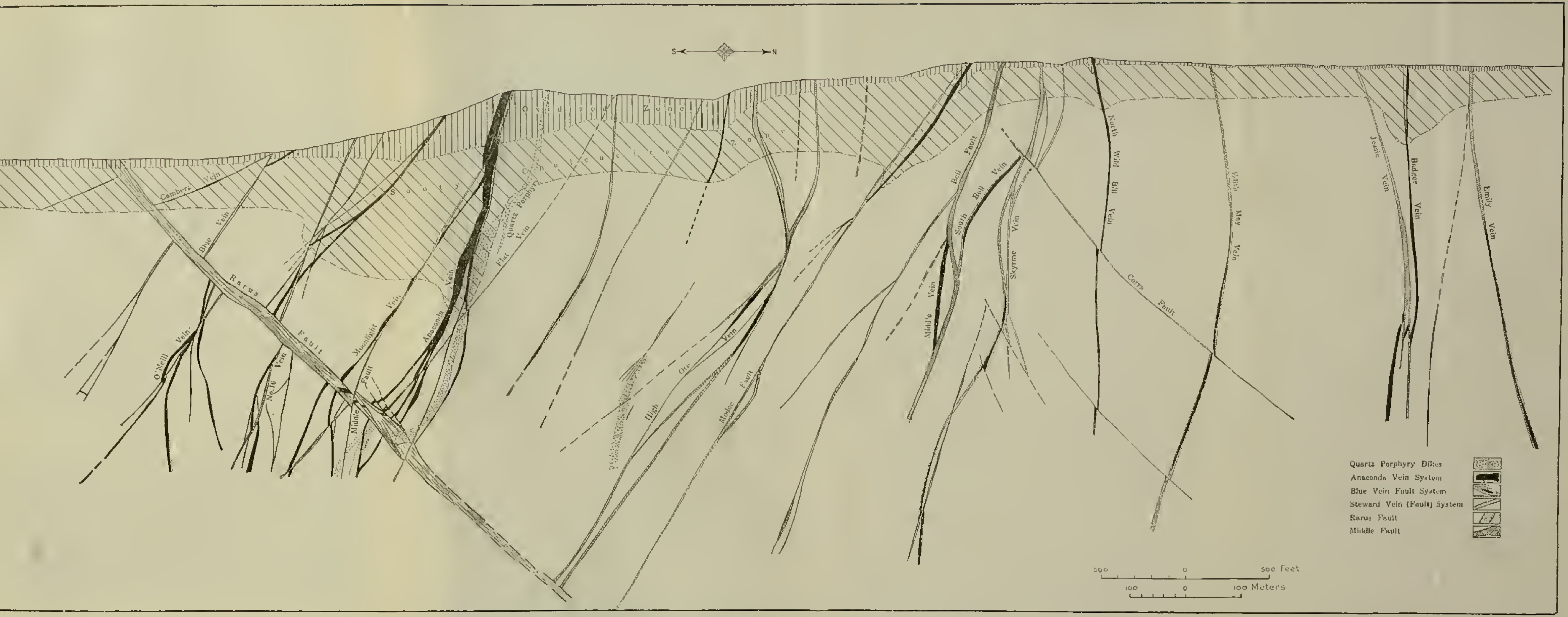
Compiled by E. S. Perry from United States Geological Survey maps and other sources

PLATE 2



R DISTRICT NEAR THE ANAC

nt. From Sales, R. H., Am. Inst. Min. Eng. T 3. (Face page 4.)



NORTH-SOUTH SECTION THROUGH THE BUTTE COPPER DISTRICT NEAR THE ANACONDA SHAFT

Shows structural relations of veins and fissures, also zones of oxidation and sulphide enrichment. From Sales, R. H., Am. Inst. Min. Eng. Trans., vol. 46, pl. 2, 1914.

111568. (Face page 4.)

PETROLOGY (22)

Five types of rocks—granite (quartz monzonite), aplite, quartz (aplite) porphyry, andesite, and late rhyolite porphyry—are found in the immediate vicinity of Butte, and lamprophyric dikes occur in outlying areas. The Butte "granite" is more correctly a quartz monzonite, because in the average rock the plagioclase and orthoclase, which together amount to about 60 per cent of the mass, occur in about equal proportions. Quartz constitutes from 15 to 20 per cent of the rock, and the ferromagnesian minerals, consisting mainly of hornblende and biotite with minor amounts of pyroxene and magnetite, range from 10 to 20 per cent.

The aplite, the second most abundant rock in the district, has a much finer texture than the granite, the content of ferromagnesian minerals may be less than 1 per cent, and the quartz may constitute nearly 40 per cent.

The early quartz porphyry resembles aplite in mineral composition. A characteristic textural feature is the rounded shape of many of the quartz phenocrysts, which resemble waterworn pebbles. This rock is found as dikes mainly in the central part of the copper area and is commonly known as quartz prophyry or "Modoc porphyry."

The later rhyolite porphyry contains an abundance of quartz and well-formed feldspar and biotite phenocrysts, and the matrix may be exceedingly fine grained. This rock is present mainly in the western part of the district as extrusive bodies, although rhyolite dikes occur throughout the area.

Small areas of late Cretaceous andesite are found on the western edge of the area.

FISSURE AND VEIN SYSTEMS (20)

CLASSIFICATION OF FISSURES

Three main fissure systems are commonly spoken of in connection with Butte ore deposits. (See pl. 1.) They have been described in accordance with their general trends—that is, east-west, northwest, and northeast. However, as the strike departs considerably from these general directions, the names Anaconda vein system, Blue vein system, and Steward-Rarus fissure system respectively have been suggested as better. In respect to age the three systems may be called early, middle, and late in the order named, but all were formed in early Tertiary time.

The application of earth stresses and the mineralizing processes were not separated by long intervals of time; more prob-

111568—32——2

ably there was a succession of closely related, recurring adjustments accompanied by more or less continuous infiltration of mineral-laden solutions. Possibly the solutions came in surges, or else they may have been somewhat more concentrated at certain times; no great lapse of time seems to have occurred between the formation either structurally or mineralogically of one vein system and that of the next.

Although the fissure systems on first inspection appear to be of distinctly different ages because of offsetting, it has been suggested that the fissuring may be ascribed to torsional force, as described by Mead,[3] and that therefore the several fissure systems may have been developed almost simultaneoulsy. Particularly, it is urged, does this suggestion seem applicable to the Anaconda and Blue vein systems.

The ore bodies commonly occur as "shoots" in veins. Thus, a vein may not diminish in thickness, but instead of being made up of copper and zinc minerals with quartz and pyrite it may become essentially a mass of quartz with little or no valuable sulphide content. The ore shoots are generally irregular in shape and may have a definite rake. (See fig. 1.)

ANACONDA VEIN SYSTEM

The earliest mineralized fissures are those of the Anaconda system, which have general east-west trends. Four main mineralized zones are recognized—from south to north the Black Chief or Ancient lode, the Anaconda vein, the Syndicate vein, and the Rainbow lode. Numerous subordinate veins of this system are spaced intermediately between the main lodes. The general strike in the copper area is nearly due east, but in the western part of the district the strike bears N. 75°–80° E., and in the southeastern part it is slightly to the south of east. Still farther east these veins bear east and then northeast. The dip of the Rainbow lode is about 80° N. to a depth of about 1,200 feet (366 meters) and then southward to the bottom of the present workings, at 3,500 feet (1,067 meters). In general, southward from the Rainbow lode the dips of veins of this system are southerly, decreasing in amount toward the south side of the district, the dip of the Black Chief lode being about 55° S. Some veins have flatter dips, and exceptions to the rule may be cited from place to place. These veins may divide downward into two or more branches.

