COPPER.

THE OCCURRENCE OF COPPER IN SHASTA COUNTY, CALIFORNIA.[a]

By L. C. GRATON.

INTRODUCTION.

LOCATION.

Shasta County lies just south of the northernmost tier of counties in California, about midway between the eastern and western boundaries of the State. The Shasta County copper region is a somewhat ill-defined area lying near the middle of the western half of the county, 80 to 100 miles east of the Pacific and at about the latitude of New York City. It is included within meridians 122° and 122° 33′ west longitude and parallels 40° 37′ and 40° 50′ north latitude. Next to the Lake Superior district of Michigan it is areally the largest copper region in the United States that can be regarded as a geologic unit. As commonly described, it is a narrow curved belt, convex toward the north, popularly known as the "copper crescent." From tip to tip this bow measures about 25 miles in a direction but little north of east, but the length measured along the curve is nearly 35 miles. In reality this "crescent" or "belt" is simply the locus of a number of deposits or groups of deposits, separated by stretches in which important deposits of copper are not known and throughout most of which such deposits probably do not exist. It is more exact, therefore, to regard the belt, so far as now developed, as a number of detached camps or districts which, more by chance than because of

[a] This paper contains a preliminary statement of the salient features of the Shasta County copper region and of some of the general conclusions already reached, and has been presented, in response to a request by the Geological Survey, in advance of a detailed geologic report now being prepared. It should be borne in mind that although the conclusions herein expressed are for the most part well established by evidence to be presented later, they are not necessarily final and are subject to any modification that may be found necessary as the result of additional study now in progress.

any evident geologic conditions, are situated on a curve. (See fig. 5.) At the west end of this curve are the deposits that extend in a northeasterly direction from Iron Mountain beyond Little Backbone Creek, a distance of about 8 miles; near the middle are the deposits

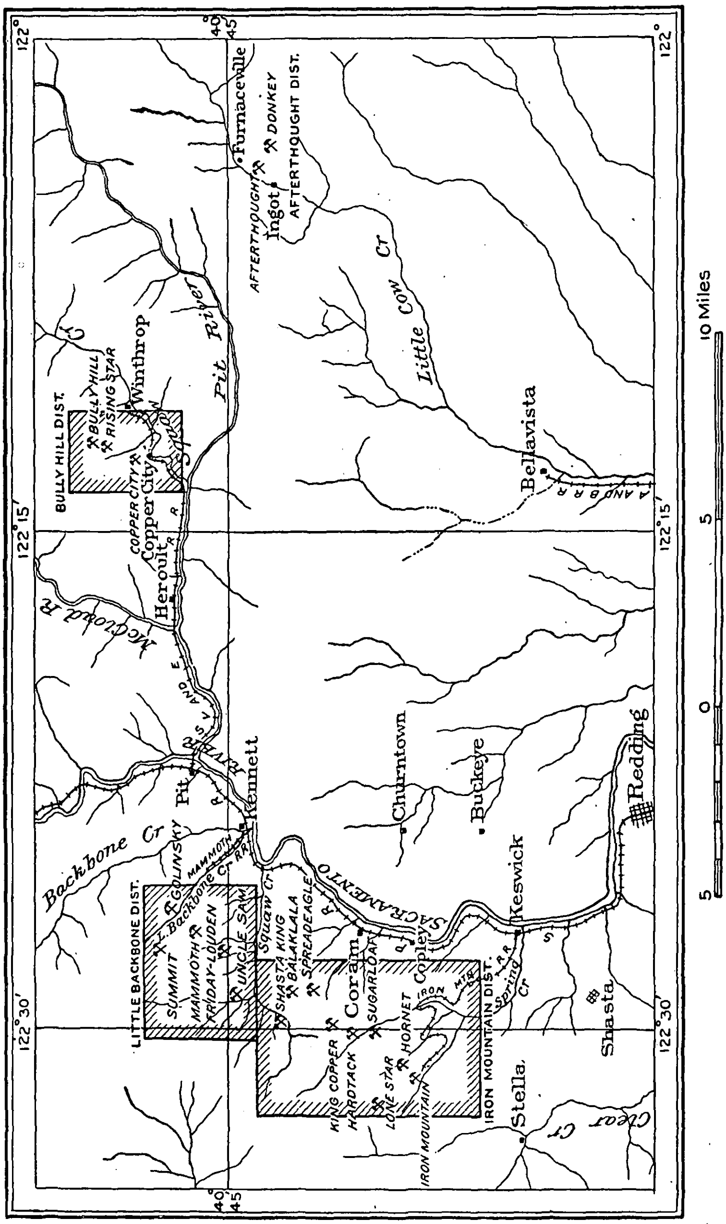

FIGURE 5.—Sketch map of copper region of Shasta County, Cal.

of Bully Hill and Copper City; and on the east are the deposits of the Afterthought district, near Ingot. More or less prospecting has been done at some intervening points.

There is also a common division of the district into two parts, one east of Sacramento River and one west. This division is useful for purposes of geographic description, but although there are certain differences in the deposits characteristic of opposite sides of the Sacramento, this distinction is often exaggerated.

Redding, the county seat and the principal town of the region, with a population of about 4,000, is the chief distributing point for the mines. It is about 10 miles southeast of the west end of the "crescent" and 20 miles southwest of the east end. Other important settlements have sprung up near the chief mines and smelters; among these are Keswick (now largely deserted), Coram, Kennett, Copper City, Winthrop, and Ingot. The Portland branch of the Southern Pacific Railroad crosses the western part of the region and provides outlet for the smelting towns of Keswick, Coram, and Kennett, and indirectly for the mines on the west side of the Sacramento. Two companies, the Mountain and the Mammoth, have built private railroad lines connecting their mines with their smelting plants, located respectively at Keswick and Kennett; one of these, the Mammoth, and one other, the Balaklala (which also transports for the Trinity Company), connect mine and smelter with aerial tramways. The Bully Hill and Afterthought districts have been served by the Anderson and Bellavista Railroad, a private branch from the Southern Pacific which terminates at Bellavista, from which these districts are, respectively, 15 and 12 miles distant. The Sacramento Valley and Eastern Railroad, recently completed, now gives to the mines and smelter of the Bully Hill district direct connection with the Southern Pacific; and the principal company in the Afterthought camp, it is understood, hopes soon to extend the Anderson and Bellavista line to its property.

The heavy precipitation of the rainy season of winter and early spring acts as a serious impediment to the mines dependent on wagon transportation, but in other respects the climate is on the whole favorable to efficient operation, the temperature being moderate and snowfalls light and of short duration. Abundant power is available from the streams and has been utilized to a considerable extent, through the medium of electricity, for mining operations and for other purposes. Timber for building and for use in the mines is still plentiful in the surrounding neighborhood.

HISTORY.

Mining in Shasta County began in the early fifties of last century. As in most other mining regions of California, deposits of placer gold were the first to be worked. Shortly afterwards quartz veins and other deposits in place began to receive attention, and with the early exhaustion of the richest placers, lode mining assumed first importance. The mining of precious metals still continues in a state of fluctuating activity, especially in the western part of the county.

Lode mining had hardly begun when it was recognized that at certain places copper occurs with the gold and silver. Probably the first place where the importance of this fact was realized was Copper City, in the Bully Hill district, from which shipments of gold-silver-copper ore were made in the early sixties. Though placer mining had been done on the slope below what is now the Bully Hill mine as early as 1853, it was not until the seventies that lode mining was attempted there, and even then most of the copper present (probably a considerable percentage of the ore) was wasted, as precious metals only were being sought. At about the same time similar attempts were made to work deposits in the Afterthought district. What was probably the first smelter in the region was erected there in 1875. About 1879 parts of the great gossan mass on Iron Mountain were found to give high assays for silver; at this place was opened the first really successful mine of those which have since become important as copper mines.

At a number of these places development had shown the presence of masses of sulphides lying beneath the ores then worked, but because of their lower grade and "refractory" nature little attention was bestowed on them for several years. In 1895, however, a company, now the Mountain Copper Company (Limited), secured the Iron Mountain property and began active development of the sulphide ore body. This really marks the beginning of the copper industry in Shasta County. A smelter was erected at Keswick, near the mine, and began operation early in 1896. Litigation over fumes from the smelting operations caused the company to erect a new smelter and refinery on San Francisco Bay and in 1905 to abandon smelting at its Keswick plant. In 1895 operations were resumed on the rich copper-silver ores at Bully Hill, and in 1901 a smelter was blown in. The principal mines in the Bully Hill district are now the property of the Bully Hill Copper Mining and Smelting Company, which is controlled by the General Electric Company. A small smelter was erected at Ingot, in the Afterthought district, in 1896. In 1905 a larger smelter was put into operation, but it is now idle. Development had been carried on for some time on sulphide masses at the Mammoth property, in the Little Backbone district, when in 1904 the mine was purchased by the Mammoth Copper Mining Company, a subsidiary company of the United States Smelting, Refining and Mining Company. A smelter was blown in at Kennett in 1905. In 1908 smelting was begun at the Balaklala plant at Coram, which was designed to treat the ore found in large bodies in the Balaklala and Shasta King mines. The Bully Hill and Mammoth smelters have been recently enlarged.

Large tonnages of ore have been developed in the mines of the Mammoth, Mountain, Bully Hill, Balaklala, and Trinity (Shasta King) companies, and it is understood that developments since the beginning of 1908 have added important reserves in the mines of at least the first four of these companies. Prospecting and development have been carried on at a number of other properties, and some of them have produced.

The total copper production of the region up to the end of 1909 has probably not been less than 300,000,000 pounds, by far the greater part of which has been produced since 1896. The production for 1909 is about 50,000,000 pounds, the largest annual output ever recorded. This makes the region rank as the sixth or seventh district in copper production in the United States, being exceeded only by Butte, Lake Superior, Bisbee, Bingham, Morenci, and possibly Ely.

FIELD INVESTIGATIONS.

The importance of the general region in which the Shasta County copper deposits are located as a field where much light might be gained on the preplexing problems of Pacific coast geology was long ago recognized. Geologic investigation in this region began as early as 1840 and to an increasing extent has continued up to the present time. Many workers have contributed to the knowledge that has been acquired and only the limitations of this preliminary statement prevent acknowledgment of the obligations to them under which the present study has been pursued. Even the briefest reference to the geology of this region must, however, recognize the contributions of J. S. Diller. Extending over a period of twenty-five years, his investigations have yielded a great fund of information concerning the geology of northern California. His description of the Redding quadrangle,[a] which includes nearly the whole of the copper district, was published in 1906. The rocks of that area contain, as he says, a more complete record of the geologic history of northern California than has thus far been found in any other similar area; yet their significance could have been grasped so comprehensively only by one who was able to study them in the light of intimate acquaintance with conditions throughout the surrounding country.

Realizing the importance of the copper deposits of this region, the United States Geological Survey undertook an investigation of their character in somewhat greater detail than was practicable in the areal work for the Redding folio, the maps in which are on a scale of 2 miles to the inch. Special topographic maps on a scale of 1:20,000, or a little over 3 inches to the mile, were made of the three most important copper districts—the Iron Mountain, the Little Backbone, and

[a] Redding folio (No. 138), Geol. Atlas U. S., U. S. Geol. Survey, 1906.

the Bully Hill. (See fig. 5.) To the writer was assigned the geologic mapping of these special areas and the study of the copper deposits. Field work was carried on during the late summer and fall of 1906. In the summer of 1907 B. S. Butler accomplished most of the mapping of the Iron Mountain and Little Backbone areas and sketched the surface geology of the Afterthought district. Underground investigations were resumed by the writer in the fall of that year and were completed by its close. The conclusions presented in this paper are therefore based only on developments up to January 1, 1908.

Although the advantages of examination in detail which the more recent work enjoyed have permitted a revision of Mr. Diller's results in one or two respects, nevertheless the main structure of his conclusions remains unassailed, and the present writer is glad of this opportunity to indorse the splendid character of his work in the Redding quadrangle, performed in the face of physical obstacles and difficulties that must be experienced to be appreciated. To Mr. Butler's careful work in the field and in the office are to be credited many of the statements found here regarding petrology and the general geology of the areas west of the Sacramento.

It is at once a duty and a pleasure to mention at this place the assistance afforded in furtherance of this investigation by officers of mining companies and by others residing in the region. For the full report must be reserved more appropriate and specific acknowledgment of this generous cooperation.

TOPOGRAPHY.

GENERAL STATEMENT.

The Shasta County copper region lies near the southeastern border of an irregular and somewhat indefinite topographic province known as the Klamath Mountains. This province, consisting of several larger ranges and many groups of ridges and hills, occupies a large area in northern California and southwestern Oregon. It lies between the Coast Ranges on the west and the Cascade Range on the east—both more sharply defined provinces than the Klamath Mountains. On the southeast it breaks off rather abruptly to the great Sacramento Valley. The copper region lies among irregular groups of low mountains or high hills near the boundary with the Sacramento Valley province; the so-called copper crescent is roughly parallel with and at a distance of 5 to 10 miles from the north end of the valley. The eastern part of the region, represented by the Afterthought camp, is to be regarded as just outside of the Klamath Mountains and as comprised within the border portion of the broad and gently sloping constructional plain that flanks the western slope of the Cascade Range at this latitude. This plain has been called by Diller the piedmont plateau.

It is of interest to note that the fifth great topographic province of northern California, the Sierra Nevada, situated along the southeastern continuation of the Cascade Range axis, has probably many points of similarity, both as to geology and as to topographic development, with the portion of the Klamath Mountains here considered. It is also worthy of remark that the "gold belt" on the western slope of the Sierra, in which are located the Mother Lode and many other important mining districts, would, if projected farther to the northwest, cross the Shasta County copper region.

RELIEF.

The surface of most of the region is irregular and rough. The highest point in the three districts of which special maps were made is located in the northwest corner of the Iron Mountain area and has an elevation of about 4,550 feet. The lowest point mapped is in the same area about a mile north of its southeast corner, where the elevation is under 650 feet. Sacramento River, which lies outside the Iron Mountain area just east of this low point, has here an elevation of about 550 feet. The maximum difference of elevation in the copper region is therefore about 4,000 feet. In the Little Backbone area, which adjoins the Iron Mountain district on the northeast, the elevations range from about 700 feet at the southeast corner of the area to about 4,450 feet at Bohemotash Mountain, near the northern boundary. In the Bully Hill district the extremes of elevation are about 740 feet along Squaw Creek, near the southwest corner, and about 2,800 feet on the western slope of Horse Mountain, which, just west of the area mapped, rises to a height of 4,040 feet; almost the same elevation is attained at the northern boundary of the Bully Hill area on the southern slope of Town Mountain, whose summit, a little farther north, is 4,339 feet high. In the Afterthought district the presence of the Cascade Range piedmont plateau is indicated by a much lower range of elevations, the mines being situated about 1,200 to 1,600 feet above sea level.

The portion of the region west of the Sacramento is, on the whole, extremely rugged. Most of the higher elevations have rounded tops, and there is little tendency to form sharp peaks. The middle and especially the lower slopes of the mountains, however, are in most places very steep, forming the walls of deep, V-shaped canyons. From a number of the highest mountains extend one or more long spurs. Some of these spurs connect two or more important eminences, forming prominent ridges; others gradually decline and broaden into flanking hills. Though marked generally by crests and saddles, the tops of these spurs and ridges are of comparatively even and moderate grade and have therefore been chosen, in preference to the more circuitous and rugged valleys, as the sites for trails and roads, except where it has been possible to spend much money in the production of more even grades for roads and railroads by blasting, filling, trestles, etc. These spurs and ridges are a characteristic feature of the topography of the western districts. Iron Mountain and Little Backbone Mountain are prominent elevations, from which the districts have been named.

The greater part of the Bully Hill district consists of a scoop-shaped surface tilted toward the southeast, formed by the coalescing east and south slopes of Horse and Town mountains, respectively. Of the irregularities of this surface Bully Hill is the most prominent.

The principal workings in the Afterthought district lie along the wall of a valley cut in the piedmont plain.

DRAINAGE.

The region lies wholly within the drainage basin of Sacramento River, which is formed, near the middle of the region, by the confluence of the Pit from the east and the Little Sacramento from the north. Important tributaries to Pit River from the north are McCloud River and, farther east, cutting through the Bully Hill district, Squaw Creek. Little Backbone Creek flows southeastward into the Sacramento, and near the northern boundary of the Iron Mountain district Squaw Creek (a different stream from the one tributary to the Pit) also empties into the Sacramento from the west. Spring Creek flows southward through the Iron Mountain district and meets the Sacramento at Keswick. A small part of the Iron Mountain district is drained westward into Clear Creek, which reaches the Sacramento about 5 miles south of Redding. Little Cow Creek cuts into the piedmont plain in the Afterthought district. These streams, together with many of smaller importance, effect a thorough drainage of the region and have served to carve its present rugged features.

The development of the present topography by the erosive and aggrading power of the streams under conditions of stability or of uplift or depression of the land, and in relation to the rocks traversed, has been considered for this region especially by Diller, but this subject need not demand further attention at this place.

GENERAL GEOLOGY.

