COPPER.

METALLIFEROUS ORE DEPOSITS NEAR THE BURRO MOUNTAINS, GRANT COUNTY, NEW MEXICO.

By SIDNEY PAIGE.

LOCATION.

The Burro Mountains lie near and southwest of Silver City, Grant County, N. Mex. Silver City is reached by a spur of the Atchison, Topeka & Santa Fe Railway, which connects with the main line at Deming, N. Mex., a town about 46 miles to the south. The Southern Pacific Railroad likewise passes through Deming.

TOPOGRAPHY.

The Burro Mountains consist of two distinct mountain masses, the Big Burros and the Little Burros (see map, Pl. IV), rising near the border of a semidesert region. For many miles to the south stretches a waste of sand and gravel, whose unwatered expanse is broken only by precipitous, isolated mountain masses. Near Silver City this desert region merges with the mountain country, and the flat, sandy, featureless plain rises gently to meet the hills. Here infrequent but torrential rains have cut numerous gullies, separated by flat-topped divides, the whole an intricately carved, sloping, gravel plain.

The Little Burro Mountains rise out of this dissected expanse of semiconsolidated gravel about 6 miles southwest of Silver City. Farther to the southwest, about 15 miles from Silver City, is the conical mass of the Big Burros.

The Little Burro Mountains trend northwest and southeast, are about 8 miles long and half a mile to 1½ miles wide, and rise to an elevation of about 6,500 feet above the sea, or about 500 to 700 feet above the general level of the surrounding area. The western face of these mountains is generally steep, locally precipitous, and rises abruptly from the dissected gravel plain. The east side, on the other hand, merges gradually with this plain.

The Big Burro Mountain mass is subconical in form, and its flanks slope from a central peak, at an elevation of 8,054 feet, at first steeply and then gently, to meet and finally merge with the desert deposits at its base.

The Continental Divide passes in a northeast-southwest direction through this region. The summit of the Big Burros is a point on this line, as also is the south end of the Little Burros. All drainage in this region north of this line is tributary to Gila River and thence by way of Colorado River to the Gulf of Colorado. All drainage south of the divide is lost in the sands of the desert. Mangas River, a tributary of the Gila, heading on the divide between the Little and Big Burros, receives much of the drainage of this region, and on the south Walnut, Cherry, and Oak Grove creeks are the more important streams which carry the floods to the desert. None of these streams flow except after heavy downpours, when their beds become the paths of muddy torrents, which disappear as rapidly as they rise shortly after the cessation of rainfall.

GEOLOGY.