Sales (20, p. 13) describes this system as "remarkably continuous complex fractures of but slight displacement with little

---

[3] Mead, W. J., Notes on the mechanics of geologic structures: Jour. Geology, vol. 28, pp. 505–523, 1920.

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. * * * As veins they are in general uniformly and continuously mineralized." Ascending solutions had free access to all parts of these great fracture zones; consequently mineralization was uniform, and the continuity is remarkable. Certain of these veins persist for 5 or 6 miles (8 to 9.6 kilometers) without interruption other than by faulting. Veins of the Anaconda system are the most important commercially.

BLUE VEIN SYSTEM

The Blue vein system, consisting of dominantly northwestward-trending fault fissures of intermediate age, comprises 20 or 30 large, well-developed mineralized fault fissures, together with many subordinate veins. Examples are the Jessie, Edith May, Skyrme, High Ore, and Blue veins (pl. 1). The general strike is N. 55° W., but toward the western part of the district it changes to nearly due west. Like the veins of the Anaconda system, those of the Blue vein system in the northern part of the district tend to dip north near the surface and to change to a southerly direction at a depth of about 1,000 feet (305 meters), whereas in the southern part of the district the dip is to the south and becomes progressively less steep. The amount of displacement along these fissures ranges from 100 to 300 feet (30 to 91 meters) in a direction oblique to the horizontal, and older veins are offset to the left. A vein may also divide downward into two or more veins. The larger members of this group tend to be spaced at uniform distances from each other.

Sales (20, p. 14) describes this system as "persistent well-defined fissures of marked displacement and of later age than group 1 * * * 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 1 these fissures are not continuously mineralized, the mineral bodies being disconnected shoots." Large veins may abruptly decrease in thickness, and mineralization may die out along either the strike or the dip; the fissure may then be traceable only by the presence of a few inches of tough blue-gray clay gouge between little-altered walls of granite. Nevertheless some of these fissures are traceable for 2 miles (3.2 kilometers) or more. In places banding of ore minerals (crusti-

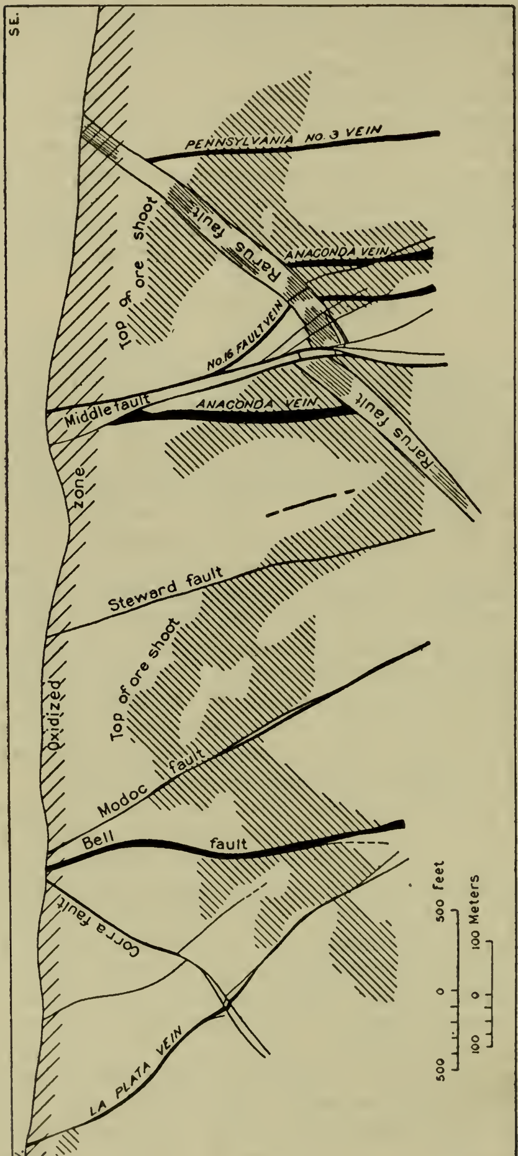


FIGURE 1.—Longitudinal vertical projection of the High Ore vein, Blue vein system, showing distribution of ore shoots and fault structure. From Sales, R. H., Am. Inst. Min. Eng. Trans., vol. 46, pl. 6, 1914.

fication) may pass uninterrupted past cut-off ends of Anaconda veins; elsewhere, especially in the deeper levels, gradations may seem apparent.

STEWARD VEINS AND RARUS FAULT FISSURES

Fissures with northeasterly trends involve a progressive series of earth adjustments, the first of which may have occurred before mineralizing solutions had ceased to circulate. Only the earliest northeasterly fissures, some of which are believed by many to contain primary minerals, are properly assigned to the Steward system; the unmineralized northeasterly fissures of somewhat later age should be classified in the Rarus system. Still other faults, such as the Middle fault, are later in age than the Rarus fault.

The strike of the true Steward fissures is N. 70°–80° E., and the dip is uniformly 50°–70° S. In places the strike is nearly that of the Anaconda system, and at junctions of the two types the Steward fissure may pass into a strike fault along the older vein. In some places strike faulting is conspicuous. The amount of displacement ranges from 50 to 100 feet (15 to 30 meters). Examples of fissures of the Steward system are the Modoc, No. 16, La Plata, and Steward. These veins are not as important economically as those of the Anaconda and Blue systems.

The Rarus and Middle faults, which are slightly different in age, and other closely associated faults strike N. 60°–75° E. across the central part of the district and dip at angles of 40° to 50°, some to the north and some to the south. In places these faults show themselves as a zone of shearing, which may be 250 feet (76 meters) wide and through which the displacement of 100 feet (30 meters) or more may be so evenly distributed between the limiting boundaries by means of small-movement planes that no actual cut-off of the intersecting vein occurs. Another fault may be compound, with two or three parallel planes of slipping. Elsewhere such zones of crushing narrow down to a few feet or even a few inches of tough dark clay gouge, which may cut ore bodies so sharply that little drag is developed. Such ore as has been found within fault fissures of this type is "fragmental or dragged from older veins, the included blocks or fragments ranging in size from small bits or pebbles up to great blocks or slices of veins which reach from wall to wall of the fault" (20, p. 27). These faults have to a considerable extent caused the complexity of structure of the district.

CONTINENTAL FAULT SYSTEM

A fourth system of fissures observed in outlying parts of the district, believed to record the latest of all major earth movements in this locality, is known as the Continental fault system, because the Continental Divide passes along the bold escarpment caused by one of these displacements, the Continental fault, just east of Butte. Their general trends are north and south. Another fault in this group is the Whisky Gulch fault, 4½ miles (7.2 kilometers) west of the Continental fault, and a third is the Rocker fault, 1½ miles (2.4 kilometers) west of the Whisky Gulch fault.