INTRODUCTORY STATEMENT.

The rocks of the Redding region outside of the Sacramento Valley province comprise a considerable number of sedimentary formations ranging in age from Middle Devonian to late Tertiary, inclusive. In this region the basement on which these sediments are supposed to have been deposited is an ancient lava formation, consisting of altered andesite, probably of early Devonian or still greater age. The various sedimentary formations extend in roughly parallel belts in a northerly direction corresponding to their strike or the intersection of their bedding planes with a horizontal plane; the dip of these stratification planes is commonly to the east, as it is in the western Sierra Nevada, farther southeast, so that the oldest rocks are at the west and the youngest ones at the east. Interbedded with the ordinary sedimentary rocks—which consist of limestones, sandstones, and shales, with some conglomerates—and forming essentially a part of the stratified series are many beds of tuff or fragmental igneous rock, formed by explosive volcanic outbursts, and some lavas of more massive character. These products of volcanic eruption constitute the oldest and the youngest rocks of the region and were also formed in nearly every intervening period. In few other regions does there exist evidence of the persistent recurrence of volcanic activity over such long eras of time.

The relations of the various members of the stratified series have been modified and complicated by the intrusion into them of several kinds of igneous rocks in various forms, comprising stocks, dikes, and sills. The surface relations have been further obscured in some places by coverings of lava of much later age than most of the rocks.

The copper region, viewed as a unit, crosses the strike of the sedimentary rocks and contains representatives of nearly every one of the formations outlined above. For a thorough understanding of the geology of the region it would be necessary to have some description of the full stratigraphic sequence, but, although copper is known to occur in some other formations, the present article will deal only with those rocks that are found within the four principal districts of the copper region—Iron Mountain, Little Backbone, Bully Hill, and Afterthought.

SEDIMENTARY ROCKS.

KENNETT FORMATION.

The Kennett formation consists chiefly of black fissile shale, with scattered lenses of light-gray limestone that stand out strikingly and numerous gray or yellowish beds of tuffaceous material. From abundant fossils contained in the limestone the age of the formation is determined as Middle Devonian. It occurs only as irregular, separated erosion remnants of what was once probably a large and continuous sheet. Its maximum known thickness is 865 feet, but at most places it is much thinner. Within the areas considered it is present only in the eastern part of the Little Backbone district. Some of the largest masses occupy the crests of spurs or ridges, but others are well down the slopes and were evidently entirely inclosed in the adjoining rock, alaskite porphyry, until revealed by erosion. The Kennett formation has no connection with known copper deposits, though small blocks of it are encountered in the workings of one of the mines, the Mammoth.

BRAGDON FORMATION.

The Bragdon formation consists chiefly of black and gray shales, with thin interbedded layers of tuff and sandstone, and especially in its lower portion as exposed in this region, bands of conglomerate. The Bragdon is known to overlie the Kennett unconformably, but in the special areas mapped the two formations are not adjacent, the Bragdon resting everywhere in a tilted position on the alaskite porphyry. The conglomerate contains many fragments of the Kennett formation and also of the basal altered andesite, though within the areas of the special maps none but sedimentary fragments were observed. Fossils found in the shale and sandstone beds show the age of the Bragdon to be Mississippian, or lower Carboniferous. The formation is present in the northwest corner of both the Little Backbone and Iron Mountain areas, but the Bragdon rocks at these places are only parts of the thinning edge of a large mass several thousand feet thick that extends northward and westward for several miles. Patches of shale or tuff probably belonging to this formation are included in the alaskite porphyry, as for instance near the summit of Iron Mountain. In only one place is the Bragdon connected with copper deposits; at the Lone Star claim, near the western edge of the Iron Mountain area, copper ore is found along the contact of Bragdon shale and alaskite porphyry, the ore occurring in both rocks.

PIT FORMATION.

Like the two formations already described, the Pit formation consists chiefly of shales, black to gray in color and mostly of fine grain. It also contains in considerable abundance interbedded layers of volcanic tuff. Fossils are not common, but such as have been found indicate that the rocks were deposited in the later half of the Triassic period. The total thickness is believed to be over 2,000 feet, but only a part of the formation is present in the mining districts. Rocks of this formation occur in the Bully Hill district as large and small blocks resting upon or partly embedded in the alaskite porphyry. A similar relation exists in the Afterthought district. Copper ore occurs in the shale only in the Afterthought district, where the ores extend from the alaskite porphyry into the shale. Small blocks of the shale are also found in the Bully Hill mine, but are not related to any known ore bodies.

IGNEOUS ROCKS.

META-ANDESITE.

A dark-greenish rock of andesitic nature, but considerably altered from its original composition, and therefore called meta-andesite, occurs over a considerable area in the southeastern part of the Iron Mountain district and in smaller patches in the southwestern and northeastern parts. It has been named the Copley meta-andesite by Diller. It was a series of flows of porous or cellular lava, but in general the individual flows are not evident within the Iron Mountain district, and most of the cells have been filled with secondary minerals, principally quartz, epidote, chlorite, and calcite, giving rise to an amygdaloidal structure. Beds of tuff occur sparingly and in places the massive lava has been brecciated. Its age can not be determined from data gained within the Iron Mountain or Little Backbone areas, but from observations elsewhere Diller finds that it is older than Middle Devonian, as it underlies both the Kennett and the Bragdon formations and by its erosion has furnished part of the material of which they are composed. No known copper deposits occur in this rock, but it is cut by numerous quartz veins, some of which carry gold in commercial quantity.

ANDESITE.

The greater part of Horse and Town mountains, near the Bully Hill district, as well as of other mountains farther north, is composed of a dark-greenish rock having the composition of andesite. It has been named Dekkas andesite by Diller. It is generally rather massive and in many places is distinctly porphyritic, containing many small light-colored feldspar crystals in a dark-green, fine-grained groundmass. Here and there, however, scoriaceous and tuffaceous varieties are seen and indicate the surficial character of the rock. The formation unconformably overlies upper Carboniferous rocks and underlies and in part grades into the tuffs and shales of the Pit formation; it is therefore regarded as of early Triassic age. Its maximum thickness is about 1,000 feet, but considerably less than this is exposed in the Bully Hill district, whose northern and northwestern parts it occupies in irregular masses. Some prospecting has been done in this rock in the northern and western parts of the district and copper minerals are known to occur in it on the east side of the saddle between Horse and Town mountains, but in general it does not hold an important relation to the copper deposits.

ALASKITE PORPHYRY.

A rock of porphyritic texture and of a composition rather similar to that of granite occurs in two general localities in the copper region and has been named alaskite porphyry. It holds sparingly small phenocrysts of quartz and feldspar in a predominant groundmass that, when fresh, is of dark-gray color, but in most places in the region the rock of this type is considerably altered and is bleached to lighter shades of gray, green, yellow, or pink. It is also much cut by joints and shearing planes. It weathers generally in rough, bold outcrops and forms steep slopes on which little soil from the complete disintegration of the rock can accumulate. Rock of this type is intimately associated with all the known copper deposits of importance and for that reason it merits rather fuller description than the other rocks.

From the results of examination in a degree of detail commensurate with folio mapping on a scale of 2 miles to the inch, Diller concluded that these rocks were surface flows and were therefore necessarily older than the overlying sedimentary formations, though from his various published statements regarding these relations it may be inferred that such a conclusion was not reached without some hesitation. Because of their composition he called them rhyolite; the mass west of the Sacramento, which extends northeastward through the middle of the Iron Mountain and Little Backbone districts, he named the "Balaklala rhyolite," and the group of irregular masses that reaches from the Bully Hill district to the Afterthought district he named the "Bully Hill rhyolite." The "Balaklala rhyolite" he considered as underlying, and therefore older than the Kennett formation (Middle Devonian). The "Bully Hill rhyolite" he regarded as generally underlying the Pit formation (Middle or late Triassic), though in places it cuts the Pit rocks; he placed it as older than the uppermost Triassic.

The more recent study, enjoying opportunity for examination in much greater detail and profiting by the final conclusions of Diller's investigation, has resulted in some modification of the views outlined above. It now appears that the rocks of both the "Balaklala" and "Bully Hill" types are intrusive [a] into the surrounding rocks. The direct evidence of this intrusive nature of the alaskite porphyry may be summarized as follows: (1) Dikes, sills, and other intrusive masses of it cut the surrounding rocks—the Copley meta-andesite and the Devonian (Kennett) and Carboniferous (Bragdon) sediments in the western districts and the Dekkas andesite and the Triassic (Pit) sediments in the eastern districts. (2) At many places along the contact with other rocks the alaskite porphyry is of finer grain than elsewhere. (3) The overlying or adjoining rocks are brecciated at many places along the contact with the alaskite porphyry and at most such points the shales [b] are indurated and more or less metamorphosed.

[a] This view had previously been implied by H. W. Fairbanks (Rept. California State Min. Bur., vol. 11, 1892, pp. 32, 46, etc.).

[b] At all points within the special areas studied the limestones of the Kennett formation are separated from the alaskite porphyry by a considerable thickness of shale, and doubtless for this reason no positive evidence of contact metamorphism has been found in the limestone.

(4) Masses of the surrounding formations are inclosed in the alaskite porphyry. These masses were evidently torn from the main bodies of the corresponding rocks by the invading alaskite porphyry magma and were enveloped in it before it solidified; such included masses consist both of large blocks, several thousand square feet in area, and of much smaller bodies, ranging down to small included fragments of shale where that rock has been brecciated at the contact with the alaskite porphyry. (5) In places the sedimentary formations have been distorted by the intrusive masses of alaskite porphyry and forced into forms that, before erosion, were doubtless arches or domes. (6) The rock is holocrystalline, no glass nor its devitrified equivalent having been found in the scores of thin sections examined from many localities; and it would seem unnatural for a rock so high in silica and so low in bivalent bases to develop holocrystalline texture throughout if it were of surface origin. Indirect evidence pointing in the same direction is afforded by the close relation as to age and source that is believed to exist between the alaskite porphyry and a rock, quartz diorite, concerning whose intrusive nature there is no question.

The recent investigation also shows that the rock in the Iron Mountain and Little Backbone districts is practically indentical in all respects with that in the Bully Hill and Afterthought districts. Almost every statement concerning the rock of the one locality would apply equally well to that of the other. The identity is strongly indicated by field relations and megascopic character and is established beyond doubt by the results of microscopic and chemical investigation. The unusual chemical character of the rock and the similar character of the masses in the eastern and western sections of the region may be shown by analyses 1 and 2 following, which were made by George Steiger on typical specimens of the freshest material. Analyses 3 and 4 represent alaskite from other regions.

Analyses of alaskite porphyry.

	1.	2.	3.	4.		1.	2.	3.	4.
SiO_2	80.09	78.50	77.33	76.04	ZrO_2	.01	None.	....	....
Al_2O_3	10.80	11.50	12.55	....	CO_2	None.	None.	Nonc.	....
Fe_2O_3	1.07	.11	} .91	....	P_2O_5	.04	.03	Trace.	....
FeO	.83	1.82	}	....	SO_3	None.	None.	....	....
MgO	.58	.46	.10	....	S	None.	.13	....	....
CaO	.38	.50	.17	.46	MnO	.02	.03	Trace.	....
Na_2O	5.60	6.04	3.19	7.58	BaO	None.	None.	Trace.	....
K_2O	None.	None.	4.80	.07	SrO	None.	None.	Trace.	....
H_2O-	.24	.30	.15	....	Li_2O	....	....	Trace.	....
H_2O+	.52	.82	.53	....					
TiO_2	.16	.27	.09	....		100.34	100.51	99.82	

1. Dark-gray alaskite porphyry from surface above Shasta King mine, Iron Mountain district.
2. Dark-gray alaskite porphyry from point near main tunnel, Bully Hill mine, Bully Hill district.
3. Alaskite from Tordrillo Mountains, Alaska. H. N. Stokes, analyst. Spurr, J. E., Am. Geologist, vol. 25, 1900, p. 231.
4. Alaskite from Silver Peak district, Nevada. Partial analysis made for H. W. Turner by George Steiger and cited by Spurr, J. E., Prof. Paper, U. S. Geol. Survey, No. 55, 1906, p. 23.

These and other analyses show that the rock is of fairly constant composition over wide areas, though here and there occur transitions to another type, as will be shown shortly. The particularly noteworthy features in the composition of these rocks are comparatively high soda, potash very low or entirely wanting, low magnesia and iron, and generally low lime, though this last-named constituent is more variable than the others. Calculation of the analyses shows that quartz and feldspar together make up between 92 and 95 per cent of the rock, the feldspar generally predominating slightly. The feldspar is mostly albite, the percentage of calcium feldspar being usually very low. The rock may be considered as a silica-rich granite porphyry in which the customary potash feldspar (orthoclase) is replaced by soda feldspar (albite). It appears to correspond most closely, however, to the type alaskite established by Spurr [a] and defined as consisting essentially of quartz and alkali feldspar with but small amounts of other minerals. The rocks originally given the name alaskite by Spurr all contain an important percentage of potash, along with soda, but there seems to be nothing in his definition that would exclude quartz-feldspar rocks in which the feldspar is chiefly albite, and he later included in the group the rock from Silver Peak (see analysis 4), in which the soda is high and the potash very low.

The phenocrysts of the rock, consisting of quartz, albite, and rarely oligoclase-albite, are generally of small size, though in a few places they may attain a diameter of one-quarter inch or even more; in such places the groundmass also commonly increases in coarseness. Much of the albite is untwinned. The fine-grained groundmass consists of a microgranular mixture of quartz and feldspar, part of which is twinned and part untwinned. Fine shreddy grains of magnetite and small particles of chlorite and of epidote that were probably derived from original flakes of biotite constitute the chief accessory constituents, but are nowhere present in important amounts. Apatite, titanite, and zircon exist sparingly as small crystals. Though of comparatively constant composition, the rock is somewhat variable in texture and appearance, especially in the area west of the Sacramento. For the most part it is distinctly porphyritic and in places is of fairly coarse grain, but locally it is dense and fine grained, doubtless as a result of differences in conditions of solidification. The chief differences in the appearance of the rock at various points, however, are the result of secondary causes. Over large areas the rock is much sheared and differences of alteration and weathering, emphasized by and partly dependent on this shearing, give it in places a banded aspect. These variations in appearance somewhat resemble those of a series of lava beds but are of different origin.

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[a] Spurr, J. E., Am. Geologist, vol. 25, 1900, p. 231.

As the alaskite porphyry is intrusive, its age is not necessarily fixed by that of the surrounding rocks. As the different bodies are without doubt products of eruption from a single magmatic source and within the same general period of time, and as in places the porphyry cuts upper Triassic sediments, it follows that the rock as a whole is at least as young as upper Triassic. Direct stratigraphic evidence further limiting its age is not found in the copper districts and probably is not present in the Redding region, but on the grounds of petrologic relationship with the quartz diorite, next to be described, which is believed to have been intruded soon after the alaskite porphyry and whose age is somewhat more readily inferred, it is thought by the writer that the intrusion of the alaskite porphyry, as well as of the quartz diorite and certain other rocks of the general region, were events that brought the Jurassic period to a close. This view would seem to gain support from generally analogous conditions existing in the Sierra Nevada.

The alaskite porphyry is the country rock of all the important copper deposits except in the few places where the ore bodies extend beyond its confines into adjoining shales. The economic significance of the fact that the rock exists as intrusive masses instead of as bedded flows will later be referred to.

QUARTZ DIORITE.

A rock which resembles granite in appearance but whose feldspars are almost entirely of the soda-lime series forms an important mass in the southeast corner of the Iron Mountain district and extends in greater area farther south. It disintegrates rather readily and forms a granular soil on slopes that are gentler and smoother than those which characterize the alaskite porphyry.

The rock is very similar in appearance to the coarser varieties of the alaskite porphyry, to all of which it shows chemical and mineralogical affinities. It cuts the alaskite porphyry, but the contact is in general difficult of precise location because of transitional facies near the boundary. It is believed that the quartz diorite was a later and somewhat differentiated product of eruption from the same general magmatic source that furnished the alaskite porphyry, but that its intrusion so closely followed that of the porphyritic rock that it found the region to which it ascended in a somewhat heated condition and therefore, cooling more slowly, it developed coarser and more even grain than its older and more siliceous porphyritic relative. It is regarded as significant, also, that the coarsest of the alaskite porphyry, in the vicinity of the Uncle Sam mine and elsewhere, which is wholly impossible of separation from the normal variety surrounding it, is closely similar in appearance and mode of weathering to the quartz diorite (though the extent of alteration at most of these places prevents absolute proof of further identity by microscopical or chemical means) and is characterized, as is the quartz diorite itself, by the relative abundance in it of basic dikes and quartz veins as compared with the normal alaskite porphyry. Feldspar, quartz, and hornblende, stated in order of decreasing importance, are the chief components of the rock. Biotite may also have been present, but if so it has been completely altered. Most of the feldspar is so altered that the more precise methods of determination can not be applied to it. A considerable portion of it is unstriated and in extinction angle and refractive index corresponds to albite. Part of this contains, in microperthitic arrangement, a little orthoclase, which probably accounts for all the potash contained in the rock. Some of the twinned feldspar is also albite, but most of it appears to have a composition near andesine. Magnetite, titanite, and a little apatite are the accessory minerals.