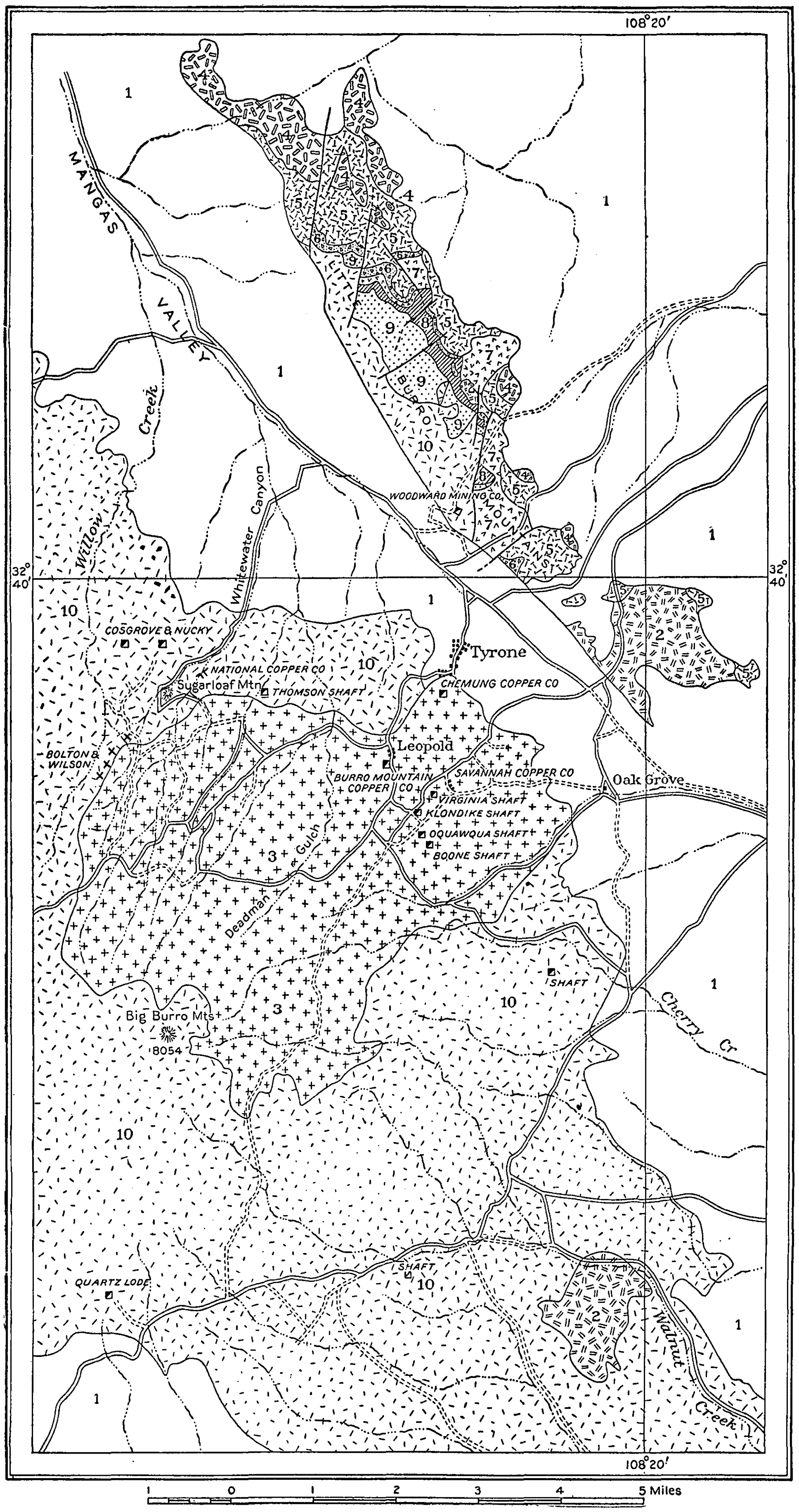
LITTLE BURRO MOUNTAINS.

The Little Burro Mountains afford an excellent example of an exceedingly fragmental geologic record. A study of the geology of the Silver City quadrangle [1] has supplied in large part the missing pages of its history. In this paper simply the principal facts will be stated and their discussion will be left for the later report.

The rocks present in the Little Burro Mountains, named in the order of their age, are as follows: (1) Basal, pre-Cambrian granite; (2) Cretaceous quartzite with overlying Cretaceous shaly and limy beds; (3) a complex of andesitic breccias and intrusive rocks, which in part flowed out (probably) upon the Cretaceous land and in part intruded the Cretaceous rocks; (4) Tertiary (?) accumulations of gravels, sands, and tuffs, accompanied by widespread successive rhyolitic and latitic and andesitic or basaltic lava flows; (5) intrusive stocks of rhyolitic or trachytic type; (6) Pleistocene and Recent gravels.

The Cretaceous sediments and the Tertiary gravels, sands, and tuffs and accompanying lavas may be considered as bedded rocks—that is, rocks which originally formed horizontal or relatively horizontal deposits. These rocks now all dip at a considerable angle toward the east. The Little Burro Mountain mass, in other words, is a tilted fault block, elevated on its west side by a strong northwest-southeast fault. In addition to this main fault, transverse faults trending northeast and southwest break the main block into smaller units, and these, combined with intrusive volcanic stocks, have disturbed what little regularity the succession may have originally had. The map (Pl. IV) will make clearer these rather complicated relations.