The Continental fault, which is the best known of this group, is traceable for 3 or 4 miles (4.8 to 6.4 kilometers) and is thought to continue in a northerly direction for 10 miles (16 kilometers) or more near the foot of the west slope of East Ridge. Directly east of Butte it dips about 70° W. and has a vertical component of displacement estimated by different observers between 1,000 and 1,800 feet (305 and 549 meters). The fault is compound and is marked by tough blue-gray clay gouge, which may be 25 feet (7.6 meters) or more in thickness.

EARLIER CLASSIFICATIONS

Sales (20, p. 12), describing these ore deposits in 1913, gave the following classification, which is similar to that just given, although at first it may appear somewhat different because it is more inclusive.

1. Anaconda or east-west system, comprising the oldest known fractures.
2. Blue or northwest system, the earliest fault fissures of any considerable displacement, much mineralized in places.
3. Mountain View breccia faults.
4. Steward system, or northeast faults occurring at the close of the period of mineralization.
5. Rarus fault, postmineral, northeast faulting.
6. Middle fault, postmineral, northeast faulting.
7. Continental fault, north-south faulting not manifest in the central part of the district.

Groups 1 and 2 of Sales are the same as the Anaconda and Blue vein systems as here described, and Groups 4, 5, and 6 of Sales are the same as the Steward-Rarus fissure system.

Group 3 of the Sales classification is distinctive and characteristic and is commonly designated in the district by his term. However, the faults are not plentiful and are not economically important, for they exhibit no displacement, although they cut both Anaconda and Blue veins, and they contain only fragmental ore. They are cut by certain late faults of the northeast or Rarus system. This type of fissure is most unusual and resembles a trench into which various kinds of rock refuse had been dumped and then cemented. Fragments of rhyolite occur with other material, and the fissures appear to have been formed by the simple pulling apart of the rock walls and the falling in of whatever material was in a suitable position. Some fragments may be rounded. Examples of this group are the ore breccias of the Gagnon mine and the Mountain View breccia fault.[4]

"HORSETAIL" STRUCTURE

A unique structural development of the Butte district is the fingering out of some of the large veins, such as the Leonard vein of the Anaconda system (fig. 2), into innumerable small veinlets, in places nearly paperlike in thickness. Such veinlets invariably turn sharply away in a direction nearly at right angles to the main vein. A large vein may become completely dissipated in a mass of small veinlets, all leaving on one side, and such a system as shown on a map resembles a picture of the tail of a horse. A single well-defined vein on approaching the horsetail area may first give evidence of a change by the presence of diagonal structure, mostly within the vein. Gradually the diagonal structure may become more marked; then the vein may develop an échelon pattern, the general trend of which is west but the detailed structure of which may be northwest. Each segment of the échelon pattern may end in a "spray" of veinlets. The horsetailing of veins results essentially in a network of veinlets somewhat similar to a stockwork; the granite wall rock is impregnated with sulphides and in large areas contains sufficient copper to make ore.

Horsetail structure is believed to have resulted from a distribution of rotational or torsional stress in a relatively homeogeneous medium (granite). It marks the eastward termination of some of the veins of the Anaconda system. Veins may horsetail in dip as well as in strike, but without marked change in dip.

MINERALOGY

The mineralogy of the Butte ores is one of the most interesting features of the district. The most conspicuous feature is the zonal arrangement of ore minerals; copper minerals form a central zone or "copper core," which is surrounded by an area of copper and zinc minerals forming an intermediate zone, which in turn is surrounded by an area of zinc and manganese minerals forming an outer or peripheral zone. A second feature is that a

---

[4] Steele, C. H., oral communication.

variable group of complex copper minerals has been deposited more or less progressively both as a filling and through replacement, the minerals replaced being earlier sulphides of iron and

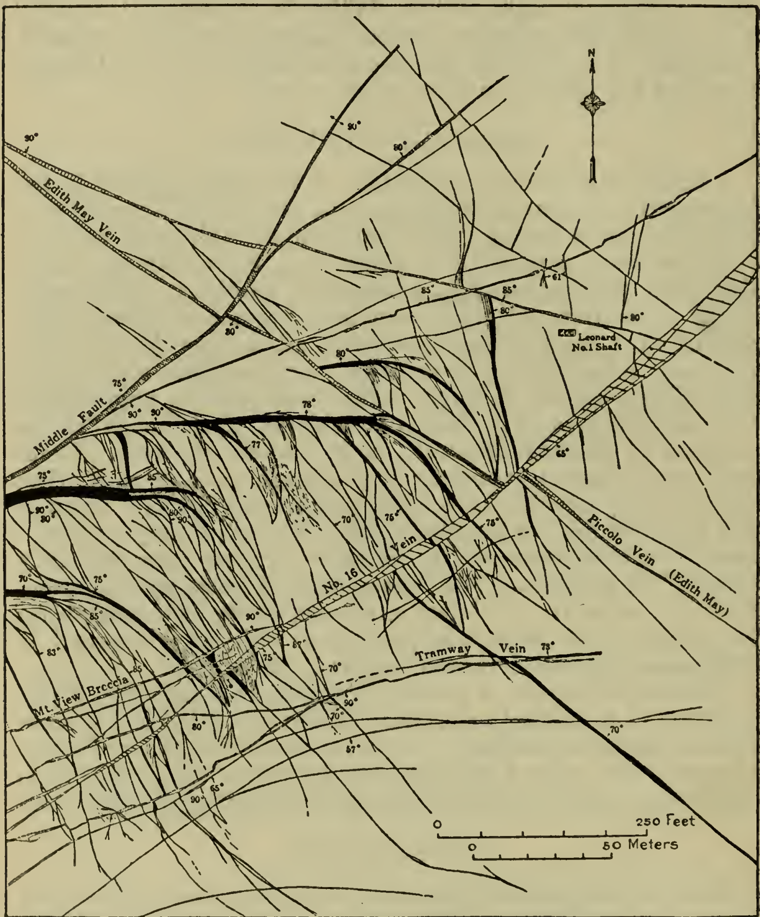


FIGURE 2.—Plan of a portion of the 1,200-foot (366-meter) level of the Leonard mine, showing transverse fissuring in Colusa-Leonard vein. This structure is typical of "horsetail" development. Shows also fault relations. From Sales, R. H., Am. Inst. Min. Eng. Trans., vol. 46, fig. 2, 1914.

zinc as well as certain of the minerals of the copper group and also the wall rock. The paragenesis of the various minerals has been and probably will continue to be debated for considerable time. Another interesting feature is that this area contains abundant evidence that the once controversial mineral chalcocite is of primary origin. Still other features of the mineralogy are the bornite-chalcocite relationships, presenting the question of simultaneous deposition versus replacement of bornite by chalcocite; the physical and chemical variations in the bornite (and possibly in the chalcocite), presenting the question of an isomorphous series of compounds versus solid solutions; and the presence of such minerals as molybdenite, hübnerite, and "colusite" (tin-bearing sulpharsenide) in a zone supposedly of intermediate intensity. A thorough impregnation of granitic wall rock by sulphide minerals, or by quartz, or by both, accompanied by extensive development of sericite, presents opportunity for studies in replacement and hypogene alteration seldom equaled.