Copper deposits are not known in the quartz diorite, but quartz veins occurring in it have been worked for gold at numerous places within and outside of the Iron Mountain area.

DIKE ROCKS.

Around the outskirts of the alaskite porphyry and the quartz diorite are dikes and sills similar in composition to these larger masses, of which they are but smaller branches or apophyses. In connection with the quartz diorite occur sparingly pegmatitic dikes of rather irregular form and somewhat more acidic character than the parent quartz diorite; these pegmatites in places pass over into siliceous masses that are virtually quartz veins and carry sulphides. Somewhat more common than the types already mentioned are dikes that cut either the quartz diorite and alaskite porphyry or the surrounding rocks, or both. Most of these dikes are dark, basic, and as a rule easily susceptible to weathering agencies. They range, however, from rocks with a composition close to that of the alaskite porphyry to rocks of very basic types consisting chiefly of ferromagnesian minerals, mainly pyroxene and augite. These extremes are connected by intervening types, and from both chemical and mineralogical considerations the dikes can best be regarded as a series of differentiation products from the magma that is most abundantly represented by the alaskite porphyry and the quartz diorite. As already implied, the basic dikes are most common in or near the quartz diorite and the quartz dioritic phase of the alaskite porphyry. In the Bully Hill mine the main ore zone parallels one of these basic dikes and at certain points the rock of the dike is more or less completely replaced by ore. In the Iron Mountain district quartz veins have formed at several places alongside of such dikes.

STRUCTURE AND METAMORPHISM.

GENERAL STRUCTURE.

In the copper districts alone satisfactory and adequate ideas of broad structural features could hardly be gained because of the relatively small areal importance of sedimentary rocks, by means of which structure is best revealed. The general structure of the region included within the Redding quadrangle is known, however, and aids greatly in interpreting the geologic relations in the vicinity of the copper deposits. As already outlined, the rocks of the Redding region have in general a northerly strike and a dip to the east, except where this simple structure has been modified by intrusion. It is believed that this eastward tilting of the strata was effected at about the close of the Jurassic period or at about the time of intrusion of the alaskite porphyry and quartz diorite. The shape which the masses of these intrusive rocks assumed was undoubtedly influenced by this generally conformable relation of the sedimentary rocks. Consequently, instead of forming stocks or batholiths that cut indiscriminately the various older rocks, the intrusive masses were limited in their upward invasion by certain thick and tough yet somewhat pliant shale formations which, in a broad way, were raised into domes or arches, though locally they were more or less shattered and surrounded by the intrusive rocks. Thus in the western districts the Kennett and Bragdon formations have been arched up by the alaskite porphyry, and in the eastern districts the Pit formation has been deformed by it. There is thus an approach toward laccolithic conditions, though it is not certain that true laccolith structure is present. A large part of the sedimentary rock entering into these structures has of course been later removed by erosion.

The possibility that the copper-bearing rock, alaskite porphyry, gives way at a comparatively shallow depth to some underlying and probably barren formation is a question of much economic significance. The chances that this actually takes place are much smaller if the alaskite porphyry exists as intrusive masses than if the rock consists of a series of flows, as is at present commonly believed in the copper region. There is no reason to suppose that the alaskite porphyry gives out at less depth than that to which mining—to judge from present developments—would naturally be carried. This statement probably applies especially to the districts west of the Sacramento.

Except for the bending of the strata caused by intrusion, as above noted, broad folding is uncommon and unimportant in the region, though minor plication of the shales is seen at numerous places. Faulting has little effect on the general structure of the rocks, but some faults are noteworthy because they displace ore bodies, and, as will be shown on a later page, many of the boundaries of the copper ore bodies may be related to faults.

METAMORPHISM AND MINOR STRUCTURE.

All the rocks of the copper region are more or less altered from their original condition, and many of them have suffered severely. The alteration has been brought about by both chemical and mechanical means and has taken place within the rock masses, as the result of deep-seated disturbance of chemical and mechanical equilibrium. Near the surface weathering has superimposed still further chemical alteration of the rocks.

The deep-seated alteration has most affected the igneous rocks, especially the alaskite porphyry. This rock is in most places so changed from its initial character that only rarely can material be found sufficiently fresh for reliable investigation and analysis. The mechanical or dynamic metamorphism resulted in brecciation, shearing, and the development of incipient gneissic or schistose structure.

As expressed by mineral development, the chemical change in the the alaskite porphyry consisted chiefly in the production of sericite,[a] secondary quartz, chlorite, metallic sulphides, carbonates, and epidote, stated in about the order of their importance over wide areas, but in and close to the copper ore bodies the proportions of these minerals are changed and some additional species, like barite and anhydrite, were developed. From the chemical work thus far completed it appears that the alteration results most commonly in a reduction of the silica content of the rock, with a corresponding increase in proportions of some of the oxides, most marked in alumina. The apparently paradoxical decrease in silica with increase in quartz may find explanation in the fact that in the transformation of albite into sericite a considerable amount of free silica is formed. In certain places a net gain in total silica results from the alteration. The original iron of the rock seems to be largely removed, but locally pyrite is introduced in varying amount. Almost invariably the percentage of magnesia is noticeably increased, though it nowhere reaches an important amount. This element seems to be added directly to the rock, mainly in the form of chlorite, though dolomitic carbonate is present in some specimens and may be, in very small quantities, more widespread than is evident. In general the small percentage of lime held in the rock is further reduced on alteration, but in and near the ore bodies calcite is rather plentiful. The high soda content of the fresh rock is much lowered by the alteration process; in its place potash is deposited, but not in quantity corresponding to the soda removed.

[a] Later work by B. S. Butler indicates that part of the shreddy or fibrous micaceous alteration product may be paragonite, the soda mica, which is analogous to the potash mica, sericite, the fibrous form of muscovite.

The percentage of combined water is of course higher in the altered than in the fresh rocks.

Both the chemical and the mechanical changes are believed to have connection with the intrusion of the alaskite porphyry itself; the solutions that brought about the change in composition are believed to have been residual mother liquors from which the alaskite porphyry, as well as the quartz diorite and the dikes, had already separated by crystallization, and the brecciation and shearing are believed to have resulted from stresses set up by contraction of the cooling rock mass, aided perhaps by adjustments that followed the transference of matter from one point to another when intrusion took place. The idea that the strains and movements closely followed the intrusion of the alaskite porphyry is supported by the facts that the shearing is largely confined to the alaskite porphyry itself, persisting but little in adjoining rocks, and that the quartz diorite and the dikes, whose intrusion is believed to have closely followed that of the alaskite porphyry, were nevertheless too late to participate to any important extent in these shearing movements.

The chemical and mechanical changes in the alaskite porphyry undoubtedly have intimate genetic connection with the deposits of copper ore, for the ore bodies are simply portions of the rock that have suffered extreme alteration, amounting locally to complete replacement of the rock by new minerals, chiefly sulphides; and this extreme alteration is believed to have been permitted by the shearing and crushing of the rock, which have not only afforded channels for the ingress of the altering and ore-bearing solutions, but also rendered the rock more susceptible to attack by these solutions. The material of the quartz veins is believed to have been derived from similar solutions. The localities of most vigorous metamorphism will be indicated and the processes themselves will receive further consideration in the discussion of the copper deposits.

In a lesser degree silicification, sericitization, pyritization, etc., have affected the quartz diorite also over large areas. In the andesite and meta-andesite the development of silica, carbonates, chlorite, and epidote has been most important. The partial metamorphism of the shales at the contacts with alaskite porphyry has already been mentioned.

THE COPPER DEPOSITS.

GENERAL FEATURES.

The important copper deposits of the Shasta County region consist of large masses of pyritic ore, surrounded in most places by alaskite porphyry but here and there extending into shale. The ores are of medium richness, yielding at present an average of about 3 to 3½ per cent of copper and $1.50 to $2 per ton in precious metals, generally about equally divided between gold and silver. The largest deposits have been found in the western half of the district, and some of these are among the great sulphide ore bodies of the world. Single ore masses have maximum dimensions of 1,200 feet in length, 300 feet in width, and nearly 300 feet in thickness. In few places is this maximum thickness attained, the average thickness being much smaller, though on the other hand some ore bodies of less than the maximum length are over 300 feet in width. As only 7 to 8 cubic feet of the massive sulphide ore in place is required to make a ton, it can readily be seen that these great ore bodies contain large tonnages; in several the tonnage runs into the millions, and the Iron Mountain ore body, before a great part of it was converted into gossan, probably contained at least 20,000,000 tons, exclusive of the unknown but necessarily large amount that has been eroded away. Masses of much smaller size also occur west of the Sacramento, and in the eastern districts, Bully Hill and Afterthought, smaller and less regular ore bodies are the rule.

In the rugged western districts tunnels afford convenient access to the ore bodies, most of which lie comparatively flat and within a few hundred feet of the surface. In the eastern districts, where the topography is more even and the ore deposits extend deeper, shafts are employed in addition to tunnels. The compact shape of most of the ore bodies allows development and operation with a minimum of drifting, and though some of the mines have thousands of feet of such openings, the amount in relation to the tonnage of ore opened is much lower than in many other districts. The deepest working in the district at the beginning of 1908 was the 970-foot level in the Bully Hill mine. At the present time (January 1, 1910) it is learned that both the Bully Hill and the Rising Star shafts have attained a depth of about 1,100 feet below the outcrops. In the largest ore bodies some of the cheaper mining methods, such as slicing and caving, have been generally adopted in place of the earlier system of square setting and filling. All of the ore is smelted without concentration and for the most part without roasting. Owing to the high percentage of sulphur contained in the ore, the coke required can be reduced to a much lower quantity than was used when roasting was employed.

The principal deposits are grouped in three localities or zones. One of these zones lies west of the Sacramento in the Iron Mountain and Little Backbone districts and includes, along a general northeasterly line, the Iron Mountain, Hornet, Balaklala, Shasta King, Mammoth, and Golinsky mines; at a number of other points along the same general belt either gossan or smaller masses of sulphide ore occur and at the Sugarloaf, Hardtack, King Copper, Spread Eagle, Friday-

Louden, and Summit properties they have received more or less development. A second zone extends a little east of north in the Bully Hill district and includes the Copper City, Rising Star, and Bully Hill mines, together with a number of prospects. The third zone, of smaller importance, includes the Afterthought and Donkey mines, in the Afterthought district. In the following pages only general features of the ore deposits of the region will be referred to, and no attempt whatever will be made to describe individual deposits in detail.

CHARACTER OF THE DEPOSITS.

DISTRIBUTION, SHAPE, AND STRUCTURE.

The ore bodies themselves are in general irregularly tabular. The larger number are of definite extent and, though for the most part very irregular, can best be referred to as lenses. Here and there, however, two or more of these bodies or lenses are present in the same general plane, which, outside of their confines, is more or less impregnated with minerals of the ore bodies and which might thus be regarded as a lode, of which the ore lenses constitute pay shoots.

All the ore bodies represent, not the filling of cavities existing before the entrance of the ore or developed during its formation, but rather a more or less complete replacement of the same kind of rock as that by which they are surrounded.[a] In this way the various components of the rock have been removed and their places occupied immediately by the minerals of the ore bodies. The evidences of this replacement are many and obvious. The most common and convincing are (1) the gradual transition from wall rock to solid sulphide ore observed in many places; of the same nature are the countless localities in the alaskite porphyry, both near and distant from masses of commercial ore, where the rock has been impregnated with sulphides or other minerals of the ore bodies, but not in sufficient amount to obscure its identity; (2) the presence in the ore of crushed fragments or remnants of wall rock only partly replaced, and of similar but larger masses or horses which for the most part have the same direction of shearing or schistosity as is shown in the main walls of the ore body and which doubtless therefore occupy the same position that they held before the introduction of the ore; (3) the retention at places in the ore of structure characteristic of the wall rock (pseudomorphous replacement); (4) the difficulty of conceiving how spaces, some of them hundreds of feet in every dimension, could have been formed and kept open even long enough for the ores to be deposited.

In the Iron Mountain ore body a specific and beautiful example proving replacement consists of massive sulphide ore in which the

[a] There are local exceptions to this in which basic dike rock and shale have been replaced.

phenocrysts or prominent crystals of quartz belonging to the alaskite porphyry are contained in their original condition and probably in their original position, but constitute the only portion or component of the rock not replaced by sulphides;[a] the same condition is seen in some of the gossan between the Iron Mountain and Hornet mines. Such occurrences, however, have not been observed at other parts of the region and are exceptional at Iron Mountain.

The reasons for the distribution of the ore deposits of the region are questions that have much concerned both geologic investigators and operators and prospectors in the region. The conditions that governed the replacement of the alaskite porphyry by ore and determined why some parts of the rock should be completely converted into ore, why others should be only partly replaced, and why still others should be nearly or quite unaffected are not plainly revealed and can not be determined directly from observation. The deductions thus far reached and expressed below concerning these conditions are not regarded as thoroughly established or altogether satisfactory, though they serve to explain some of the perplexing features and though no other hypothesis worthy of serious consideration has suggested itself. It may be safely averred that variations in the original composition of the rock did not influence the replacement in any important degree. The generally constant composition of the alaskite porphyry masses is evidence against such an idea, and the indiscriminate manner in which the ores have replaced the siliceous alaskite porphyry and a basic dike in the Bully Hill mine indicates that chemical composition was not the determining factor of replacement.

The localities where ore was deposited in place of the rock originally present are believed to have been determined primarily by the physical or mechanical condition of the rock at such places. It is a fact that can not escape immediate observation that in or around the places where ore has been deposited the rock is in a particularly crushed or sheared condition and in many localities is practically a schist. This shattering and shearing of the alaskite porphyry has already been referred to under the heading "General geology." The belt containing copper deposits that extends from Iron Mountain northeastward to the Golinsky mine is a zone in which shearing has been, on the whole, much more intense than in the regions immediately southeast and northwest of it. Similarly the principal deposits in the Bully Hill district lie in a zone of intense shearing and the rock at both mines in the Afterthought district is also much sheared. The trend of the zone crossing the Iron Mountain and Little Backbone districts and of the shear zone of the Bully Hill district corresponds to the general direction along which the shearing movements

[a] See Campbell, D. F., Min. and Sci. Press, vol. 94, 1907, p. 29.

took place and therefore coincides with the general strike of foliation or schistosity of the rock, though there are local deviations of more or less magnitude from such general directions. The trend of each of these shear zones also corresponds rather closely with and is probably in some way related to the direction of longest dimension of the alaskite porphyry stock in which the zone occurs. This shearing is believed to have taken place just after the intrusion and consolidation of that rock and shortly before the formation of the ores. In the Afterthought district local influences, particularly the proximity of a large mass of shale, have apparently affected the direction of shearing. Within these general zones or localities of shearing the extent of shattering or comminution of the rock is not equal. Whether the differences are due to unlike rigidity of various portions of the rock mass or to lack of uniformity in the forces applied is not apparent. It is not unlikely that both factors existed. At any rate, the resulting strains range from a simple fracturing or shattering of the rock through a sheared or foliated condition to a state of intense brecciation, in which the rock has been ground up into small fragments or particles. In the last-mentioned condition, although there has probably been little relative displacement of adjacent particles, the foliated or schistose structure is present in extreme degree, though not always so evident in the hand specimen as in portions that have undergone less shearing. The intermediate condition in which the rock has been drawn out into a noticeably gneissic or schistose structure is most common within the shear zones, and the two extremes are local exceptions.

As implied on an earlier page, it is this shattering of the rock that is believed to have allowed the entrance of the solutions from which the ores were deposited. Where the rock was little broken it was relatively impervious; where most shattered or brecciated it was naturally most pervious and permitted with greatest readiness the ingress and transmission of the ore-bearing solutions. More than this, however, the finely comminuted rock, exposing to the solutions an area of surface far greater in proportion to its mass than that afforded by the less shattered portions, was in corresponding or even greater degree susceptible to chemical attack by these solutions and therefore could be replaced by the ore materials with comparative readiness, while the more massive rock not only failed to receive a proportionate quantity of the ore-bearing solutions but also was not in condition to be easily attacked by such as did reach it. Portions that had undergone intermediate degrees of brecciation would naturally experience a degree of replacement by ore materials intermediate between that of the most comminuted parts and that of the most massive parts. Microscopic study of a great number of thin sections of the ores and of the wall rocks more or less impregnated by ore minerals appears to substantiate the foregoing hypothesis, though from the very fact that the most complete replacement has generally obscured and made difficult of observation the condition in which the replaced rock existed, the evidence is not wholly conclusive.