[1] Paige, Sidney, Silver City folio, Geol. Atlas U. S., U. S. Geol. Survey (in preparation).



GEOLOGIC MAP OF THE VICINITY OF THE BURRO MOUNTAINS, GRANT COUNTY, N. MEX., SHOWING THE LOCATION OF THE DEPOSITS DESCRIBED.

1, Pleistocene and Recent gravels; 2, volcanic stocks of rhyolitic facies; 3, quartz monzonite and quartz monzonite porphyry; 4, basaltic and andesitic lavas; 5, trachytic and rhyolitic lavas; 6, tuffs and sediments of Tertiary (?) age; 7, basic complex of pre-Tertiary flows (?) and dikes; 8, Cretaceous shale; 9, Cretaceous quartzite; 10, pre-Cambrian granite.

The west-central part of the mountains is made up of pre-Cambrian granite, upon which lie the basal quartzitic beds of the Cretaceous rocks. The remarkably even surface of the granite upon which the quartzites were deposited is of considerable significance as indicating the thoroughness with which erosion acted when planing off these rocks. Moreover, the presence of Cretaceous rocks resting upon a pre-Cambrian basement, when it is known that a few miles to the east hundreds of feet of sediment lie between the pre-Cambrian rocks and the Cretaceous quartzites, indicates without question the long period of erosion preceding the deposition of the Cretaceous sediments.

It is probable that after the deposition of the Cretaceous quartzites and the succeeding limy shales, another erosion interval preceded the next stage in the geologic history of this immediate vicinity. This stage consisted in the intrusion of dark-colored andesitic material into the Cretaceous and older rocks and probably also the extrusions of lavas which flowed out upon the surface, for such igneous rocks overlie and cut the Cretaceous shales. Once more erosion probably had opportunity to alter the surface of the land, for the younger rocks of the region, rhyolitic and latitic, and basaltic lavas, with interbedded sediments and tuffs, lie as a blanket alike upon pre-Cambrian granite, Cretaceous sediments, andesitic breccias, and intrusive rocks.

This last outburst of volcanic material was followed by a period of faulting, perhaps post-Pleistocene, which resulted in the fracture of the mountains, and after these movements undoubted post-Pleistocene faults uplifted the western edge of the mountains. In connection with these fault movements rocks of volcanic types were intruded.

BIG BURRO MOUNTAINS.

The geology of the Big Burro Mountains is far simpler than that of the Little Burros. The basal pre-Cambrian granite has been intruded by a quartz monzonite mass of subcircular outcrop, probably of post-Cretaceous age. Rhyolitic dikes and stocks penetrated later the pre-Cambrian complex and perhaps intruded also the quartz monzonite, though evidence of this relation is not conclusive. The quartz monzonite is intruded, however, by aphanitic, rather acidic dikes, and also by dikes of quartz monzonite porphyry, identical in mineralogical composition with the parent mass.

ORE DEPOSITS.

CLASSES.

The ore deposits about to be described may be placed in three classes: (1) Quartz veins; (2) irregular sulphide-impregnated fracture systems, or shear zones in the pre-Cambrian complex; and (3) secondarily enriched deposits of disseminated cupriferous pyrite in the quartz monzonite. Class 3 has many of the characteristics of class 2, but differs in that it is dominantly associated with the quartz monzonite, and in that the deposits are far more extensive than those of the other class.

QUARTZ VEINS.

LITTLE BURRO MOUNTAINS.

Well-defined quartz fissure veins traverse the pre-Cambrian granite of the Little Burro Mountains, about 1¾ miles north of Tyrone post office. (See Pl. IV, p. 132.) The veins examined by the writer are included in a group of 12 claims controlled by the Woodward Mining Co. The map (fig. 17) shows four veins which have a northerly or northeasterly trend. The easternmost is known as the Contact vein; the next is the Wyman vein; the Casino is the next; and the westernmost vein is not named to the knowledge of the writer.