ZONAL ARRANGEMENT (20, pp. 57–61)

Butte is often cited as a type example of zonal arrangement of ore minerals about a center of dispersion. The zonal arrangement shows itself both in plan (see fig. 3) and in section, and at the surface each zone is approximately half a mile (0.8 kilometer) across. Sales has distinguished three zones, within each of which all veins, regardless of age, have the same general mineralogic characteristics. He describes the zones as follows (20, p. 58):

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 * * * the copper minerals are predominantly chalcocite and enargite in a gangue of pyrite and quartz. Bornite is present also, * * * chalcopyrite and sphalerite are extremely rare, * * * and rhodonite, rhodochrosite, and galena are unknown. * * * The central copper zone coincides in part with the great zone of rock alteration.

2. An intermediate 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 rhodonite and rhodochrosite are of frequent occurrence. * * * The sphalerite does not appear suddenly in great quantity, but it comes in rather gradually * * * within a distance along the strike of 1,000 feet [305 meters]. * * * 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. * * * The silver content increases materially. * * * The net result is a decrease in copper content with an increase in silver, zinc, lead, and manganese; quartz as a gangue does not vary, but pyrite is less abundant toward the outside limits.

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. * * * 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 other two zones. Quartz is the most abundant gangue mineral. * * * Galena is present in considerable quantities

* * * Extending outward from the peripheral zone the fissures appear to become less mineralized, sulphides largely disappearing, the vein filling consisting principally of quartz with scattered pyrite, and curiously enough arsenopyrite has been noted at extreme distances 2 miles [3.2 kilometers] or more from the central copper zone.

It should be kept in mind that the dividing lines between these three zones are of an arbitrary nature; the passing of one zone into another is gradual and can not be correctly represented by a mere line.

The copper zone appears to widen with depth. Numerous veins on the outer edge of the copper area are zinc-bearing in the upper levels and copper-bearing in the lower levels; the reverse condition is very exceptional.

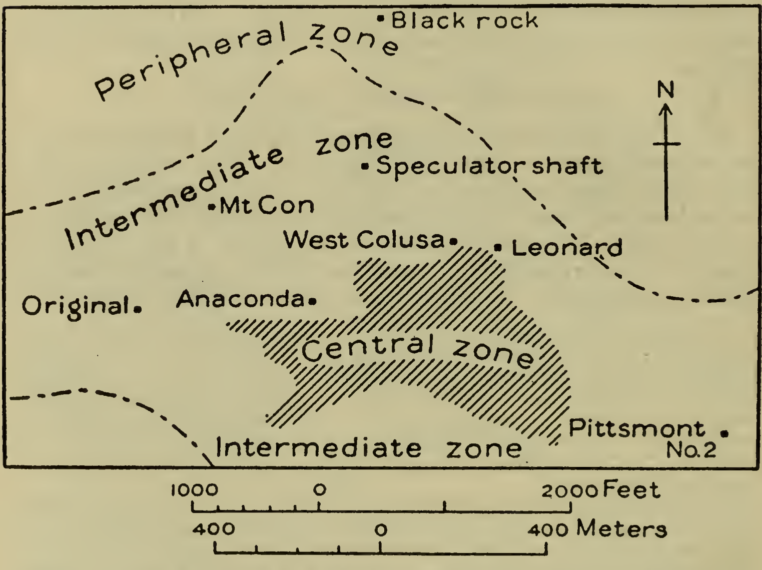


FIGURE 3.—Plan at altitude of 4,600 feet (1,402 meters), showing general zonal arrangement of ore minerals. From Sales, R. H., Am. Inst. Min. Eng. Trans., vol. 46, fig. 7, 1914.

One of the most interesting features of the zonal arrangement is that veins of different ages in passing from one zone to another change their mineral content so as to conform to the particular zone in which they may lie. The late mineralization of the copper zone or of the peripheral zone is not particularly different from the early mineralization. Change in mineral content is not limited to well-defined veins, but horsetail structure also passes out of the copper zone southeastward into a zinc-producing area. Such behavior of veins may indicate that the several periods of mineralization were not separated by any considerable length of time, and that a central zone within the granite became heated and remained heated throughout both early and late ore deposition, the fracturing and fissuring continuing through this zone while thermal conditions were still somewhat intense. Other explanations may be offered—for example, early quartz, pyrite, sphalerite, and manganese minerals might have been subjected to a late copper mineralization which replaced the early minerals and in addition deposited copper minerals in a later set of fissures. Evidence cited against this explanation consists of the clean "cut-offs" of early copper veins by later copper veins, with the banding of the later veins passing uninterruptedly past the faulted ends of the earlier veins. At lower levels the two vein systems tend to merge together[5]—a fact which indicates that the late solutions circulated through both vein systems at depth.

ORE MINERALS

The metals recovered in any considerable quantity from the ores of the Butte district are copper, zinc, manganese, arsenic, lead, silver, and gold. Other metals known to occur are iron, tin, tungsten, molybdenum, bismuth, antimony, tellurium, selenium, cadmium, and platinum. (See analyses, p. 24.)

Zinc and lead occur in the primary ore bodies as the sulphides, sphalerite and galena. Sphalerite is widely distributed. It is most abundant on the border of the productive part of the district and is rather rare in the central part of the copper area. It is associated with all the copper minerals, also with manganese and lead minerals. Certain zinc veins in the intermediate zone have been found to turn into copper veins with depth, but on the other hand zinc in considerable quantity may be found in a vein below large bodies of copper ore, and it is present at the deepest levels (3,800 feet or 1,158 meters).

Galena, found disseminated through the ore bodies away from the copper area, is a fairly common mineral but is nowhere sufficiently abundant to be mined for lead alone. In the lead-zinc ore lead is about one-sixth as plentiful as zinc. Probably galena is most abundant in the peripheral zones, where the valuable content of the veins lies largely in the manganese and silver bearing minerals.

Arsenic and antimony occur combined with copper and silver as enargite, tetrahedrite, and tennantite.

The primary manganese mineral is the carbonate, rhodochrosite. Rhodonite is not found. The carbonate occurs intimately associated with quartz, even in microscopic grains, and

[5] Steele, C. H., oral communication.

it is accompanied by pyrite, sphalerite, and galena. Manganese is found principally in the peripheral area and has caused the blackened quartz outcrops of the silver-producing veins.

Silver and gold have been found frequently in native form, generally with chalcocite, but silver may occur also in tetrahedrite and, in the peripheral areas, in stephanite and argentite. Gold may occur in definite "shoots" in which the value may be $100 to the ton of ore. Wires of free gold have been found adhering to chalcocite in vugs. All the ores of the district contain some gold and silver, but the copper ore contains ten times as much gold and one-third as much silver as the zinc ore. Much of the silver produced has come from enriched portions of veins in the peripheral area, in part as "ruby silver."

A tin mineral locally known as "colusite" is present in small amount in the central part of the copper area, apparently as "shoots" in small east-west veins. It may be closely related to stannite, but more probably it is a tin-bearing tennantite. "Colusite" has constant and distinctive characteristics, is bronze-colored, somewhat resembling pyrrhotite, and occurs in veins mainly with enargite, with which it appears to have been deposited simultaneously. The tin-bearing mineral appears and also disappears abruptly.

Hübnerite is found rarely in the district and is not commonly recognized, though locally it may be plentiful.

Molybdenite is fairly common in certain localities as small specks or as paperlike films in fractured rock.