Another and related feature concerning the shape and disposition of the ore bodies is their relation to the walls or adjoining masses of rock. This relation may be exhibited in any one of three ways. (1) In numerous places there is a gradual transition from country rock to ore, the percentage of minerals that constitute the ore increasing progressively over a distance of several feet or even scores of feet. In such places the direction of foliation of the wall rock generally corresponds locally with the outlines of the ore body. (2) In comparatively few places the change from solid ore to barren or little-mineralized country rock is abrupt, but the contact between the two is tight or "frozen," indicating, as in the first case just mentioned, that the ore was formed adjacent to the same portion of country rock as now adjoins it. (3) In many cases, especially in the deposits west of the Sacramento, the solid ore abuts abruptly against a sharp fracture or "clean" wall, on the other side of which is found "waste"—that is, country rock containing much less or very little or perhaps even none of the sulphides. The nature of these breaks suggests that they are faults, and such some undoubtedly are, carrying a gouge in which are ground-up fragments of both ore and wall rock and bounded by somewhat shattered ore and country rock. One of the best shown of these faults that cut the ore and are therefore of later age than its deposition is that which is encountered in some of the old Windy Camp workings of the Balaklala mine and has divided the ore body into two parts.

Along many of the sharp walls above mentioned the ore and in some places the country rock also may be no more broken and shattered than away from these walls, and though a little clayey material is present in the fracture, this is in many places so thin that the point of a miner's candlestick or even a knife blade can barely be inserted between the ore and the country rock, and this close relation of the ore and the wall may be found at every place along the whole side of an ore body where development has exposed the wall. Where the gouge along such fractures is thicker it proves in many places to contain no recognizable fragments of either the ore or the wall rock, but instead not uncommonly holds more or less perfect crystals of pyrite. At most points the actual surface of the sulphide ore, against which this gouge rests, is in a broad way even and flat, but in minute detail is rough and composed of portions of the faces of very small crystals of sulphide. There are places, however, where the face of the ore adjoining these fractures is scoured, and even very highly polished. In some places, particularly in the Mammoth mine, small lenses of ore in unshattered and unworn condition are found in some of the thickest bands of gouge; in other places the wall rock adjoining these fractures is locally impregnated to some extent by sulphide minerals. Many of these fractures, instead of being approximate planes, are more or less curved and in places are so irregular that they may almost be described as billowy. It is believed that these fractures also are planes along which movement has taken place—that is, they are faults—but they are believed to be different in time and mode of formation from the postmineral faulting, such as that already referred to as occurring in the Balaklala mine.

The explanation of the character of these earlier faults and of the other kinds of boundaries between the ore and the wall rock is believed to depend on the hypothesis outlined above, namely, that the ores were formed at places of most intense shattering and comminution of the rock. It is believed that where the ore and wall rock grade into each other, as noted above, in (1), what is now ore was originally very finely brecciated alaskite porphyry and what is now little-impregnated wall rock was sparingly replaced by ore because it was less permeable and susceptible of attack, while the intervening material showing an intermediate degree of impregnation by the ore minerals was of correspondingly intermediate character as regards fineness of its fragments. It is also believed that at other places instead of a gradual transition from a mass of very finely ground rock into that less affected by shattering, areas of finely brecciated material were brought abruptly, probably through the medium of faulting, against faces of much more massive rock, as in (3). Movements along these sharply defined faces resulted in the development of more or less clayey material or gouge. Then when the ore-bearing solutions permeated through the most shattered portions, they extended as far as these sharp fractures or fault planes, but, partly because of the impervious layer of gouge and partly because the rock on the other side of these planes was dense and but slightly permeable, they were confined to the region of the most shattered material, which they replaced more or less completely. In this way solid ore was formed on one side of the old fault plane and country rock little affected by the ore-bearing solutions is found on the other side, no displacement having occurred along the fault after the formation of the ore. The polishing of the faces of sulphide ore that is seen along such fault planes at some places is probably to be explained by slight oscillatory movements, and probably could not have been effected by the grinding that would attend important displacement of one side of the fault, for such movement would certainly have resulted in greater disturbances of the ore than have actually taken place. The small lenses of ore and the crystals of pyrite found in the bands of gouge are believed to be direct replacements either of a portion of the gouge or of some masses of probably shattered wall rock contained in it; and the local impregnations by sulphides of the country rock on the side of the fault planes opposite from the main ore bodies are believed to represent those comparatively rare places where the ore solutions penetrated through the gouge layer and were able to attack and to partly replace country rock on the other side. The kind of boundary between ore and inclosing rock, indicated in (2)—namely, that in which solid ore changes abruptly into little-altered rock without any separating fracture—is believed to represent those places where so little gouge was developed at the boundary between massive rock and much-brecciated material that the ore-forming solutions extended up to the very face of the massive rock and began to attack its surface and replace it with ore, but were unable to penetrate into it.

In addition to the evidence which was obtained by means of the microscope regarding the relative degrees of shattering undergone by the alaskite porphyry and which, though not final or conclusive, tends to support the view indicated above, there is another kind of evidence that points in the same direction. Quartz veins carrying chalcopyrite and in places enough gold to make their extraction profitable are not uncommon in the region. They cut the alaskite porphyry and some of them cut the ore bodies. They are believed to have been formed immediately after the formation of the large sulphide bodies and to have derived their materials from the same general source that furnished the copper ores. In at least two mines, the Mammoth and the Balaklala, veins of this kind cut through the alaskite porphyry wall rock, across fault gouge and into the massive sulphide ore bodies. Two of the quartz veins sent out side branches into the gouge, but except for a small amount of fracturing at the fault plane, due to slight adjustments of the two sides of the fault, none of the quartz veins was displaced at the fault. If, as seems probable, the formation of these quartz veins closely followed that of the sulphide ore, their direct passage without displacement across fault planes that bound the ore suggests strongly that these fault planes were developed before the ore was formed. There is no reason for supposing that the formation of these faults was confined to that probably very brief interval between the formation of the sulphide ores and the formation of the quartz veins; rather the development of these fault planes may be ascribed to the time of intense dynamic disturbances that resulted in the shearing and crushing of the rock, and that certainly antedated the formation of the copper deposits.

Although the places of deposition of ore are confined to broad zones or regions where the rock has been sheared, the exact outlines of the ore body formed at any place have been further limited by local variations within these main belts of dynamic disturbance. Consequently the ore bodies, which, as stated, are commonly of rather tabular shape, do not necessarily conform with the plane nor the strike along which these dynamic disturbances are expressed by extensive schistosity and shearing.

In the Bully Hill district the main ore bodies occur in steeply inclined lodes or local zones of intense shearing, which are parts of and correspond broadly in direction with the main shear zone of the district. Extension in depth in the case of these deposits is therefore a vital matter, whereas cross sections of the ore bodies at any given elevation are of small area in comparison with the flat and comparatively thin deposits west of the Sacramento. Conditions somewhat similar to those at Bully Hill probably exist in the Afterthought region, though developments there are less extensive and the relations are less evident.

West of the Sacramento, on the other hand, the main shear zone crossing the Iron Mountain and Little Backbone districts appears to comprise more complex components of extreme intensity of movement, so that the principal ore bodies that are formed in these greatly crushed places do not correspond in strike to the main direction of the zone. They are mostly rather flat lying and have been followed, up to the present time, to comparatively shallow depths below the surface. Just why the bodies of ore representing originally masses of rock most thoroughly crushed should have the shape and attitude that they possess is a matter concerning which no satisfactory evidence of direct nature has been observed. In many places the walls that bound the sides of these ore bodies are regarded as fault planes formed earlier than the ore, as previously explained. The roof and the floor, which are boundaries of greater areal importance, are probably in some places similar faults of flat attitude, but most of them are comparatively abrupt transitional boundaries between portions of the rock that are greatly brecciated and portions that are much less shattered. But why such planes and boundaries should be prevailingly of flat dip is a question to which only one answer has suggested itself—that in the arching up of the shales of the Kennett and Bragdon formations, which without doubt originally covered the alaskite porphyry mass at no very great distance above the present surface, the cooling porphyry may have been subjected to stresses approximately parallel with this gradually yielding cover of shales, and these stresses resulted in flat zones of crushing and shearing. The presence of shale in the Afterthought district is thought to have thus influenced in a small and intimate way the structure of the near-by porphyry. The Iron Mountain ore body is limited above by a capping of gossan and appears to be limited at the bottom by the convergence of two distinct walls, which are believed to be faults that antedated the formation of the ore; but the results of extensive diamond drilling in the gossan, which was derived from the original sulphide body of Iron Mountain, indicate that that original body also, like the Balaklala, Shasta King, and Mammoth ore bodies, had a comparatively flat roof and floor of alaskite porphyry. In some of the smaller deposits of ore, as, for instance, at the Golinsky mine, the flat attitude of the deposits is less evident and there is some indication of conditions more resembling those at Bully Hill, though the size of the ore bodies and the amount of development do not justify final conclusions in this regard.

Faulting since the formation of the ores does not appear to be of general importance. Faults of small throw are known to cut the Iron Mountain and Hornet ore bodies, and one or more faults separate the originally continuous Balaklala ore body into sections. There is some evidence pointing toward the idea that the Balaklala and Shasta King ore bodies were originally parts of the same great mass and have been separated by one or more faults, probably of the same system that is known to occur in the Balaklala mine. One of these faults may be approximately indicated by the line of Squaw Creek. The amount of development is not yet sufficient to settle this important question, but some light may be thrown on it by exploration work which it is understood is being done at present by the Balaklala Company on an outcropping of ore lying between the known ore bodies of the Shasta King and Balaklala mines. It is not beyond the bounds of possibility also that other faulted blocks of the original Balaklala ore body may exist to the south of those now known, though, on the other hand, such blocks that might have existed may have been removed by erosion. A transverse system of faults later than the ore is also present in the Balaklala mine.

It is not unlikely that some of the fault planes, formed before the deposition of the ores, have later been the scenes of additional movement, so that the wall rock originally adjoining the ore body has been displaced to some extent. Boundaries that are regarded as possibly of this nature occur in the Mammoth and Shasta King mines.

Bodies of some of the most massive sulphide ore, as in the Mammoth mine, are cut into small blocks of more or less regular shape by various systems of joints which are wholly confined to the ore body and which in some places fail near the walls so that the outer portion of the ore body is a hard, continuous shell of ore a foot or two in thickness. Here and there, however, joints cut even this peripheral portion, which is most apparent near the roof of the ore body. Along some of these joints within the mass of the ore slight displacement has occurred, producing faults ranging in throw up to 2 or 3 inches.

It is obvious that channel ways must have existed through which the ore-bearing solutions were carried from their source to their places of deposition. In the case of the ore bodies occurring in steeply inclined shear zones of indefinite depth, as in the Bully Hill district, it may be readily assumed that these shear zones are themselves the channels along which the ore-bearing solutions ascended. In the principal deposits of the western districts, however, no such feeding channels have yet been discovered; whether they are small and have escaped observation and recognition, whether they have in general been cut off by subsequent faulting, or whether they have not yet been revealed by development can not be stated. Exclusive of the surface outcrops, which must be considered simply as chance exposures by erosion, feeding channels from above are more certainly absent.

MINERALS AND THEIR RELATIONS.

The mineralogy of the Shasta County copper deposits is exceedingly simple. Pyrite, the ordinary sulphide of iron, is the most abundant ore mineral, and chalcopyrite, the copper-iron sulphide, is the chief one which gives to the ores their value as sources of copper. Sphalerite, or zinc blende, is also present in varying amount; on the average it possibly exceeds the chalcopyrite, but in only one place, the Donkey mine, has this mineral been found in sufficient abundance to be utilized up to the present time as a source of zinc. Other metal-bearing minerals are present only in small amount. Galena is found in small crystals and grains generally associated with the zinc sulphide, especially in the eastern districts of the region. Coatings of radially arranged fibers of iron sulphide of lighter color than pyrite and thought to be marcasite occur on pyrite in one of the Arps tunnels near Copper City. Minute black grains and needles or blades, the latter in places arranged in feathery or dendritic forms, are found surrounded by pyrite and chalcopyrite in the Bully Hill district; the appearance is suggestive of magnetite, but the grains are too small for detection without the microscope, and tests for magnetic material can not therefore be applied; furthermore, even if this mineral is magnetite, it is not certain that it was deposited with the ore—it may possibly be original magnetite of the alaskite porphyry unchanged by the ore-forming solutions, though this seems doubtful. Bornite, a copper-iron sulphide richer in copper than chalcopyrite, and chalcocite, the cuprous sulphide, are present in small amount in the ores of the eastern districts in the same manner of occurrence as that shown by the chalcopyrite, which will be referred to shortly. Diller states[a] that tetrahedrite, the copper-antimony sulphide, has been reported from the Bully Hill mine, and the presence of antimony in the ore or in the copper bullion has repeatedly been mentioned; but the "gray copper" pointed out to the writer in the Bully Hill mine proved to be ore blackened by the presence of secondary chalcocite.

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[a] Redding folio (No. 138), Geol. Atlas U. S., U. S. Geol. Survey, 1906, p. 12.

No minerals have been found which account for the presence of antimony or of the bismuth, arsenic, and selenium that have been stated to occur in the Bully Hill ores and to some extent in those of Iron Mountain. It is the belief of some that the refractory character of the ores, occasioned by their content in zinc and barite, was responsible for the idea that some of these unusual and metallurgically rebellious elements were present.

The minerals that have resulted from the alteration of the primary ore minerals above mentioned include limonite and perhaps other hydrous oxides of iron; magnetite; secondary chalcopyrite, bornite, and chalcocite; cuprite or red copper oxide; native copper; small amounts of malachite and azurite, the copper carbonates; chalcanthite, melanterite, and goslarite, the hydrous sulphates of copper, iron, and zinc, respectively; and small veinlets believed to be smithsonite (zinc carbonate). Diller reports native silver;[a] argentite (silver sulphide) was probably also present. These products of alteration will be again referred to on a later page.

The minerals that can, without qualification, be called gangue minerals consist of quartz, calcite, and barite, or heavy spar. The calcite perhaps carries manganese in places, for manganese oxide (wad) is found in the oxidized zone. Here and there it appears also to carry some iron and approach siderite in composition. Because of their common occurrence in the ore, two other minerals must be regarded as gangue minerals, namely, chlorite and sericite,[b] though both of these, as well as a part of the quartz, were not formed entirely from the minerals carried in the ore-bearing solutions, but were produced by the interaction of these solutions and mineral components of the alaskite porphyry. The chlorite was derived from the basic silicate minerals of the alaskite porphyry, and the sericite was formed from the feldspars of the porphyry chiefly through the solution of soda and the deposition of potash in place of it. Bodies of gypsum, the hydrated sulphate of calcium, are found associated with pyrite and a little chalcopyrite in deep levels of the Bully Hill and Rising Star mines. Microscopic examination of specimens of this gypsum shows that it contains cores of anhydrite, the anhydrous calcium sulphate. Anhydrite was undoubtedly the primary mineral in this region wherever gypsum has been found, and was probably formed under conditions similar to those which permitted the development of the similarly constituted barium sulphate (barite), which is present in much greater quantity. Extremely minute shreds of material found in the ore of many deposits are believed to represent one and possibly two other minerals, though as yet their identity has not been ascertained.

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[a] Loc. cit.

[b] Possibly paragonite in part. See footnote on p. 88.

As has previously been stated, the replacement of crushed country rock to form ore did not progress to the same degree everywhere. At few localities has replacement of the country rock, by ore and gangue minerals wholly supplied by the ore-bearing solutions, been complete. The most complete replacement of important masses of the rock appears to have occurred in the Mammoth and Iron Mountain ore bodies, and much of the ore of those mines is practically solid sulphide with very little quartz and, in the Mammoth, at least, an occasional grain of barite. Locally, in ore bodies of the Bully Hill and Afterthought mines also, replacement has been complete. As a rule the ore consists rarely of sulphide minerals only, but contains more or less abundantly calcite, barite, and less commonly quartz.

The characteristic and typical ore of the region, such as might be encountered in any chance specimen, is a product of only partial replacement of the country rock by the materials derived from the ore-bearing solutions. In such ore quartz is generally more abundant than in the ore that represents complete replacement, and with the quartz are associated more or less sericite and chlorite. The quartz, which appears to be about the youngest constituent of the ore, commonly surrounds the grains or crystalline clusters of sulphide minerals as a mesh work of veinlets which for the most part are much narrower than the diameter of the sulphide grains. In some places the quartz of these interstitial streaks consists of grains showing radial extinction under crossed nicols and corresponding in all respects with the quartz often met with in ordinary veins. As a rule, however, the quartz has a shredded or coarsely fibrous appearance, the fibers extending at right angles to the face of the adjoining sulphide grain and very commonly showing a curving or twisting similar to that which would result if it had been crushed since crystallization. In some places, notably in a tunnel of the Reno group, in the southwestern part of the Bully Hill district, originally solid sulphide has been finely shattered and the spaces between the minute angular fragments have been filled with quartz of this nature. In general the shredded or fibrous appearance is probably not due to pressure and crushing, but to the influence of sericite which the quartz replaced. Quartz is most plentiful at the Balaklala[a] and Shasta King mines, but this is due to the fact that parts of the rock have resisted impregnation by sulphide minerals though allowing the deposition of quartz; ore of this nature has the appearance of a breccia in which the sulphides, as matrix, include numerous small fragments of much silicified country rock. Intergrown with this

[a] The average content of total silica, free and combined, for the Balaklala ore body is stated to be between 15 and 20 per cent.

shredded quartz are more or less abundant foils and shreds of the sericitic variety of muscovite mica, also similar particles of chlorite, though this last-named mineral occurs locally in more distinct blades or in vermicular aggregates of minute plates. Calcite also occurs with the quartz, both as elongated grains between the quartz fibers and in more compact forms surrounded by these fibers. Where particularly abundant it also forms veinlets surrounding the sulphide minerals like the mesh work of quartz.