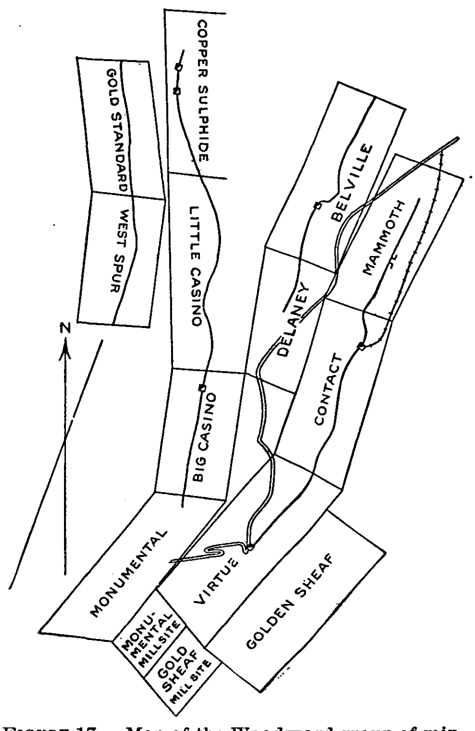


FIGURE 17.—Map of the Woodward group of mining claims, north of Tyrone, N. Mex.

In general, it may be said that all these quartz veins follow fairly well defined fissures in pre-Cambrian granite. The Contact vein, for much of the distance over which it can be traced, follows a well-defined fault plane. The Casino fissure, too, shows some evidence of such an origin. It is not known that the walls of the two remaining veins have suffered any relative movement. The Contact vein, at present being developed near its south end by an incline, which at the time of the writer's visit was 170 feet deep, is opened by several other cuts and shallow shafts. From this incline, called the Virtue shaft, the vein trends N. 60° E. for about 500 feet and then follows a N. 10° E. course for the remaining distance over which it can be traced. At the bottom of the Virtue shaft a drift has been run northeast 12 feet and southwest 6 feet. A short crosscut also has been driven. Forty feet above the bottom a 60-foot drift has been run and 20 to 30 feet higher the vein has been opened for 40 feet. At 60 feet below the surface a stope has been opened to the southwest and carried to the surface. At the bottom the quartz vein is about 18 feet wide. On the next higher level a 16-foot crosscut had not yet reached the hanging wall. On the surface the vein varies in width and locally vein matter is intermixed with country rock.

The gangue mineral in the Contact vein is quartz, usually massive, though drusy cavities may be observed. The metalliferous minerals are pyrite, a little chalcopyrite, a mixture of manganese oxides (probably pyrolusite and psilomelane), and a silver and lead bearing sulphide which is very finely disseminated in the quartz, is intergrown partly with pyrite, and appears in blotchy, grayish-black, cloudlike aggregates. A considerable quantity of this blotchy quartz was crushed to pass through an 80-mesh screen and most of the sulphide when examined under the microscope showed a lustrous black color. Some pieces showed a granular fracture, others had lustrous cleavage faces suggesting galena, and one piece seemed to be a crystal having faces combining a cube and an octahedron. When this material was examined qualitatively in the chemical laboratory for the presence of antimony, in order to prove, if possible, the presence of silver-antimony sulphides, a negative result was obtained, but a good test for lead and silver resulted. It seems probable, therefore, that the mineral is finely granular argentiferous galena. Gold also is present, probably associated with the pyrite. The content of copper is not enough to make the mineral of commercial value. Locally, where the vein follows the fault plane, manganese is conspicuously abundant.

The vein at its south end terminates against a strong fault which passes along the west face of the Little Burro Mountains. At its north end it becomes ill defined and there is some evidence that it passes into a system of smaller fractures, finally dying out entirely.

The ratio of silver to gold values in the Contact vein is about 4 to 1 when silver is 60 cents an ounce. The crosscut and drifts at the bottom of the Virtue shaft are reported to run 15 ounces to the ton in silver. The bottom of the shaft proper is reported to carry 42 ounces in silver and about $5 in gold to the ton. At another locality values as high as 126.8 ounces of silver and 0.64 ounce of gold are reported; also 44 ounces of silver and 0.1 ounce of gold.