Pyrite is the most abundant sulphide mineral in the district, but the amount of iron in the Butte veins is said to be no greater than that in ferromagnesian minerals in typical Butte "granite" (4, p. 125). Pyrite is commonly replaced by copper minerals.

The primary copper minerals, named in the order of abundance, are chalcocite and bornite, enargite, chalcopyrite, covellite, tennantite, and tetrahedrite. The first three supply more than 85 per cent of the copper output of the district. Both primary and secondary chalcocite are believed to be present. The former, known as "steely" chalcocite, is found at all levels, but the latter, known as "sooty" chalcocite, is found only in the 400 or 500 feet (122 to 152 meters) immediately below the area of leaching. "Steely" chalcocite and bornite are so intimately associated that it is difficult to find a specimen of either which under the microscope does not show more or less of the other mineral. The two minerals may occur as graphic intergrowths, first one predominating and then the other; or the boundaries may be irregular but with mutual relations. (See pl. 3, *A*.) In some chalcocite there appears to be a residual cleavage, which certain observers have taken to indicate chalcocite replacement of bornite. Bornite observed under a reflecting microscope shows more than one color, and the variously colored portions behave somewhat differently when treated by the same reagent. The same is true of chalcocite. It has been suggested [6] that there is more than one variety of "bornite" and perhaps more than one variety of chalcocite, but it seems quite probable that the copper content may be variable, thereby giving an isomorphous series of minerals of which typical bornite (or chalcocite) is but one member.

Enargite is found abundantly in all the copper veins but appears most commonly in the central part of the copper area and has been thought to increase with depth. Enargite occurs in irregular masses, which in many places are underlain by large bodies of chalcocite or bornite. Much of it occurs in large well-formed crystals, some of which may be an inch across. Although it is not intimately associated with chalcocite and bornite, all three occur together, and a polished surface of a single enargite crystal may show considerable bornite or chalcocite.

Chalcopyrite has a wide distribution, and most polished specimens show it in microscopic grains, not visible in hand specimens. It is not plentiful, however, and is not important as a source of copper. It is said by a few observers to be characteristically a mineral of the border zone of the central copper area. It may be considered as an "edge" mineral, because of its geographic position, or as a late mineral in the copper deposition, because it is found in cracks, vugs, and cavities within older vein filling and as thin coatings and replacement deposits on older copper and iron minerals. (See pl. 3, *B*.) Microscopically it may form Widmannstätten figures in bornite.

Covellite occurs massive and as bladed crystals in several parts of the copper-bearing area, and from shallow depths to more than 2,400 feet (732 meters). It is intimately associated with chalcocite, and polished surfaces show some specimens to be crisscrossed with innumerable veinlets of chalcocite that is unquestionably replacing the covellite. Covellite deposition appears to have been localized, but in places it is an important ore mineral.

Tennantite occurs commonly in the northeastern part of the district as crusts and coatings in vugs, and less commonly in the massive form. It is suggested that tennantite develops through the alteration of enargite to chalcopyrite.

Tetrahedrite, found in small quantities in nearly all mines at Butte, is of less importance as an ore mineral. It is most plentiful outside the central copper zone. The gold or silver content may

[6] Schneiderhöhn, Hans, oral communication.

increase with an increase of tetrahedrite, and it may be one of the chief primary silver-bearing minerals.

The gangue minerals consist essentially of quartz and pyrite, with smaller amounts of calcite, barite, gypsum, and fluorite. Quartz and pyrite are the most abundant vein minerals in the Butte ores, and quartz is far more plentiful than pyrite. The quartz is separated in milling, and much of the iron of the pyrite serves as fluxing material in smelting. The chief constituent of the ore is "altered granite," and 80 per cent of the mass shipped for treatment may be this material.

According to Sales (20, p. 62), "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." Likewise a suite of copper minerals collected from the 3,500-foot (1,067-meter) level is not greatly different from a suite collected on the 2,000-foot (610 meter) or 1,000-foot (305-meter) level. "The distinctions where recognizable are in the relative quantities of the minerals present or in matters pertaining to physical character (such as texture). The variation in mineral composition of veins is a matter of geographic position rather than of geologic age" or of vein systems.

PARAGENESIS

Determination of the order of deposition of the vein minerals at Butte is not a simple problem, and differences in opinion have been expressed by different observers. The problem has been complicated (1) by the zonal arrangement of the ore minerals, probably brought about by a delicate balance in physical and chemical conditions which locally may have varied enough to cause alternate deposition of closely related minerals; (2) by the deposition of each of a group of 12 or more minerals more or less continuously throughout a mineralizing period long enough to allow the development of two sets of fissure veins of different age; and (3) by the presence of the mineral chalcocite, which for many years had been thought to be of supergene origin.

One of the most thorough studies of the ores was made by Agar (1), who concluded that "pyrite, quartz, and sphalerite form one generation of minerals" and that they are "replaced by the intricately intergrown copper sulphides. The intricate relations among the copper sulphides point to continuous deposition under somewhat variable conditions. They are essentially contemporaneous." In his discussion of the appearance of the minerals under the reflecting microscope Agar (1, p. 706) states:

To sum up, many of these [copper] sulphides show mutual boundary and graphic relations; one may appear to be older in one specimen and younger in the next. * * * Clear replacement along visible cracks, so characteristic of supergene conditions, is lacking, and replacement is local and subject to reversal. * * * These relations do not point to successive periods of mineralization, either hypogene or supergene, but appear rather to result from continuous deposition in a more or less regular series, subject to control by local variations in the composition of the solutions as well as by a general increase in their copper content. * * * The copper sulphides are believed to belong to one period of deposition and to form a series younger than pyrite and sphalerite.

Other observers disagree in some respects with Agar's conclusions. However, nearly every one of their analyses of the paragenesis pertains to a particular suite of specimens and does not take in the larger and broader features of the district as a whole. Conclusions on paragenesis must be based on relative age of veins and structural relations, such as fault "cut-offs," as well as on microscopic characteristics, and conclusions that do not involve these larger and broader features are subject to just criticism.

HYPOGENE ROCK ALTERATION

Regarding rock alteration, Sales (20, p. 30) says:

The rocks in two principal zones or areas, associated with the copper veins, are altered to an unusual degree and are closely related to the more important development of the earliest formed veins. * * * One of these alteration zones follows closely the Syndicate system. * * * The largest and most important area of altered granite is in the vicinity of Anaconda Hill (Anaconda vein), * * * and in this whole area it is next to impossible to find a hand specimen of rock which has not undergone marked chemical and physical changes. * * * There is an unmistakably close genetic relation to the Anaconda vein system. In these two zones intense alteration has taken place not only within and along the veins and faults, but the entire rock mass, whether granite, aplite, or quartz porphyry, has been invaded by active metasomatic processes, resulting in a product differing markedly both in chemical and physical character from the original rock. The hard dark-colored granite has been changed to a whitish or mottled gray, less firm rock, peppered generously with pyrite.

In the area surrounding intensely altered rock the joints and fissures are fringed with several inches or a foot or more of altered granite. Where the joints run in three directions, central cores of dark, slightly altered granite lie in a matrix of bleached altered granite. The zone of intense alteration widens with depth.