Barite may be regarded as the characteristic mineral in the districts east of Sacramento River; quartz is most abundant in the western districts. Barite, however, is not important in all the eastern deposits, occurring in the Rising Star mine, in the Bully Hill district, for example, so far as observed, only as a few exceedingly small crystals. Moreover, barite is not absent in the western districts. It occurs in good-sized grains in the gossan directly above the Mammoth ore body and has been recognized in much smaller particles in the sulphide ore of both the Mammoth and Golinsky mines, and it is reported to be present in grains of sufficiently large size to be detected in hand specimens of the ore from the Golinsky mine. It is thought to be present also in extremely small grains in some of the Iron Mountain and perhaps other ore bodies, but it could not be identified with certainty under the microscope, and chemical investigation of these ores is not yet completed. According to Diller, however, barium occurs in the wall rock not far from the Iron Mountain ore body; it seems probable that it was deposited there by the ore-bearing solutions,[a] and it is therefore not unlikely that barite is present also in the ore. Similarly, quartz, though especially characteristic of the ore deposits of the western districts, is found in some amount in those of the Bully Hill and Afterthought districts and is particularly common in the ore of the Rising Star mine. Quartz and barite, therefore, may be regarded in a sense as complementary, one being important where the other is absent or rare, and vice versa. Where most abundant the barite is in more or less regular prisms which are of better crystalline form than the surrounding minerals and therefore doubtless crystallized slightly earlier. It is also present, however, sometimes in the same specimen, as aggregations of small irregular grains that exhibit the same meshlike relation to the sulphide minerals that quartz commonly does, and in some places it is intergrown with the shredded quartz in the same manner as the sericite, chlorite, and calcite. Calcite is rather more abundant in the ore that is richer in barite, and is particularly noteworthy in the ore of the Copper City and Afterthought mines, in both of which the ore bodies are situated close to large masses of shale or tuff. The gypsum, so far as its presence has been recognized, seems to occur in large bunches or masses

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[a] See footnote, p. 108.

which commonly have a banded structure, due to the inclusion of thin parallel films of sericitic and chloritic material. Though these bunches contain sulphides, they are not directly adjacent to commercial ore; ore occurs near by, however, in the same shattered zone in which they are situated. This material has been found at least as deep as the 870-foot level in the Bully Hill mine and nearly as deep in the Rising Star mine. It contains countless disseminated crystals and grains of pyrite and can not be regarded as the result of leaching from overlying calcareous material. The presence in it of anhydrite establishes the secondary nature of the gypsum and indicates that the calcium sulphate substance was introduced by the ore-bearing solutions. From the readiness with which plaster of Paris, which is anhydrous calcium sulphate, equivalent to anhydrite, becomes hydrated and assumes the same composition as gypsum, it may be inferred that the anhydrite has been preserved only in the most impervious parts of its original mass. The remnants of anhydrite show that the mass was composed of small crystalline grains which possessed a structure similar to that of fine-grained marble. The only other known occurrence, in this country at least, of anhydrite in connection with ore deposits is in the Frisco district of Utah,[a] where it is present in copper ore along with its hydration product, gypsum, and with barite, but in a very different mineral association from that of the Shasta County region.[b]

Among the ore minerals pyrite was the first to crystallize in most places, and where it was not so abundant that various crystalline particles interfered with each other in their growth, the mineral is present in cubes and less commonly in pentagonal dodecahedrons (pyritohedrons) of more or less perfect crystalline outline. Where it constitutes a large percentage of the ore, however, as is generally the case, the develoment of crystalline faces has for the most part been prevented, but small irregular grains, of individual internal crystalline structure, adjoin along irregular boundaries. The material that is thought possibly to be magnetite is surrounded by the pyrite and is therefore of older formation. In rare instances small grains of chalcopyrite, bornite, chalcocite, and sphalerite are inclosed in the pyrite individuals. The zinc sulphide in such places commonly has crystalline boundaries.

Zinc blende is, on the whole, of later formation than the pyrite, spreading around the grains of the iron sulphide in many places along certain crude bands which appear in the hand specimen as narrow dark streaks and give much of the zincky ore a characteristic banded

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[a] Lindgren, Waldemar, Science, new ser., vol. 28, 1908, p. 933.

[b] The ore body of the Cactus mine in the Frisco district of Utah is a mass of much-shattered monzonite impregnated and replaced by pyrite, chalcopyrite, galena, sphalerite, tetrahedrite, specularite, quartz, calcite, siderite, tourmaline, barite, anhydrite, and, of secondary derivation, gypsum. This association of minerals indicates that they were formed under conditions of high temperature and pressure.

appearance. In a few places it can be seen that these bands correspond to the original direction of shearing in the country rock now replaced. Except where inclosed within the pyrite the zinc sulphide consists of aggregates of tiny crystalline grains and no definite crystal faces have been developed. The sparing quantity of lead sulphide that has been formed possesses a more perfect crystalline development than the zinc blende, by which it is inclosed and which probably was deposited immediately after its formation.

Chalcopyrite is in general the youngest of the important metalliferous minerals, for it occurs in the ore as indefinite and irregular branching veinlets that form a network around and in cracks of the other sulphide minerals. Where zinc blende is present the chalcopyrite seems to prefer association with that mineral rather than with the pyrite, and it may be noted that in the mines carrying the lowest grade of copper ore zinc is less abundant than elsewhere. The chalcopyrite also shows affinity for quartz or barite, and where either of these two gangue minerals forms a network among the pyritic material the chalcopyrite is most likely to occur along the boundaries of these irregular veinlets as borders to the pyrite grains.

In the western districts quartz veins that normally carry a very small percentage of chalcopyrite cut through the ore here and there. In many places on reaching the ore body they split and branch and ultimately fade out. It is generally true that they hold much larger proportions of chalcopyrite where they are inclosed within the sulphide ore bodies than where they are bounded by the country rock, and in extreme cases they become veins of practically solid chalcopyrite in which the normal amount of quartz has dwindled to a few included prismatic grains. In many places along but definitely outside the boundaries of these quartz-chalcopyrite veins the ore is richer in chalcopyrite than elsewhere. Where these veins fade out they send out many minute stringer-like offshoots into the ore. These tiny quartz stringers appear to merge gradually into the shredded quartz normally present in the sulphide ore. All along these microscopic branches of the definite quartz veins chalcopyrite is deposited in greater amount than usual.

Bornite is only rarely present in large amount in the primary ore; it occurs most plentifully in the Bully Hill and Afterthought mines and is present in very small amount in some of the other deposits. It is very commonly associated intimately with copper glance, or chalcocite, and these two together apparently take the place of chalcopyrite wherever they occur, forming the same kind of irregular network through and around the other sulphides. These two richer copper sulphides are in some instances intergrown with the chalcopyrite, in places inclosing it and in places being inclosed by it. These two minerals were found in the deepest workings of the Afterthought mine, at a depth of about 600 feet, and in the deepest workings of the Bully Hill mine, at 970 feet, as well as at higher levels. In places they are intergrown with and even entirely surrounded by barite, and there is no reason whatever to consider them as other than primary constituents of the ore. Both bornite and chalcocite, as well as chalcopyrite, however, are also formed in the upper portions of some of the ore bodies by the process of secondary enrichment, but almost all such occurrences can be readily distinguished from those in which the minerals are of primary origin.

The statement made at the beginning of this section, that chalcopyrite is the mineral which generally gives to the ores their value as sources of copper, is probably, though not certainly, strictly true. Certain thin sections of ore from small specimens, assays of which show the presence of copper up to more than 2 per cent, appear under the microscope to contain no recognizable chalcopyrite, the only sulphide that can be identified being pyrite. Whether the copper contained in such ore exists as chalcopyrite, in such small grains and so intimately mingled with the pyrite that it escapes detection, or whether the pyrite contains, as an essential part of its composition, some copper, can not now be stated, though the former view seems the more reasonable, especially in view of the fact that this copper-bearing pyrite has an appearance somewhat different from that of the pyrite of the ore which is nearly barren of copper, the thin section being of slightly more yellowish color and of rougher surface on the ground faces. It is probable that the pyrite in all the ore that is commercially valuable carries copper in this way from a very slight percentage up to 2 per cent or more. The gold and silver values contained in the ore appear to be carried within the sulphide minerals, for no definite gold or silver minerals of primary origin have been found. Some of the zincky ore carries more than the normal quantity of silver. Both gold and silver are on the whole more plentiful in the ore rich in barite, but the cause of this relation is not known.

Most of the replaced country rock that is sufficiently rich in sulphide minerals to appear to be composed largely of such minerals carries sufficient metal values to make its extraction possible. Exceptions to this rule occur, however, in some places, and of course the exceptions are influenced by the lowest limit of value at which the ore can be profitably handled. Some of the fairly massive sulphide that is too low in copper to be extracted owes this condition to the fact that the copper values have been to some extent removed by leaching; where that is the case the sulphide is likely to be crumbly and may even become merely pyritic sand. Material of this kind is found in places in the Mammoth, Shasta King, and Iron Mountain ore bodies, and perhaps elsewhere. Conversely, little material not composed in large part of sulphides carries enough copper to be workable, though locally in the Bully Hill and Afterthought districts precious metals make possible the mining of ore that resembles the "waste" of other camps. The upper limit of richness in copper in the primary ore is practically fixed by the theoretical copper content of chalcopyrite, which is 34.5 per cent, though in the Afterthought mine portions of stopes are so rich in bornite and chalcocite that this percentage is locally exceeded. A few masses of pyritic ore of homogeneous appearance yield assays as high as 30 per cent of copper. Rich ore of this kind has been found in places in the Mammoth, Iron Mountain, and Bully Hill mines, but the great bulk of the ore is, of course, of much lower grade. Exclusive of the enrichment that has taken place in the upper portions of some of the ore bodies, which is due to additions of cupriferous material from the oxidized zone above, there appears to be little uniformity in the distribution of richer portions of the ore. In the Bully Hill mine there seems to be a tendency for the best ore to be found near the middle of the ore body, though in places the borders of the ore body are rich in barite and correspondingly high in copper as well as in gold. In the Mammoth and Shasta King mines probably the richest general portion of the ore bodies lies near the bottom wall or floor. Whether or not such conditions exist in the other mines is not known. At the Mammoth the harder shell that is found especially at the top of the ore body is said to be a little richer than the ore just inside of it. It may be that the shell itself and its higher copper content are the result of cementation and enrichment by solutions that have slowly seeped down the slanting roof of the ore body from positions nearer the surface, but no direct evidence of this has been observed.

ALTERATION.

Some of the ore bodies, like the main mass of the Hornet mine, do not reach the surface; and others, like the Balaklala, Shasta King, and Mammoth, have comparatively small outcrops of what was originally actual ore. At Bully Hill the steeply inclined ore body extended to the surface, and at Iron Mountain there is an enormous outcrop representing an original body of ore far greater in size than that which has been available for extraction. The rock surrounding the ore bodies is comparatively impervious to atmospheric waters and has well protected from oxidation and solution such portions of the ore bodies as lie below it. The exposed portions of the ore bodies, however, have been much altered, and at the Bully Hill and the Iron Mountain mines this alteration has extended to considerable depths. The most important result has, of course, been the production of an iron hat or gossan, consisting chiefly of limonite, some magnetite, and perhaps other ferruginous oxides. Much of the iron contained in the pyrite and chalcopyrite has thus been oxidized and rendered comparatively stable to atmospheric conditions. In the process of this oxidation the copper has been dissolved and removed from its original position. A large part of the copper thus taken into solution has undoubtedly escaped or has been precipitated in meager amounts through wide stretches of rock, but in some places an important portion of the copper derived from the oxidized ore has found its way downward below the zone of active oxidation into the underlying less altered ore and has there been precipitated upon and by the influence of the primary sulphides, according to the now well-known process of secondary sulphide enrichment. In this way secondary chalcocite, bornite, and chalcopyrite have been formed. These minerals on oxidation have produced native copper, cuprite, and the carbonates in sparing amounts. At Bully Hill and Iron Mountain these enriched zones of oxide and secondary sulphide material were of importance, though in both camps the silver values, which had likewise been concentrated with the copper from the overlying oxidized masses, were chiefly sought at the time these enriched zones were worked, and a large part of the copper therefore undoubtedly failed to be recovered. Enrichment in much smaller amount has taken place near the outcrops of the Mammoth, Shasta King, Balaklala, and Afterthought ore bodies.

The rock, partly impregnated by sulphides, that surrounds the ore bodies and occurs at other places has at the surface also undergone alteration; the sericite has been converted into kaolin and the contained pyrite has been oxidized to limonite, which has been partly absorbed in the kaolin and has stained the rock with various colors of red, yellow, or brown. Such altered wall rock, deeply stained with iron oxide but containing far less of that constituent than the true gossan derived from heavy sulphide material, is also given the name gossan in the Shasta County region, but, as pointed out by Hausmann,[a] such a designation is erroneous and, it may be added, has led to misconceptions regarding the relations of sulphide ore bodies to oxidized outcrops.

GENESIS.

There can be no doubt that the Shasta County copper deposits, like most ore deposits elsewhere, have been formed through the agency of aqueous solutions, either liquid or gaseous, which held dissolved in them part or all of the material now comprising the ore. An explanation of the origin of these ore bodies must give information as to the chemical character of these solutions, their source, and the manner in which the materials that they furnished were precipitated from them.

[a] Bull. California State Min. Bur. No. 50, p. 64.

The simple mineralogy of the Shasta County ores—the general absence of minerals of critical or diagnostic character—makes it difficult to draw conclusions concerning some of these questions, and the incomplete state of chemical and microscopical investigation of the material collected from this region makes any conclusions that might now be presented still more uncertain. Some views, however, seem to be fairly well justified by the studies thus far accomplished and may here be recorded. The unfailing connection of the copper deposits with the alaskite porphyry has already been emphasized, and the view regarding differentiation of the magma which is believed to have yielded the alaskite porphyry, the quartz diorite, and the basic dikes has been outlined under the heading "General geology." It is believed, moreover, that the quartz veins which carry chalcopyrite and in places gold and the copper ore bodies and the similar materials which impregnate both the surrounding walls and the general country rock have also been derived as final stages of differentiation from the same magma. The geographic and time relations of the ore and the alaskite porphyry are in accord with such a view.[a] The ideas held regarding this hypothesis may be further stated as follows: The shattering and shearing of the alaskite porphyry took place directly after the solidification of that rock. Immediately afterward came the intrusion of the quartz diorite and, finally, that of the basic dikes, which represent the latest rock product of the magma and which in some places, as in the Bully Hill mine, have been intruded along shear zones already developed in the alaskite porphyry. As these various rocks separated out from the magma, a progressive concentration of water and of various other elements resulted, and after the intrusion of the last rock product, the dikes, there still remained in the magma reservoir water-rich material or solutions that might be regarded as the mother liquor from which the various rocks had crystallized. These solutions are believed to have been rich in the elements that would form quartz, iron and copper sulphides, barite, calcite, etc., and because of the fact that sericite has been formed abundantly from the original sodic feldspar of the alaskite porphyry, it is believed that potassium, probably in the form of carbonate, was present in important amount.

[a] Two analyses of the alaskite porphyry, from Bully Hill and from Iron Mountain, published by Diller, show the presence of small quantities of barium in the material analyzed, and to account for its presence he explains that the feldspar of the rock contains this element. If the barium were actually an original constituent of the rock, its appearance in the ore deposits also would constitute the strongest available evidence of the relation of the ore solutions to the porphyry magma (the theory of lateral secretion being disregarded as of no application in this case at least). However, the fact that both of Diller's specimens were obtained near the ore bodies, and so might have received from the ore-bearing solutions small amounts of barite, and the added fact that, though searched for especially, no barium was found by the Survey chemists in any of the freshest specimens of alaskite porphyry collected during the recent investigation (one of these specimens—see analysis, p. 83—was obtained near the Bully Hill mine) make it appear unlikely that barium was present in appreciable quantity in the alaskite porphyry, which was the first product of differentiation from the magma.