The Casino vein dips steeply to the east (see fig. 17) and may be readily traced on the surface. The fracture is not a clean break throughout. Locally considerable country rock is admixed with quartzose material in alternating narrow bands, the whole being impregnated more or less with metallic sulphides. At a 110-foot shaft near the south end of the vein, where an old surface stope may be seen, the quartzose material varied in width between 5 and 10 feet.

At one locality in this stope 3 feet of material, mostly quartz, was followed by 2½ feet of brecciated vein matter against the hanging wall. The values are said to be highest in the brecciated material. Rich streaks up to 18 inches in width and values up to 20 ounces of silver and $5 in gold to the ton across a distance of 5 feet were reported. A clay gangue next the hanging wall suggests a fault fissure.

To the north on this vein the values in gold and silver are said to decrease, while zinc, lead, and copper values increase. Three-quarters of a mile north of the shaft just described the outcrop of the vein may be well seen in a small creek. Here the vein is about 10 feet wide but consists of a ribboned system of quartz stringers and country granite. The mineralization is still strongest near the hanging wall, probably the locus of greatest disturbance at the time of fissuring. Chalcopyrite, pyrite, sphalerite, and galena are conspicuous minerals.

Still farther north, at the Copper Sulphide shaft, 100 feet deep, the vein was worked for the galena and chalcopyrite. Values in gold and silver were reported low. An assay from this shaft is reported as follows: Silver, 4.7 ounces; gold, 0.04 ounce; lead, 5.9 per cent; zinc, 10.2 per cent; copper, 2.1 per cent.

The Wyman vein has been worked over a distance of about 500 feet and not below a depth of 110 feet. The richest returns came from the part above a depth of 40 feet. Silver chloride and gold furnished the values in these upper levels. Zinc and copper are reported to have increased as greater depth was attained and gold and silver to have fallen to $3 to $5 a ton. In the upper portion of the vein much of the ore is reported to have assayed $200 to the ton.

These veins are good examples of simple fissure fillings. In two of them, the Contact and the Casino, there is evidence of faulting; a part of the Contact vein undoubtedly follows a strong fault. Solutions carrying silica and metallic sulphides circulated through the fractures and deposited their load. Surficial alteration has played an important part in the enrichment of the deposits. The locally porous condition and the limonite-stained quartz of the veins at the surface give evidence of this, and chlorides of silver and exceptional values in gold are reported from the upper parts of the Casino and Wyman veins. It is very clear that there is surface enrichment in these deposits and there should be changes of value in depth. However, where unaltered galena, sphalerite, pyrite, and chalcopyrite outcrop and where the quartz has not a stained or porous aspect assays at the surface are a fair indication of what may be expected below.

The presence of manganese dioxide in these veins is interesting in the light of the recent contribution to the study of secondary enrichment by W. H. Emmons,[1] who shows that chlorine salts reacting with sulphuric acid will produce hydrochloric acid, which in the presence of manganese dioxide yields nascent chlorine, a solvent for gold.

Emmons also points out that ferrous sulphate, a precipitant of gold, can not exist in the presence of MnO_2 or of higher manganates, and concludes that the gold will travel downward until a point is reached where no new sources of oxygen are available and the excess of acid in the solutions is removed by reactions producing kaolinization. It is at this stage that iron sulphate becomes increasingly prominent and effective as a precipitant of gold.

Chlorides are reported from the upper levels of the vein described, and abundant MnO_2 may be seen locally on the surface. An explanation for the enrichment of the vein seems therefore to lie in the chemical reaction indicated above.

The fissures which the veins fill are persistent along the strike and if they are not faulted will probably be found to persist in depth. The value of the veins, therefore, exclusive of their surface enrichments will depend directly on the assay values of the unaltered material and the persistence of such values in shoots of workable size. Naturally any values from the enriched upper portions will serve to balance lesser values as greater depth is reached. The Wyman vein indicates the depth to which alteration has taken place at one locality. Such a depth might differ considerably at another locality where the character of the gangue was not such as to favor the percolation of surface water. Solid quartz, for example, might prevent enrichment.