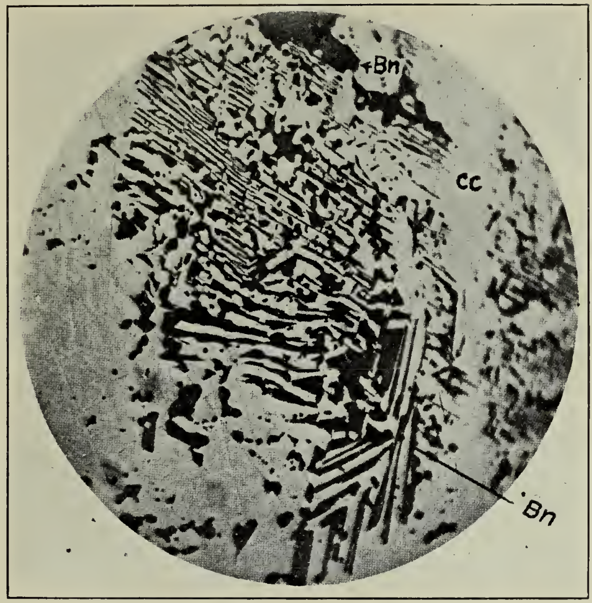
These rock changes began with the development of chlorite, accompanied by the formation of pyrite. Ferromagnesian minerals were first attacked and were altered to chlorite, epidote, secondary silica, and pyrite. It is suggested that some of the iron of these minerals combined with sulphur or hydrogen sulphide, thus developing pyrite. Additional iron may have been introduced. Feldspars next became altered, largely to sericite and secondary silica, an alteration that gave the bleached and friable character to the altered granite. The chlorite and epidote of the early stage largely disappeared in advanced stages of alteration and the rock became distinctly silicified and pyritized. The mineral constituents of the final product are sericite, quartz, and disseminated pyrite.

SUPERGENE ALTERATION

Surface or supergene alteration has been superimposed upon the area of hypogene alteration, but only the upper 300 or 400 feet (91 to 122 meters) of the ore deposits is believed to be much affected by it. Below 500 feet (152 meters) the mineralogic characteristics are those of hypogene deposition (in places hypogene enrichment), and the deeper ores are believed to be essentially unaffected by supergene alteration, although a few traces of such alteration have been found as deep as 1,000 feet (305 meters).[7] At the surface leaching has been intense, but the leached metals, copper, zinc, and lead formed oxidized precipitates only sparingly. Oxidized minerals of these metals are uncommon and were only exceptionally abundant enough to be mined as ore. Large quantities of earthy silver minerals were found in weathered portions of some veins, particularly in the peripheral area, and the second stage of development of the Butte district was that of mining relatively shallow oxidized silver ores. Veins containing manganese are characteristically stained black at their outcrop, and many of them are marked by the presence of "honeycomb" or "box work" structure in the quartz, with limonite and pyrolusite filling cavities. During war time this material was mined for its manganese content. Veins that contain a considerable amount of sulphide material have become so thoroughly leached at the surface that the outcrop is inconspicuous and is discernible only as a band of light-gray or iron-stained soil. On the other hand, veins barren of sulphide minerals commonly contain a massive variety of quartz, which on weathering stands out in bold relief as conspicuous "quartz reefs." Barren quartz veins are more common in the peripheral areas. Outcrops are noticeably inconspicuous in the copper area, and veins 5 to 10 feet (1.5 to 3 meters) wide may readily be passed over unnoticed. The zone of sulphide enrichment in copper veins is marked by the presence of "sooty chalcocite" which is most abundant 100 to 400 feet (30 to 122 meters) below the surface.

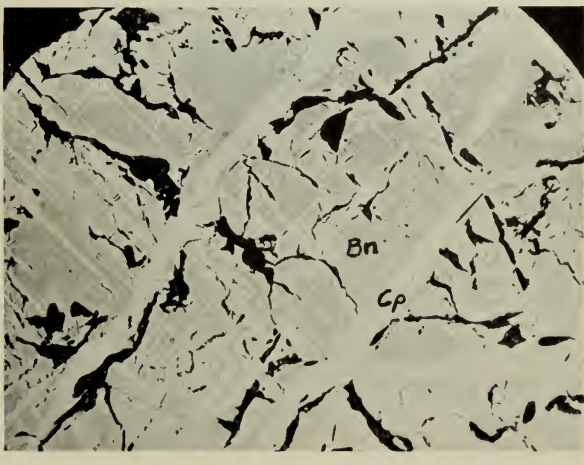
---

[7] Gidel, Murl, oral communication.