Shortly after the intrusion of the dikes these solutions were probably forced upward from their source through such channels as they were able to discover, and these channels proved to be places of shearing in the alaskite porphyry. These solutions, which in their heated condition were probably vigorous chemical reagents, attacked the porphyry, especially where it was most crushed. The rock was more or less replaced by the elements carried in solution, and the deposition of the ores and the widespread alteration of the country rock were in this way accomplished. The silica or quartz of the rock was probably partly dissolved by the alkaline (potassium) carbonate of the solution and such of the feldspar and bisilicates as were not completely replaced by minerals of the ore bodies were converted mainly into sericite and chlorite. The quartz veins carrying chalcopyrite and gold are believed to have closely followed the intrusion of the basic dikes. One possible evidence that may be cited in favor of this belief is the fact that both dikes and veins are commonly found occupying the same fractures, each in turn having found these fractures to be places of greatest weakness. The formation of these quartz veins is believed to have so closely followed the development of the great copper ore bodies that the minerals of these great sulphide masses were scarcely precipitated when the quartz veins penetrated them. The manner in which the quartz veins finger and fade out into the sulphide masses and the way in which the quartz veins and the sulphide ores have mutually influenced each other in the abnormal deposition of chalcopyrite in and near the veins seem to point to such a conclusion. In fact, it is believed that the quartz and chalcopyrite of the distinct quartz veins and the quartz and chalcopyrite which were the latest minerals to be formed in the copper ore are practically identical in character, source, and age. Whether or not the definite quartz veins carrying chalcopyrite and gold are to be regarded as most intimately related to and really a phase of the irregular sulphide-bearing quartz masses or veins that constitute a special type of the pegmatitic dikes connected with the quartz diorite is a matter not yet decided. Consideration of all the evidence seems possibly to favor the idea that such immediate relationship does not exist, but that the pegmatitic quartz was of somewhat earlier formation. In any event, these pegmatites, though not abundant, are of interest and significance as indicating that these water-rich portions or products of the magma carried sulphide minerals and high silica, just as did the ore-bearing solutions.

There is in this region little evidence of pneumatolysis—that is, the action of mineralizing solutions in gaseous form. It is probable that most or all of the ore-forming materials were carried in the liquid state.

If the foregoing views of genesis are correct, every important circumstance connected with the origin of the primary copper ores is definitely related to one event, namely, the intrusion of the alaskite porphyry and its closely subsequent relatives. The inclosing rock, the channel ways that permitted ingress of the ore-bearing solutions, the comminution of the rock that made it easily attacked by these solutions, and the solutions themselves that furnished the material of the ore and brought about the alteration of the surrounding walls are thus but component elements of a single broad geologic phenomenon—intrusion. The hypothesis that the ore deposits are the work of descending, meteoric waters which derived ore-forming materials from the rocks overlying and adjoining the places where the ore bodies are situated is not believed to have application in the Shasta County region. It is believed that at the time the ores were deposited the alaskite porphyry was everywhere covered with a blanket of shales which would tend to prevent the direct and free circulation of surface waters; if they reached the region of the ore bodies at all, they must have traveled by a roundabout route and to considerable depths. Furthermore, it is believed that the ores were formed so soon after the consolidation of the rock that it was probably still at comparatively high temperature, a condition in which surface waters in large amount could probably not have penetrated into it.

Evidence as to the depth at which the ore bodies now known were deposited below the surface of the country existing at that time is rather meager. From mineralogical, structural, and physiographic evidence, however, it may safely be concluded that all the portions of ore bodies now known were at the time of their formation so deeply buried that they had no direct relation to the surface then existing. On the other hand, the fine-grained texture of most of the porphyry and the generally small extent to which the surrounding sediments have been metamorphosed at its contact, as well as the mineralogical character of the ores themselves, make it seem probable that the thickness of rock overlying the ore bodies at the time of their formation was not extremely great; 5,000 to 6,000 feet is believed to exceed the initial depth of most of them below the surface. In the classification with respect to physical conditions existing at the time of formation,[a] these Shasta County deposits would correspond to veins of the middle zone. In age they may be ascribed to the interval, characterized in the western Cordilleran region by intense eruptive activity, that marked the close of the Jurassic and the beginning of the Cretaceous. They thus belong in the third or late Mesozoic metallogenetic epoch as established by Lindgren.[b]

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[a] Lindgren, Waldemar, Econ. Geology, vol. 2, 1907, pp. 105-127.
[b] Econ. Geology, vol. 4, 1909, pp. 415-416, 419.

Inasmuch as the present topography of the region is known to be decidedly different from that existing when the ores were formed, the fact that many of the important ore bodies of the region are flat and not far below the present much diversified surface is probably without scientific significance. There is no reason to expect, therefore, that other ore bodies than those now known are not present at greater depth, though such ore bodies do not, of course, necessarily exist, and the chances of finding them are much lessened by their greater depth and their absence of surface indications. It seems probable that of all the ore bodies ultimately to be found in the region those already known are among the best, though important new bodies, or extensions of known bodies in the same general zone of shearing, may very well be discovered. It is not impossible that prospecting at points distant from known deposits, where the rock shows the greatest amount of shearing and alteration, may be rewarded by the finding of important masses of ore.

GEOLOGY OF THE COPPER DEPOSITS NEAR MONTPELIER, BEAR LAKE COUNTY, IDAHO.

By Hoyt S. Gale.

INTRODUCTION.

The copper deposits in the vicinity of Montpelier, Idaho, in the "Red Beds" of supposed Triassic age, appear to be entirely analogous to deposits of the same geologic age noted elsewhere throughout the Rocky Mountain region, and even in other parts of the world.[a]

Copper carbonate and some sulphide minerals, found in sedimentary rocks, where they are characteristically associated with the carbonized fragments of plant remains, and apparently without relation to igneous rocks, have been the subject of some interest in the Montpelier district for a number of years. A moderate amount of prospecting has been done on these deposits, but has not yet proved their character or value below the surface. The territory in which most of the prospecting has been done lies in a narrow strip represented on the accompanying map (fig. 6), extending almost due north and south through Tps. 11, 12, and 13 S., R. 45 E., of the Boise meridian, Idaho. The outcrop of the rock formation including the copper-bearing beds is readily traceable much beyond the area described here, and these rocks are also easily identified in neighboring mountain ranges, but from present information it can not be stated just how far the copper minerals may be traced or where they will be discovered again.

[a] Emmons, S. F., Copper in the red beds of the Colorado Plateau region: Bull. U. S. Geol. Survey No. 260, 1905, pp. 221–232.

Lindgren, Waldemar, Notes on copper deposits in Chaffee, Fremont, and Jefferson counties, Colo.: Bull. U. S. Geol. Survey No. 340, 1908, pp. 170–174.

Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: Prof. Paper U. S. Geol. Survey No. 68, 1910 (in press).

GEOLOGY OF THE COPPER-BEARING ROCKS.

The copper minerals found in this district occur in rocks of probable Triassic age. So far as known they are confined with notable persistence to a well-defined horizon or stratum in the formation

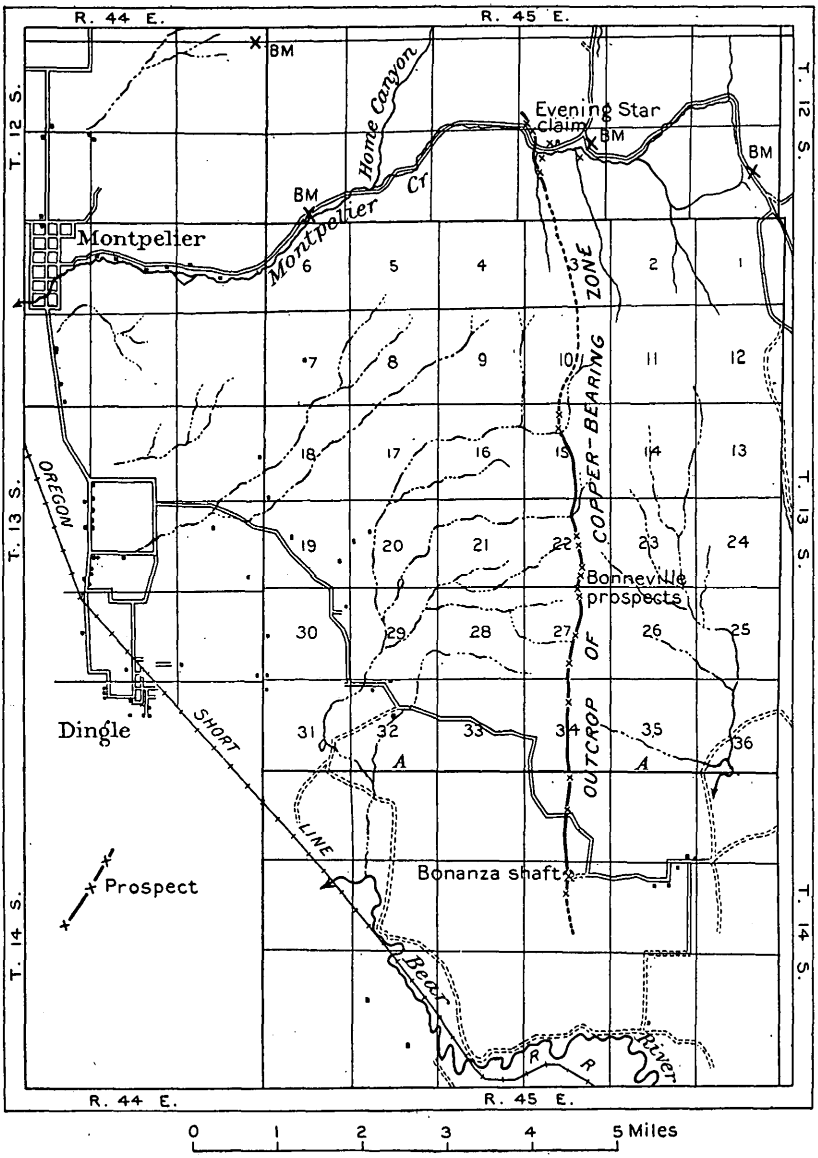

FIGURE 6.—Map showing distribution of copper-bearing rocks near Montpelier, Idaho. *A–A*, Line of section (fig. 7).

that has been named the Ankareh shale. The relation of the Ankareh shale to overlying and underlying geologic formations is indicated in the table following.

Geologic formations in Montpelier district, Idaho.

Jurassic:
- Twin Creek limestone.

Jurassic or Triassic:
- Nugget sandstone.

Triassic or Carboniferous:
- Ankareh shale. } Permian (?); the "Permo-Carboniferous" of the Fortieth Parallel Survey.
- Thaynes limestone. }
- Woodside shale. }

Carboniferous:
- Pennsylvanian—
  - Park City formation.
  - Weber quartzite.
- Mississippian.

The Ankareh shale of the Park City section was originally described from exposures in Big Cottonwood Canyon southeast of Salt Lake City, Utah.[a] This formation consists chiefly of clay shale of deep maroon and chocolate colors, massive where fresh, though commonly breaking down into thinner-bedded shaly material on exposure to the weather. It includes also some pale-greenish clayey and sandy strata, locally in beds of mottled green and maroon. It also contains harder layers of red or greenish sandstone and limy strata, and in the Montpelier district is defined at the top and bottom by massive limestones. The overlying limestone distinguishes the Ankareh from the massive sandstones and sandy shales of the Nugget sandstone. The limestone at the base of this "red-bed" formation is the uppermost of the massive limestone strata that constitute the greater part of the Thaynes limestone. The total thickness of the Ankareh, as measured between the two limestones near the Bonanza shaft, is about 670 feet, including the upper limestones but not including massive underlying limestone strata, more naturally classed with the main body of massive limestones in the Thaynes.

The Thaynes limestone is the formation occurring next below the Ankareh shale in a normal sequence and was named from its occurrence in Thaynes Canyon, near Park City, Utah. It includes the "*Meekoceras* beds" of southeastern Idaho, which have yielded a fauna that has been referred to the Lower Triassic by Hyatt and Smith and others.[b]

It is evident from recent works that the Thaynes is also a part of the "Permo-Carboniferous" of the Fortieth Parallel Survey.

The Thaynes is characterized chiefly by massive ledge-forming limestones, in many places abundantly fossiliferous. It also includes many shaly layers and to a minor extent some brown-weathering calcareous sandstones that grade into the limestone. The limestones contain a considerable percentage of clay or sand, so that on weathering they assume a sandy or muddy aspect which makes

[a] Boutwell, J. M., Stratigraphy and structure of the Park City mining district, Utah: Jour. Geology, vol. 15, 1907, pp. 434–458.

[b] Hyatt, Alpheus, and Smith, J. P., The Triassic cephalopod genera of America: Prof. Paper U. S. Geol. Survey No. 40, 1905, pp. 17 et seq.

many of them difficult to distinguish from sandstone except on broken surfaces. The thickness of the Thaynes limestone is about 2,000 feet, as measured in Raymond Canyon.

The Woodside shale next underlies the Thaynes limestone. It also received its name from the Park City mining district. In some places the Woodside is composed of dark-crimson shales which appear to form a fairly distinct member of the section; in others the bright-red colors are either absent or are concealed by the débris of adjacent harder strata. Red beds do not constitute the entire body of the Woodside, as the basal beds of that formation are rather uniformly composed of shaly or platy brown or rusty and muddy weathering limestone, somewhat similar to some of the Thaynes limestone beds. The base of the formation is marked by a prominent cherty limestone ledge, which is a part of the next underlying formation. The thickness of the Woodside shale is about 1,000 to 1,200 feet.

The Nugget sandstone, overlying the Ankareh shale and the copper-bearing strata, is composed chiefly of massive sandstone. It also includes intervals of sandy shale, which are, however, generally obscured at their outcrops by the talus of the harder ledges. The sandstone is at places, or even over considerable areas, vitrified to quartzite. On account of its resistance to erosion it usually forms high ridges or elevated plateau lands, according to the attitude of its beds. A most distinguishing feature of the formation is in general the massive red sandstone, in places marked by cross-bedding. An upper zone of several hundred feet is locally distinguished as a massive white sandstone, and at a number of localities, notably in the Sublette Range in Wyoming, a prominent ledge-forming white sandstone with conglomerate also occurs a few hundred feet above the base of the Nugget. The total thickness of the Nugget sandstone is about 1,900 feet, as measured in Raymond Canyon, in the Sublette Range.

Although in the normal stratigraphic succession the Nugget sandstone overlies the Ankareh shale, that order is reversed by the geologic structure at the locality of the copper deposits. The higher hills bordering the east side of the Bear River valley southeast of Montpelier, or between Montpelier Canyon and Dingle, represent an overturned anticline on whose crest or axis the massive limestones of the Thaynes are brought to the surface. Thus, while the copper-bearing rocks dip to the west and apparently pass under the massive limestones of the Thaynes, the whole section is, in fact, upside down, and these rocks probably become vertical and pass into an eastward dip in depth, from which they are continuous, merging with the general structures east of this area. The accompanying diagram (fig. 7) explains the relation of these beds along an east-west line, shown on the general map (fig. 6).

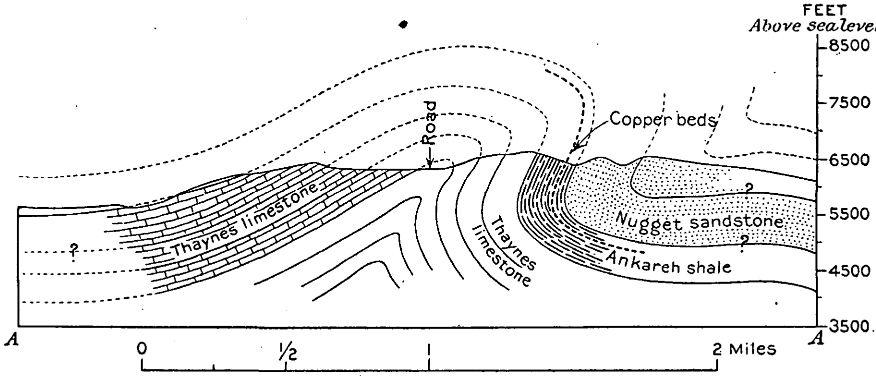

FIGURE 7.—Section along the township line on the south side of T. 13 S., R. 45 E., Idaho, showing the relations of the copper-bearing rocks.

OCCURRENCE OF THE COPPER.

Copper carbonate stains are very persistently associated with the beds at a particular stratigraphic horizon in the Ankareh shale. This horizon is about 110 feet stratigraphically below an upper limestone stratum, or 170 feet below the uppermost limestone recognized between the Ankareh and Nugget formations in the Montpelier section. The rocks at this horizon are underlain by maroon and chocolate or mottled green and red shales. On account of the overturned geologic structure of the region, the upper beds dip under those which would underlie them in the normal stratigraphic sequence, as shown by the cross section (fig. 7).

Throughout the greater part of the district examined the occurrence of copper minerals seems to be confined very constantly to approximately the same stratigraphic horizon, the only exceptions noted being those on the Bonneville claim. The section of the copper-bearing strata represented in figure 8 is apparently characteristic of this horizon, although details were found to vary as the horizon was traced along the outcrop.

As shown at the surface, the copper stains consist chiefly of the green mineral malachite and to a lesser extent of the blue azurite. These minerals occur in joints along the bedding of both the massive, usually somewhat calcareous, sandstone and in the more shaly rocks. There is no well-defined mineral streak and these oxidized minerals are, of course, secondary.

At one place where the development has been carried down on the mineralized zone to a depth of 100 feet or more the sulphide minerals chalcocite and covellite have been found in evident replacement of the woody fibers of fossil plants, roots, or tree stems. Some of the prospects are described as found at the time of examination (October, 1909).

DEVELOPMENTS AND PROSPECTING.

The principal development is on the Bonanza claim, in sec. 10, T. 14 S., R. 45 E. Here a shaft has been sunk to a reported depth of 350 feet. The mining equipment was idle when visited in October, 1909, but was in good condition. This property is said to belong to the Bonanza Mining Company, of Montpelier, organized in December, 1908.

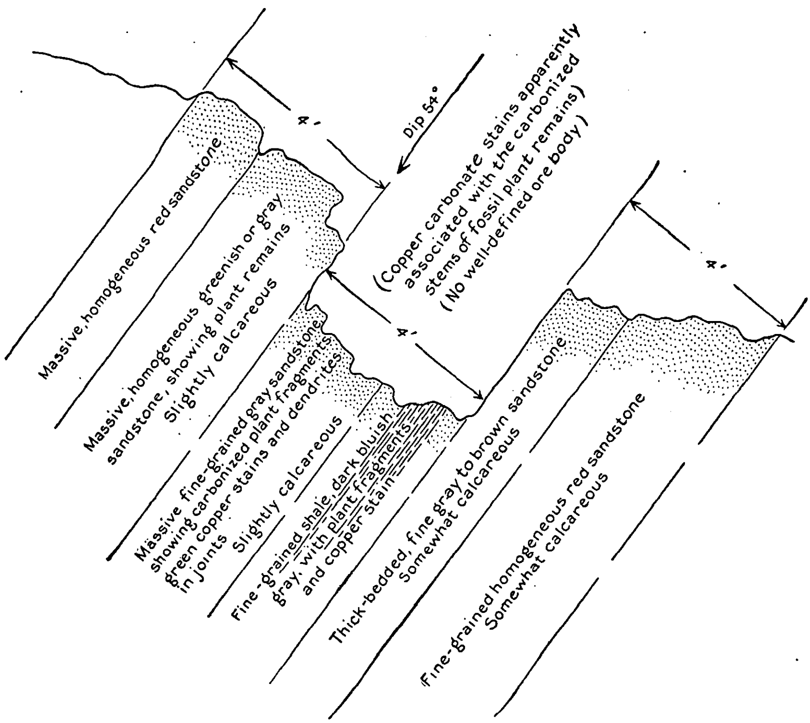

FIGURE 8.—Section of copper-bearing rocks at prospect south of Bonanza shaft, near Montpelier, Idaho.

No ore has yet been taken from the Bonanza shaft. The outcrop of the ore-bearing zone is opened by a small prospect about 130 feet east of the shaft house, where the dip is 50° W. If this dip is constant in depth, the ore-bearing beds should intersect the shaft at much less than the present depth, but no record is available, either of ore or of change in the attitude of the strata, which might explain a failure to encounter the ore. The shaft was largely filled with water and was inaccessible when the property was visited by the author.

The showing of the mineralized zone near the Bonanza shaft has already been described. (See fig. 8.)

A shaft or incline of the old Montpelier Mining Company (now incorporated in the Bonanza Mining Company) is situated on the top of the ridge about one-fourth mile south of the Bonanza shaft. The development here consists of an incline 50 feet in depth, following the copper-stained strata on the dip of the beds. The strike of the rocks is N. 10° W. and the dip 66° W. The ore at the surface is evidently of the same stratigraphic horizon as that shown near the Bonanza shaft, but occurs in brecciated zones locally more completely saturated with the carbonate minerals. These are deposited, as already noted, in joints, fractures, and bedding planes of the country rock. The mineralization is clearly not confined to any particular bedding plane or stratum, but is distributed in a very irregular way through 5 feet or more of clayey and sandy rock included between strata of massive, even-bedded red sandstones. At the bottom of the 50-foot incline, which pitches somewhat toward the north, a level has been cut to meet a timbered shaft beyond, said to have been sunk to a depth of 200 feet. Several sacks of selected ore, said to be from the 100-foot level, lie at the mouth of the pit. This ore contains much that is evidently fossil wood, in which the carbonaceous material has been replaced by chalcocite. A polished cross section of this ore proves under the low power of the microscope to be made up of rounded or fibrous masses of chalcocite; an indigo-blue iridescent mineral of metallic luster, probably covellite formed by alteration from chalcocite; and seams or veins of malachite, cutting both of the other minerals as well as the country rock.

The rocks to the south appear, from a general view across the ridges, to continue with much the same structure to the Bear River valley and beyond. In tracing the outcrop of the beds at this horizon northward from this point numerous shallow pits are noted, most of them showing more or less of copper stain, although this rarely occurs on the natural outcrop of the strata.

Another claim on which considerable work has been done is that known as the Bonneville, located near the middle of the north side of sec. 27, T. 13 S., R. 45 E., formerly owned by the Claire Mining Company. Near the head of a gulch on this property are several prospects, a shaft, and two tunnels of considerable depth. The strike here is N. 27° E. and the dip 55° W. The principal ore-bearing stratum is a light-colored calcareous sandstone, which is very hard. Ore appears to occur at more than one horizon here, a feature that was not noted elsewhere. Two tunnels run in on the north side of the gulch, opening up beds at separate horizons. The eastern of these is the main tunnel. The stratigraphic interval between the two is 60 feet.

The main tunnel has been driven to a depth of about 200 feet; from it a crosscut has been opened to the northwest, and a stope and incline have been driven on several lenticular and mineralized streaks. The mineralized beds are at least four in number within a stratigraphic thickness of 10 or 15 feet. The copper minerals are found in thin foliated shaly lenses, containing seams of black carbonaceous material, reported to constitute the richest ore. This is locally referred to as "black" copper ore, but some specimens tested showed the black substance to be largely, if not wholly, carbonaceous matter upon which the copper carbonate minerals are deposited. Surrounding such lenses of more concentrated mineralization are zones in the sandstone impregnated with the green and blue carbonates, but none of these form continuous ore bodies, nor are they well defined.

The western tunnel on the Bonneville claim, about 120 feet somewhat south of west of the main entry, was driven to follow an iron-stained ledge apparently accompanied by a smaller indication of copper minerals. The mineral here is associated with a light-colored calcareous sandstone, included in dark-maroon shale, resembling the typical occurrences noted farther south. There is relatively little copper-stained rock on the dump of this entry, which shows, however, some iron-stained sandstone.

About one-fourth of a mile north of the Bonneville tunnels and shaft, near the top of the ridge, is an old incline shaft showing copper-stained rock in striking exposure. The copper minerals are exhibited across a face about 8 feet thick, although the rock is not uniformly saturated, the minerals being chiefly thin vein fillings in joints or cracks. Some portions of the rock are more richly impregnated, these being the thin-bedded, foliated material associated with the black carbonaceous plant remains. At this place copper minerals also show at a horizon whose beds outcrop 50 feet or more west of the prospect pit.

Some prospects were observed in secs. 22 and 15 north of the Bonneville claim, but the only other noteworthy showings of copper minerals found were those in Montpelier Canyon in and near sec. 34, T. 12 S., R. 45 E. The Montpelier Canyon prospects consist of a small group near the main road leading from Montpelier to Star Valley about 7 miles from Montpelier. The prospects here, as elsewhere, are in the Ankareh shale, showing dark-maroon and red shale, with some mottled red and light-greenish clay shale and associated red sandstones and limestone. The openings are not confined to the horizon so uniformly prospected farther south, but with the exception of a few pyrite specks in a massive limestone ledge at one of the prospects there appear to be no noteworthy indications of copper, except at the horizon previously described. The structure at this place is, however, more complicated and the attitude of the beds less easy to interpret with certainty. In this northern extension of the belt of copper prospects the overturned anticline already described appears to revert to the normal attitude a short distance north of the canyon of Montpelier Creek, and the overturned formations of the lower or eastern flank pass through some more local structural contortions and then merge into a broad syncline to the northeast, so that the outcrop of the Ankareh shale may be traced in a general way in two directions, toward Joes Gap on the one hand and northward on the other.

Several small prospects on the Evening Star claim, in the NW. ¼ sec. 34, T. 12 S., R. 45 E., show brecciated and copper-stained clay and sandy rock under a hanging wall of maroon shale, similar to the wall rocks of the copper ledge near the Bonanza claim. A sample taken by the author representing 14 inches across the face of a mineralized zone at the discovery monument on the Evening Star claim was tested, showing 2.85 per cent of copper. This specimen as collected afforded an impartial test, and undoubtedly consisted of somewhat leaner material than much of that shown at some of the prospects farther south. It may serve, however, as a conservative guide in estimating the general grade of the oxidized ores in this belt.

GENERAL SUMMARY AND CONCLUSIONS.

Deposits of copper in the "Red Beds" of presumed Triassic age belong to a well-recognized type. The constant association of copper minerals with carbonaceous matter, such as with coal or, as in this region, carbonized plant fragments, is considered good evidence that the carbon has acted as the precipitating agent which has caused the accumulation of the copper. It is assumed that copper may be or probably was present in widely distributed though minutely disseminated form in the sedimentary rocks as they were originally laid down. Such copper may have been taken into solution in the ground waters, to be precipitated again and concentrated when these waters came into contact with the carbon. It is known that organic matter acts as a reducing agent in some places, and that by its action sulphide minerals may be formed. Later oxidation of the sulphides has to a certain extent disseminated the carbonate minerals throughout the country rock, especially in brecciated zones. This theory is confirmed by the finding of chalcocite replacing the woody fibers of plant stems at the only place where these deposits have been opened in depth.

Prospecting in the green, maroon, and chocolate-colored shales of the Ankareh formation appears to be general throughout this region. On the whole it is probable that the vivid green color of some of the shales is too often mistaken for an indication of copper, and that the coloring substance is usually rather a form of iron, possibly reduced in association with organic matter, that gives on further exposure the dark-red and chocolate hues already described.

The copper minerals that have already been found may, however, prove to be of commercial value. Selected rock containing the copper carbonate minerals may be obtained to run 2 per cent or over, perhaps in considerable quantities. It is possible that such ore submitted to an economical process of leaching and precipitation by means of scrap iron or by electrolysis might be made to pay with efficient management.

The search for concentrated deposits in depth may be rewarded, but the chances are good that richer deposits if found will consist largely of chalcocite or chalcocite and covellite, for which other methods of treatment than those suggested above must be adopted.

THE COPPER DEPOSITS OF SOUTH MOUNTAIN IN SOUTHERN PENNSYLVANIA.

By George W. Stose.

INTRODUCTION.

Copper ore and native copper occur in the pre-Cambrian eruptive rocks of South Mountain from the Chambersburg-Gettysburg pike in Pennsylvania into Carroll County in Maryland. In Pennsylvania the copper belt lies largely in Adams County but partly in the eastern portion of Franklin County. The ore is associated chiefly with the basic lavas and occurs generally at or near the contact with acidic lava. In most places the copper is found native in little blebs, grains, or wires. In some occurrences it is surrounded by the red oxide, cuprite, and at the surface and along joint planes it is generally altered to the brilliant green and blue carbonates, malachite and azurite, which stain large areas of the adjacent rocks.

GENERAL GEOLOGY.

The oldest rocks in the area are metamorphosed lavas of pre-Cambrian age. Two classes of these rocks are recognized—a basic rock, greenstone, which was derived from a basaltic lava by static or regional metamorphism, and an acidic eruptive derived from a rhyolitic lava by similar metamorphism. As both of these rocks show evidence that they were originally in large part of a glassy texture but have become devitrified by slow metamorphic processes during a long period of time, they are termed, respectively, apobasalt and aporhyolite. In this paper, however, the terms "greenstone" and "porphyry" will be used because they are less technical and are generally employed by the miners and prospectors.

The greenstone is both massive and schistose and usually all traces of its original character are lost. Numerous amygdules give evidence of the vesicular character of much of the original rock, and under the microscope other evidences of its eruptive character are shown. The original minerals have been almost entirely changed to epidote, chlorite, and quartz, with numerous minor accessory minerals, but in some specimens the basic feldspars are still preserved. In places large bodies or layers of epidote-quartz rock (epidosite) occur in chlorite schist, but in general these mineral segregations are small masses and amygdule fillings.

The porphyry is usually red, purple, or bluish in color and includes not only porphyritic lavas, but dense felsites and sericite schist. Most of the rocks are intensely squeezed and sheared and have acquired a slaty structure dipping to the southeast. The sericite schist is the extreme form of this dynamic metamorphism. Many of the felsitic and porphyritic rocks still preserve the flow banding of the original rhyolitic lava, which weathers in relief in minute wavy and crinkled lines. They also contain numerous spherulites and microscopic textures and inclusions that testify to their volcanic origin. Amygdules are not so plentiful in the acidic lava as in the basic. The minerals of the porphyry have not been altered as extensively as those of the greenstone, and chlorite and epidote are not common constituents of the rocks.

The distribution of the greenstone or copper-bearing rock is shown on the geologic map, figure 9. In the vicinity of the Maryland-Pennsylvania state line the greenstone covers a wide area in which lie small patches of the porphyry. From the distribution of these patches, which generally occupy crests of ridges or spurs, and the fact that both rocks are largely surface lavas and not intrusive, it appears that the porphyry overlies the greenstone and is younger. To the east this greenstone area ends abruptly where the mountains give place to the Triassic plain. On the north the greenstone is partly concealed by overlying Cambrian sediments, and beyond it is cut off by a diagonal fault running northeastward, the pre-Cambrian area north of the fault being occupied largely by porphyry. A rather wide band of greenstone continues northward in the direction of the strike of the rocks for several miles along the western margin of the pre-Cambrian area, and other long, narrow parallel bands lie inclosed in the porphyry. The relation appears to be one either of interbedding of the acidic and basic volcanic rocks or of intrusion of tongues of basic rocks into the acidic lava. On account of the excessive shearing, the original layering or bedding in the lavas can not generally be discerned, and therefore the relative age of the two lavas can not be positively determined, but it is tentatively concluded that the eruption of a great body of basaltic lava was followed by a large flow of rhyolite, which either was intruded by narrow sills of a later basic eruption or inclosed several thin recurrent basic lava flows.

These pre-Cambrian rocks were brought to the surface by a great uplift and the erosion of most of the covering of younger rocks.

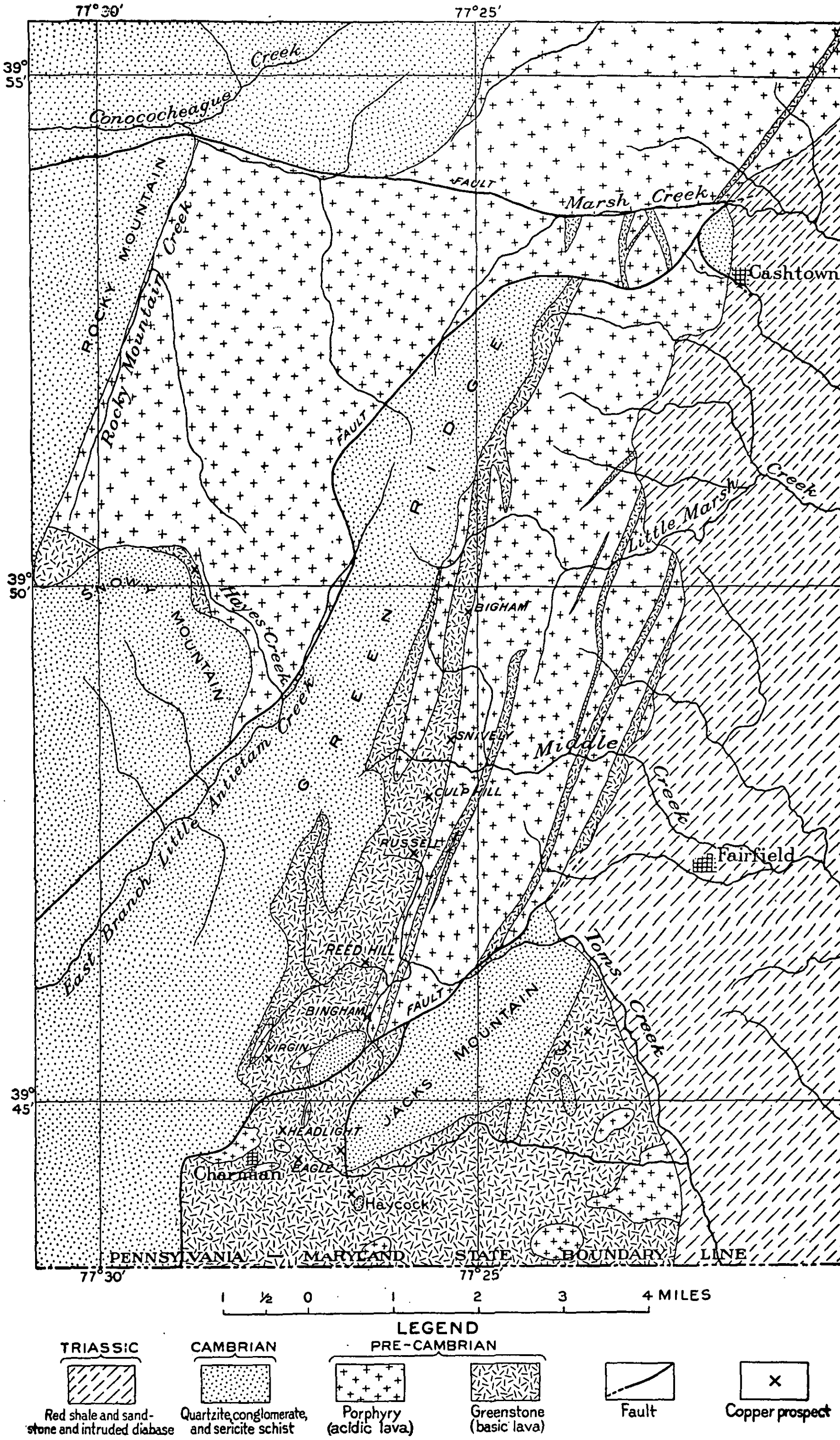

FIGURE 9.—Geologic map of part of South Mountain, southern Pennsylvania. By G. W. Stose.