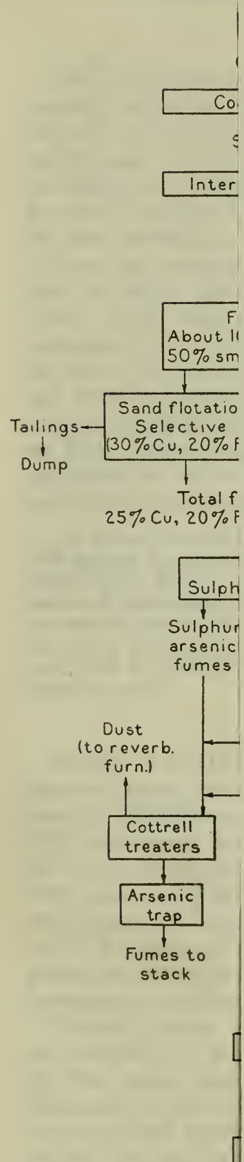
A. BORNITE-CHALCOCITE GRAPHIC STRUCTURE WITH TENDENCY TOWARD LATTICE STRUCTURE

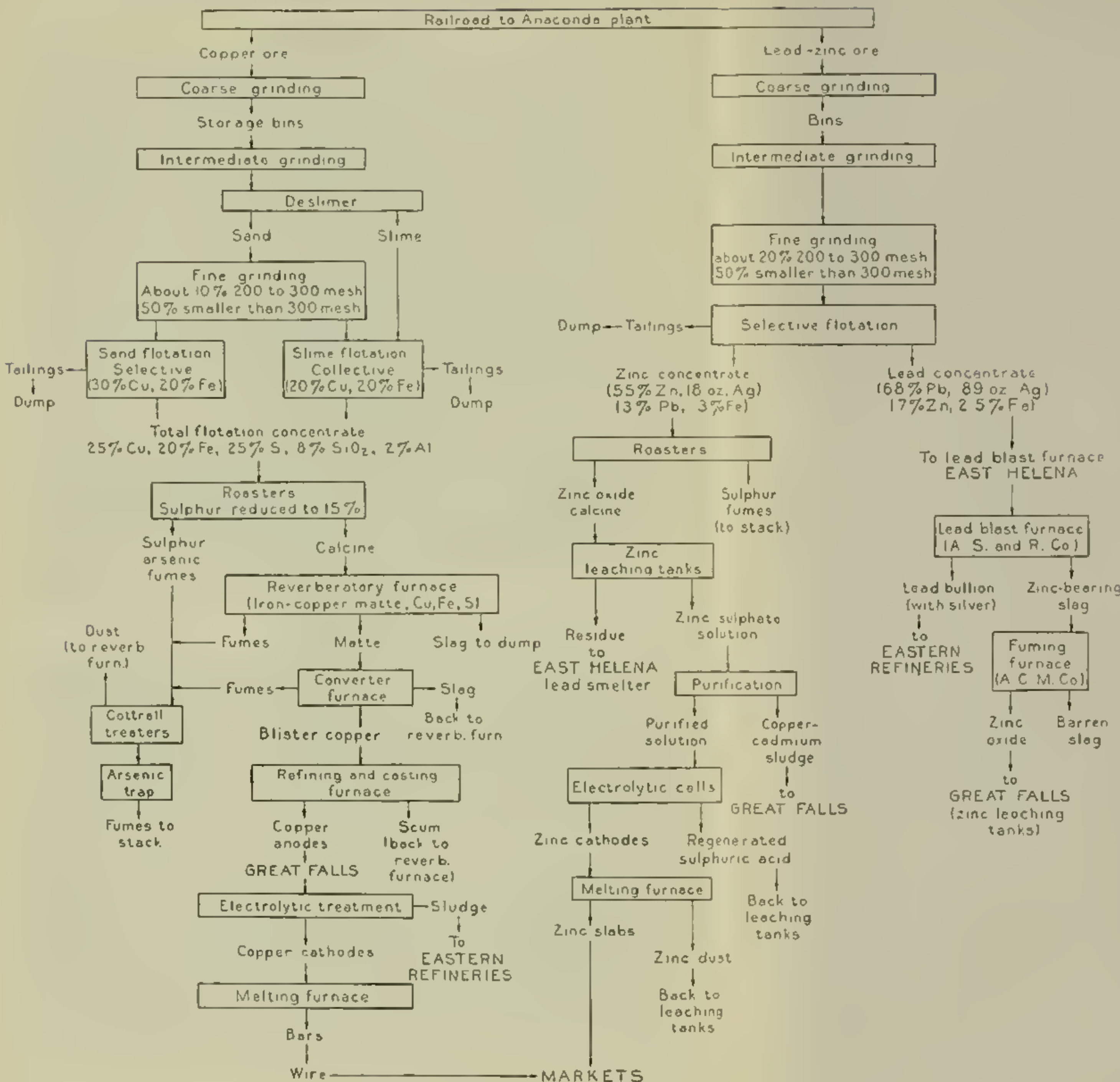
Shannon vein, 1,400-foot level. Enlarged 290 diameters. From Locke, Hall, and Short, Am. Inst. Min. Met. Eng. Trans., vol. 70, p. 946, 1924. Bn, bornite; cc, chalcocite.



B. CHALCOPYRITE REPLACING BORNITE WITHOUT VISIBLE RELATION TO FRACTURES

A rather characteristic mode of occurrence of chalcopyrite. The black areas are cracks. Enlarged 60 diameters. A hand specimen of this material seen without the aid of a microscope may appear to be pure bornite. From Agar, W. M., Econ. Geology, vol. 21, No. 7, November, 1926. Bn, bornite; cp, chalcopyrite.


Co
Inter
About I
50% sm
Sand flotatio
Selective
(30% Cu, 20% F
Tailings
Dump
Total f
25% Cu, 20% F
Sulph
Sulphur
arsenic
fumes
Dust
(to reverb.
furn.)
Cottrell
treaters
Arsenic
trap
Fumes to
stack



FLOW SHEET OF ORE, BUTTE DISTRICT

ORE BODIES

Ore at Butte occurs as true fissure fillings, as deposits completely replacing country rock, and as deposits disseminated through the country rock. All these types may be included in a single vein, and the proportion of replacement and filling differs in different localities. In the central copper area, where the horsetail variety of fracturing has occurred, disseminated deposits are abundant. The early east-west or Anaconda system shows the greatest tendency toward replacement of wall rock, and in places great zones of crushing 100 feet (30 meters) or more across may be so completely mineralized as to give the appearance of a single vein. Some observers state that as much as 60 or 70 per cent of the mineralization of the Butte district has been accomplished by replacement of the granite wall rock and included blocks. Many of the ore bodies of the northwest or Blue system consist of fissure fillings, but blocks of granite included in the veins may be largely replaced. In connection with the character of ore bodies Sales (20, p. 57) states:

> The fissure-vein structure is the rule; * * * the ore bodies display rather well-defined boundaries when broadly considered. * * * In the Leonard, West Colusa, Rarus, and Tramway mines the largest ore bodies are more in the nature of mineralized highly fissured granite, having boundaries which are often commercial rather than geological. * * * 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.

MINING

About 4,270,000 tons (3,873,680 metric tons) of ore was shipped from the mines at Butte in 1929, and about 2,406,000 tons (2,182,687 metric tons) in 1930. The average copper ore of 1929 contained from 4 to 5 per cent of copper, with 2 ounces of silver and 0.01 ounce of gold to the ton (56 grams of silver and 0.28 gram of gold to the metric ton). The average zinc-lead ore contained from 12 to 14 per cent of zinc, 2 per cent of lead, and 8.5 ounces of silver and 0.008 ounce of gold to the ton (240 grams of silver and 0.23 gram of gold to the metric ton). The manganese ores contained from 30 to 38 per cent of manganese.

Twenty mines were operating during 1929, fifteen of which were under the management of the Anaconda Co. Practically all the mines are connected with one another underground. However, even mines that are under the same management are operated more or less independently. Unification, standardization, and systematization have greatly facilitated operations at Butte and have made possible the exploitation and development of ore bodies that otherwise might never have been discovered or if discovered might not have been developed. Each major operation in all mines operated by the Anaconda Co. is under the supervision of a single department. Geologic information collected by the geologic department is filed, placed on standardized maps, interpreted, and issued to the several mines of the organization from one staff—perhaps the best organized and systematized staff of mining geologists in North America.

Compressed air is supplied through a pipe-line system to different mines from two central compressor plants. Two central pumping stations take care of the mine water, which, because of carefully planned mine levels, drains from all mines within a radius of 2 miles (3.2 kilometers). Water enters the mines at different depths, and some water is introduced at the surface. The 2,800-foot (853-meter) level is the main drainage level, and an average of 3,500 gallons (13,250 liters) a minute of water is lifted by plunger pumps to the surface. The water, which contains an average of 0.025 to 0.04 per cent of copper in the form of copper sulphate, is passed through a precipitating plant, where between 90 and 95 per cent of the copper is saved. An average of 5,000,000 to 6,000,000 pounds (2,268,000 to 2,722,000 kilograms) of copper is recovered in this manner each year.

The rock drills are of the standard wet-drilling types. Drill bits of the detachable Hawkesworth type are sharpened and treated in a central shop. Mine timbers are framed (cut to proper lengths and ends dressed) in special mills before being hauled to the mines. All power is electrical, except as compressed air is used for power in rock drills, mine-timber hoists, certain pumps, and some main hoists. Electricity is supplied by the Montana Power Co. from hydroelectric plants situated mainly along the Missouri River 60 to 250 miles (97 to 402 kilometers) away.

Underground haulage is done mainly by storage-battery locomotives, the batteries of which are charged daily from stations underground. Hauls to hoisting shafts generally are 500 to 1,500 feet (152 to 457 meters) and rarely more than half a mile (0.8 kilometer). The average depth of mines at present is between 2,000 and 3,000 feet (610 and 914 meters), and the deepest levels in two mines are approximately 4,000 feet (1,219 meters) below the surface. Direct-motion electric hoists are installed at five shafts; other hoists are driven by compressed-air engines, the air coming from one of the central compressor plants. Ore is carried to the surface in 3 to 7 ton automatic dumping skips, which are replaced by "cages" when men are being lowered or raised. Ore at the surface is shipped over a company-owned electrical railroad to the mill and smelter at Anaconda, 25 miles (39 kilometers) away.

Ventilation is both natural and artificial; "downcast" and "upcast" shafts cause air to circulate through main passageways, but electrically driven fans and blowers are necessary to force air through 12 to 24 inch (30 to 60 centimeter) tubing of canvas or special fabric into drifts and stopes. Temperatures increase with depth at approximately a normal gradient, but local conditions within the mines cause variations—either a decrease or increase in the expected temperature.

Underground mining at Butte is accomplished by standard methods such as are commonly employed in other mining camps in the Rocky Mountain region. Shafts are sunk, crosscuts and drifts are run on several levels, winzes and raises are driven, and stopes ascend from levels, the ore passing downward through chutes to main levels. Moving or "heavy" ground necessitates much timbering, and Butte exemplifies "square-set" mining on a large scale. Caving of stopes is prevented by the installation of many square sets. The square sets start from "drift sets" on main levels and continue upward one above another as ore is taken out. Although each set is placed above the one below, all sets are wedged or blocked against the walls so as to maintain themselves independently of other sets. As mining proceeds open timbering is filled with waste vein material and rock, so that more than two floors of open square sets below the mining floor seldom exist at one time. "Rill stopes," in which as little timber as is possible is used, are found advantageous in some places.

All development work for the Anaconda Co. is guided by the counsel of the geologic staff, and it is the duty of this staff to advise the mine foremen in case of any difficulties in development work, such as fault "cut-offs" or failure of ore shoots. The geologic staff blocks out areas of workable ore. A thorough yet simple system of sampling is maintained in all parts of all mines. The three departments—sampling, engineering (surveying), and geologic—are so coordinated that they function more nearly as a single department, even though at times 15 different mines, operating on perhaps 500 veins over an area of about 12 square miles (31 square kilometers), are involved.

MILLING AND SMELTING AT ANACONDA

The copper and lead-zinc ores of Butte, amounting to about 10,000 tons (9,072 metric tons) a day in normal times, are shipped to Anaconda for treatment. Manganese carbonate ore is roasted to "nodulated" manganese oxide at Butte. In 1929, when all mines were operated to capacity, the average of all ore was as follows:

	Copper ore	Lead-zinc ore	Manganese ore
Zinc per cent	Some	12 to 14	Negligible.
Copper do	4 to 5	0.16	Do.
Lead do		2.2	Do.
Silver ounces to the ton	2.00	6.4	Do.
Gold do	0.10	0.008	Do.
Iron per cent	11	3	Some.
Sulphur do	13	8.5	Do.
Arsenic do	About 0.4	Negligible	
Antimony do	About 0.04	do	
Silica do	58	56	About 2.
Alumina do	8	5	Negligible.
Lime do	0.6	1.4	Do.
Manganese do			30 to 38.

The copper and lead-zinc ores are treated separately, metallic copper, metallic zinc, and metallic lead being the end products. The concentrating processes, except for lead smelting, are carried on under one general supervision and within one inclosure at Anaconda. Raw copper is further refined at Great Falls, and finished copper wire is manufactured. Some zinc is electrolytically refined at Great Falls and at Anaconda. (See pl. 4.)

Morrow and Bender (15) give an excellent description of the processes carried on at Anaconda in 1929.

BIBLIOGRAPHY

1. Agar, W. M., Minerals of the intermediate zone, Butte, Montana: Econ. eology, vol. 21, pp. 695–707, 1926.

2. Atwood, W. W., The physiographic conditions at Butte, Montana, and Bingham Canyon, Utah, when the copper ores in these districts were enriched: Econ. Geology, vol. 11, pp. 697–740, 1916.

3. Bacorn, F. W., An amendment to Sales's theory of ore deposition: Am. Inst. Min. Eng. Trans., vol. 49, pp. 300–306, 1915.

4. Bard, D. C., and Gidel, M. H., Mineral associations at Butte, Montana: Am. Inst. Min. Eng. Trans., vol. 46, pp. 123–127, 1914.

5. Billingsley, Paul, The Boulder batholith of Montana [discussion of ore deposits]: Am. Inst. Min. Eng. Trans., vol. 51, pp. 31–56, 1916.

6. Braden, William, Certain conditions in veins and faults in Butte, Montana: Canadian Min. Inst. Jour., vol. 5, pp. 296–308, 1902.

7. Brown, R. G., The ore deposits of Butte City: Am. Inst. Min. Eng. Trans., vol. 24, pp. 543–558, 1915.

8. Daly, W. B., and others, Mining methods in the Butte district [including an account of the geology]: Am. Inst. Min. and Met. Eng. Trans., preprint 1225, 55 pp., 1923.

9. Emmons, S. F., Notes on the geology of Butte, Montana: Am. Inst. Min. Eng. Trans., vol. 16, pp. 49–62, 1887.

10. Emmons, S. F., and Tower, G. W., Jr., Economic geology: U. S. Geol. Survey Geol. Atlas, Butte special folio (No. 38), 1897.

11. Kirk, C. T., Conditions of mineralization in the copper veins at Butte, Montana: Econ. Geology, vol. 7, pp. 35–82, 1912.

12. Lindgren, Waldemar, Paragenesis of minerals in the Butte veins: Econ. Geology, vol. 22, pp. 304–307, 1927.

13. Linforth, F. A., Applied geology in the Butte mines: Am. Inst. Min. Eng. Trans., vol. 46, 110–122, 1914.

14. Locke, Augustus, Hall, D. A., and Short, M. N., Rôle of secondary enrichment in genesis of Butte chalcocite: Am. Inst. Min. and Met. Eng. Trans., vol. 70, pp. 933–963, 1924.

15. Morrow, B. X., and Bender, L. V., Both copper and zinc ores treated by selective flotation: Eng. and Min. Jour., vol. 128, pp. 295–302,1929.

16. Ray, J. C., Paragenesis of the ore minerals in the Butte district, Montana: Econ. Geology, vol. 9, pp. 463–481, 1914.

17. Rogers, A. F., Upward secondary sulphide enrichment and chalcocite formation at Butte, Montana: Econ. Geology, vol. 8, pp. 781–794, 1913.

18. Sales, R. H., The localization of values in ore bodies and the occurrence of shoots in metalliferous deposits; ore shoots at Butte, Montana: Econ. Geology, vol. 3, pp. 326–331, 1908; Eng. and Min. Jour., vol. 86, pp. 226–227, 1908.

19. Sales, R. H., Superficial alteration of the Butte veins: Econ. Geology, vol. 5, pp. 15–21, 1910.

20. Sales, R. H., Ore deposits at Butte, Montana: Am. Inst. Min. Eng. Trans., vol. 46, pp. 3–109, 1914.

21. Thompson, A. P., The occurrence of covellite at Butte, Montana (with discussions): Am. Inst. Min. Eng. Trans., vol. 52, pp. 563–603, 1916.

22. Weed, W. H., Geology and ore deposits of the Butte district, Montana: U. S. Geol. Survey Prof. Paper 74, 262 pp., 1912.