Overlying the lavas are patches of quartzites, conglomerates, and sericite schist of Cambrian age, remnants of a cover that once extended entirely over the top of the fold. These Cambrian rocks appear in full force on the western flank of the uplift in Green Ridge, which limits the pre-Cambrian outcrops along a sharp line. The pre-Cambrian rocks reappear to the west, however, in another upfold of the uplift. The fine sericite schist and schistose arkose at the base of the Cambrian are followed by the hard conglomerate and quartzite that form the higher ridges and peaks of South Mountain.

ORE DEPOSITS.

The copper ore is associated chiefly with the basic lavas, but in a few places is found in the porphyry. It is further restricted chiefly, if not entirely, to the large greenstone mass, previously referred to as a large flow apparently underlying the porphyry, for copper is not known to occur in the narrow bands and tongues extending into the porphyry east of the main mass. Traces of copper are said to have been found along the entire belt from the Gettysburg pike to a point beyond the Maryland state line, the prospected properties merely being located at stream gorges, where exposures are better and the copper is more readily discovered. This belt of greenstone, therefore, is known to be copper bearing for at least 8 miles in Pennsylvania. Small prospects where only blue and green copper stain show at the surface have been opened at many places throughout the belt, but only those openings that are either of considerable size or expose a deposit of ore will be described. Those located in Maryland were not visited and will not be further referred to in this paper.

Virgin Copper Company.—At the present time the most actively worked property in the area is that of the Virgin Copper Company. It is located near the crest of a small hill 1 mile north of Charmian station, east of Gum Spring, on the Old Furnace road. Through the courtesy of Mr. C. E. Wills, manager, the mine was inspected and the following data were obtained.

A slope 215 feet deep enters near the top of the west side of the hill. The greenstone, which covers the top and east side of the hill, is chlorite schist with great masses and layers of epidote-quartz rock and small veins and nodular masses of quartz, epidote, and asbestos. About 80 feet below the mine, on the west side of the hill, occurs massive porphyry, and near the contact fragments of coarse amygdaloidal greenstone and breccia were found. At the mine entrance the greenstone is schistose and sheeted with epidote-quartz rock (epidosite) and stained with copper carbonate. The slope was started down the dip of the sheeted zone, but in depth the epidosite, with copper at intervals, occurs largely near and below the floor. At a depth of 150 feet a 10-foot drift to the west under the slope exposed the sheeted epidosite with calcite, chlorite, quartz, and strings of bright native copper. The copper is mostly in the chlorite schist, which is thickly impregnated for about 2 feet, but it also coats the sheeting and joint planes. The sheeted zone impregnated with copper had been previously encountered in two bore holes to the east of the slope, in one at a depth of 308 feet and in the other, farther east, at a depth of 600 feet. The 308-foot bore hole was reported to have passed through 7 feet of ore at the bottom. It is the intention of the owners to drift in at this level, as they believe that the ore at this depth will be rich enough to work profitably. Samples of the ore were not analyzed by the writer, as the run of mine could not be determined until drifting in the ore was begun. Picked samples from the pocket at a depth of 150 feet are rather rich.

The 6 by 8 foot slope is fitted with an 8-horsepower hoist and pump, iron skip car, and head frame, and two compressed-air hammer drills are in use. A good wagon road leads downhill to Charmian station and, if production warrants, an aerial carrier and gravity chute could be constructed down the east slope of the hill direct to the railroad at the foot.

Bingham mine.—Next north in this greenstone belt is the old Bingham or Copper Furnace mine, now being prospected by the National Copper Company. It is located about 1 mile northeast of the Virgin mine, in the porphyry on the eastern edge of the greenstone belt. Native copper occurs in the altered amygdaloidal rhyolite as small specks and blebs, surrounded by a zone of red oxide of copper. The joint planes are brilliantly stained blue and green by the copper carbonates, appealing to the prospector as representing large quantities of copper. The country rock is a beautiful fine, even-grained rhyolite, mostly drab with pink blotches, in part spotted with dark epidote-filled amygdules. The body of the rock is in places largely altered to epidote and quartz, derived from the adjacent greenstone. The opening consists of an open cut extending 40 feet into the hill and about 30 feet deep in the deepest part. An eastward-dipping crushed zone, composed partly of red clay, is exposed in the cut, and it is probable that the concentration of ore is associated with this channel for circulating waters. Samples from this mine are reported to have analyzed 4 per cent of copper, but the rock seen on the dump was too lean to constitute a workable deposit.

About the year 1840 this mine was developed by a Philadelphia company and worked for six months or so, the ore being smelted in a furnace on the property. The old workings and furnace have since entirely disappeared. J. T. Bailey[a] reported in 1883 a shaft 40 feet deep in quartzite (probably epidosite). He stated that the ore

[a] Copper deposits of Adams County, Pa.: Eng. and Min. Jour., February 17, 1883, pp. 88-89.

appeared to lie in three distinct veins upon the hill and that 4 or 5 tons of float ore had been shipped to a smelter for treatment.

Reed Hill mine.—One-half mile farther north in the greenstone belt, on the north slope of the Toms Creek valley, is an old prospect operated by the Reed Hill Copper Company. This lies in the center of the belt of greenstone, which is here in part dense, massive, and crystalline, in part scoriaceous and altered to epidote, quartz, and chlorite. Only copper stain was seen at the large opening, but at other small pits on the property the rock was peppered with native copper and cuprite.

An open cut runs 100 feet north into the hill and from it branch two tunnels 30 feet or more long. It has been closed down for two years, but the equipment is still in good condition and the tunnel open. Specimens of native copper weighing over 1 pound are reported to have been found in the soil and wash in this vicinity.

Russell property.—About 1½ miles northeast of the Reed Hill opening, at the place where Copper Run cuts across the greenstone belt, the copper deposits have been extensively explored on the old Russell farm. They are at present being exploited by the Reed Hill Copper Company, but active work was not in progress at the time of visit. Considerable development work has been done. A 6 by 12 foot double-compartment shaft 120 feet deep is well timbered and fitted with a double bucket hoist. Pumps are occasionally used to keep the water down. The shaft intercepts an older slope which enters about 200 feet to the west and is reported to run eastward from the bottom of the new shaft. The ore-bearing rock was reported by Henderson[a] to be 8 feet thick and to lie between two walls of chlorite schist. The ore is an amygdaloidal epidote-quartz rock, the amygdules being filled with epidote, red jasper, and calcite, in which are fine flecks of native copper.

The Bechtel shaft, another old opening on this property, is located a short distance to the northeast, at the contact of the greenstone and rhyolitic sericite schist. A large quartz vein lies in the schist parallel to the contact. Nothing is known about the ore from this shaft.

Snively mine.—About 1¼ miles farther north, where Middle Creek cuts across the greenstone band, the Snively or old Musselman Hill prospect is located high up on the north slope. Here are remains of two old shafts, one 53 feet deep, and a tunnel. The ore is reported by Henderson to occur in an 8-foot layer of epidosite lying between walls of chlorite schist that dip 52° SE. Samples of amygdaloidal greenstone altered to epidosite and impregnated with native copper and cuprite were obtained from the dump. Some of the finest

[a] Henderson, C. H., The copper deposits of South Mountain: Trans. Am. Inst. Min. Eng., vol. 12, 1883, pp. 85-90.

specimens of copper ore have been found as float on this property. Selected samples of the ore analyzed by Henderson gave 5.83 per cent of copper, but a careful sample made by him of the run of mine from the ore pile gave only 1.82 per cent. The less altered rock is a fine amygdaloid, the cavities being filled with quartz and bright-green epidote. It is near the contact with the rhyolite to the east, which is here a sericite schist, the same as at the Bechtel shaft, farther south. The schist has also been prospected near the stream level by a large tunnel, but no copper indications were seen. On top of Culp Hill, south of the creek, there is another prospect shaft, reported to be 22 feet deep and to lie in epidote rock between chlorite walls. A sample of ore from this shaft tested by Henderson gave 5.93 per cent of copper.

Copper stain was observed a mile west of the Snively mine, in an arm of greenstone that is separated from the Snively mass by a parallel band of porphyry and passes under the Cambrian sandstone of Green Ridge.

Bigham tract.—A mile and a half north of the Snively mine copper-bearing epidosite occurs at the contact of the greenstone schist and porphyry. The deposit has not been prospected. Similar copper-bearing rock is reported from the Bailey farm, 1 mile farther north, and the belt of greenstone with the same quartz-epidote rock that contains the copper continues in narrowing width to the Gettysburg pike.

Hayes Creek prospect.—Near the head of Hayes Creek a small area of greenstone emerges from beneath the Cambrian sandstone of Snowy Mountain in a branch anticline to the west of Green Ridge. This rock is a tough, fine-grained greenstone with masses of epidosite that contain in places native copper and cuprite. Some of the rock is finely amygdaloidal and brecciated. No deep excavations have been made here.

Eagle Metallic mine.—On Minie Branch, half a mile due east of Charmian, in the large greenstone area adjacent to the Maryland state line, the Eagle Metallic Company has put down a slope extending eastward at an angle of 35°, said to be 450 feet long. It enters at the contact of copper-stained massive epidosite with overlying highly altered and weathered chlorite schist. The dump showed vein quartz with specular hematite, chlorite, epidote, and copper-stained schistose greenstone. Chalcocite was reported to have been obtained at a depth of 100 feet.

The mine is equipped with a 20-horsepower engine, hoist, blower, pump, and air compressors, and although it was closed and full of water at the time of visit, the equipment was in good condition. The present company was being reorganized, and activity was to be renewed shortly.

Minor copper prospects in the large greenstone area to the east are located on the lower southern slope of Tunnel Hill and on the C. E. Wills farm, on the northern slope of Haycock, where copper-stained rock is plentiful on the surface.

Headlight mine.—An old tunnel, which enters the hillside just below the pike half a mile east of Charmian, was formerly very promising and actively prospected. It is 160 feet long and lies in quartzose greenstone impregnated with native copper. Bailey reported in 1883 that at a distance of 60 feet from the mouth of the tunnel an oblique impregnated chute was encountered, exposing an area of 24 square feet of ore-bearing rock, in which the copper was uniformly disseminated for a width of 5 feet, running 10 to 20 per cent. Later a second strike of rich ore was reported, but development work was shortly afterward abandoned.

Jacks Mountain shafts.—On the lower eastern slope of Jacks Mountain are several old caved-in shafts in the greenstone. The rock brought out is amygdaloidal and massive greenstone highly altered to epidote and quartz. Some amygdules are filled with specular hematite and epidote. Mineralization is indicated by copper stain, but native copper was not observed. No recent work has been done at this place.

ORIGIN OF THE ORE.

The segregation of the copper in its present form is undoubtedly secondary. The native copper is associated chiefly with epidote and quartz, secondary minerals derived from the alteration of basaltic lava. It has not been proved that the lava was originally copper bearing, but it is generally believed that minute particles of the metal, probably as sulphide, were disseminated through the basic flows as original constituents.

In pre-Cambrian time and again late in the Carboniferous the rocks were subjected to great compression and heat, and in the presence of heated waters the original minerals were altered. The hornblende or pyroxene was changed to chlorite. The basic feldspars and the ferromagnesian minerals reacted and formed a mixture of epidote and quartz, called epidosite. Much of the lava was vesicular and porous and furnished a passageway for circulating waters. Elsewhere the rocks were sheared and sheeted during the great dynamic alteration, and circulating waters followed these sheeted zones. Alteration was most active along these channels. Amygdules and cavities were first filled with various minerals derived from the original constituents, largely quartz and epidote, with some calcite, chlorite, and zeolites. In the most excessively altered portions the amygdaloid structure was entirely destroyed and the rock was changed to a massive epidosite. The disseminated copper in the original lava was concentrated during the process and is found as flakes in the filling of amygdules in the less altered rocks and on joint planes and as impregnations in the country rock in the highly altered zones in the epidosite.

The occurrence of many of the ore deposits at or near the contact of the acidic and basic eruptive rocks might be accounted for, if the later of the igneous rocks were intrusive, by assuming that the intrusion was accompanied by hot solutions that brought up the copper from deeper-seated sources. As it has been conclusively proved by microscopic examination that the larger areas of both these rocks with which the ores are associated were originally surface lavas, the occurrence is rather explained by the assumption that this contact marks the top surface of the basic flow, which was vesicular and porous in its upper portion and therefore subject to circulation of waters and consequent excessive alteration.

The transportation and concentration of the ore must have been effected by solution. The copper mineral, probably sulphide, originally disseminated in the lavas, was dissolved as sulphate and possibly changed to carbonate or silicate. The solutions, either oversaturated with dissolved minerals, lowered in temperature, or acted on by some precipitating agent, deposited the minerals on the walls of cavities and crevices. In one mine copper sulphide was reported, but all the samples seen by the writer were either native copper or its surficial derivatives, oxides and carbonates. It is probable that the copper was deposited from solution in the native state, like the rich deposits in the Lake Superior region, where native copper continues to great depth. Pumpelly[a] accounted for the deposition of native copper from solution on the assumption that the precipitation occurred in the presence of a strong reducing agent, such as the ferric oxide in the epidote and other ferriferous minerals with which the native copper is closely associated and which were probably formed at the same time. The higher oxidation of the iron in these minerals would be effected by the reduction of the copper oxide to native copper.

This theory of ore deposition has been tested in the laboratory and proved to be tenable. Stokes[b] has found that hornblende and siderite precipitate native copper from sulphate solution at 200° C.; that ferric sulphate, pyrite, and chalcocite reduce cupric sulphate to metallic copper under certain conditions; that hot cupric sulphate is reduced to cuprous sulphate by the addition of copper, and the solution when cooled gives off native copper, so that native copper could be deposited by hot solutions ascending to cooler levels.

It is generally conceded that epidote is essentially an alteration product. The massive layers of copper-bearing epidote and small

[a] Pumpelly, Raphael, Copper district: Geology of Michigan, vol. 1, pt. 2, 1873, pp. 1-47.
[b] Stokes, H. N., Econ. Geology, vol. 1, 1906, p. 648.

blebs of epidote and quartz in the center of relatively fresh rock are undoubtedly the result of deeper-seated alteration, under the influence probably of heated water, and it is concluded that most if not all the concentrated copper in the South Mountain district was deposited in this manner. As the metamorphism of these rocks and the production of most of the epidote occurred in pre-Cambrian time, the concentration of the copper in its present position and form must also have taken place at that time. This statement is at variance with the conclusions of Weed[a] and Phalen[b] in regard to similar occurrences of native copper in the same belt of pre-Cambrian volcanic rocks in Virginia. They regard the richer deposits as recent concentrations due to the downward percolation of surface waters, limited to shallow depth where leaching and concentration have gone on. The alteration of the country rock to epidote, quartz, and chlorite is also regarded by them as largely a surface phenomenon that accompanied the deposition of the ore. Minute disseminated specks of metallic sulphide, apparently chalcopyrite, were observed in the country rock from which it is believed that the concentrated copper deposits were derived.

FUTURE OF THE MINING INDUSTRY.

It is not possible to state what measure of success will be realized in the search for workable deposits of copper in this region. The fact that extensive and careful prospecting for seventy years or more has thus far not been rewarded is not encouraging to the miner. As the ores do not change in depth to sulphide, there is no hope of concentrated deposits in that direction. The ores occur sporadically along highly vesicular and shear zones, and the locations of deposits of sufficient concentration to be profitably mined can not be predicted, but can be ascertained only by actual prospecting and development. The present activity in a systematic search is to be encouraged in the hope of proving either the presence or absence of such workable deposits.

[a] Weed, W. H., Copper deposits of the southern United States: Trans. Am. Inst. Min. Eng., vol. 30, 1900, pp. 449-504. Weed, W. H., and Watson, T. L., The Virginia copper deposits: Econ. Geology, vol. 1, 1906, pp. 309-330.

[b] Phalen, W. C., Copper deposits near Luray, Va.: Bull. U. S. Geol. Survey No. 285, 1906, pp. 140-143.

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The government publications, except those to which a price is affixed, can be obtained free by applying to the Director, U. S. Geological Survey, Washington, D. C. The priced publications may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C. Those marked "Exhausted" are not available for distribution, but may be seen at the larger libraries of the country.

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