In the Contact vein, at the Virtue shaft, commercially valuable ores are known to a depth of 170 feet, and it is doubtful if enrichment has reached this depth. Therefore the ore may be relied upon to be of more even tenor, though of lower value, at considerable depth than at or near the surface. No one can predict the persistence of the shoots in the solid quartz.

QUARTZ LODE SOUTH OF BIG BURROS.

Three miles south of the summit of the Big Burro Mountains, on property owned by Theodore W. Carter, a strong quartz lode cuts the pre-Cambrian granite. The lode strikes about N. 85° E. and dips steeply south. It can not be traced east of the gulch east of the shaft but may be seen cutting the country rock to the west. A 150-foot shaft has been sunk and drifts run west along the lode, which is exposed by four crosscuts. It is reported to be 30 feet wide at the bot-

[1] The agency of manganese on the superficial alteration and secondary enrichment of gold deposits in the United States, a paper read before the American Institute of Mining Engineers at the Canal Zone meeting, November, 1910.

tom of this shaft. In a second shaft 50 feet deep the lode measured 15 feet or more in thickness. The hanging wall is a narrow dike, probably a rhyolite. Pyrite, chalcopyrite, secondary chalcocite, galena, and hematite are present. The total values in gold, silver, copper, and lead are said to aggregate $10 a ton. On the footwall in the 50-foot shaft a banding or veining of the quartz may be seen, as if the quartz had entered along narrow, nearly vertical fissures. Much of the vein has a barren appearance and contains considerable hematite. The values are associated with the sulphides. The relations of this lode suggest considerable persistence in depth, but no prediction can be made as to the values which will be encountered.

IRREGULAR SULPHIDE-IMPREGNATED FRACTURE SYSTEMS OR SHEAR ZONES.

A number of prospects were examined within the area of pre-Cambrian granite, in which iron and copper sulphides and gold occur in more or less well-defined fracture zones.

The properties which were visited are those of Knucky & Cosgrove, National Copper Co. (C. P. Laughlin), Bolton & Wilson, R. P. Thomson, and several prospects southeast of the Big Burros.

The claims of T. E. Knucky and E. R. Cosgrove are located 3½ miles almost due west of Tyrone and west of Whitewater Canyon. The examination of the writer was confined to the showings in the National shaft and at the dump of the Mayflower shaft.

The National shaft is 180 feet deep and for the lower 125 feet is an incline following a slip which strikes N. 70° E. and dips 60° S. The shaft is sunk in granite which, though fractured, shows no well-defined fissure to a depth of 55 feet, where the shaft turns to follow the slip mentioned. The upper 90 feet of the shaft is in oxidized ground, and scattering carbonates may be seen in vertical fractures. The lower 90 feet of the shaft passes through unoxidized pyrite, except that the above-mentioned slip contains a narrow seam or film of chalcocite an inch or less in thickness. Enrichment processes have not operated extensively here.

At the Mayflower shaft, about 2,000 feet west of the National shaft, some carbonates and much unoxidized pyrite were seen on the dump. The country rock is granite. The feldspar in the sulphide-impregnated granite is altered to sericite, the body of the sulphide-bearing rock being an aggregate of original quartz, secondary quartz, sericite, and pyrite.

It is reported that the unaltered sulphides were struck at a depth of 100 feet. The shaft is 112 feet deep. No encouragement can be given that an ore body will be found at greater depth.

The property of the National Copper Co. is located 3 miles due west of Tyrone, in a gulch at the head of Whitewater Canyon. At this point a tunnel has been driven eastward into the hill for a distance of 300 feet to strike a shear zone carrying chalcopyrite. At the end of this tunnel a drift has been run 47 feet south and 125 feet north. At a point in this drift about 50 feet north of the tunnel a winze was sunk 212 feet; at a depth of 100 feet a 90-foot crosscut was driven in the hanging wall and at the bottom of the winze a 42-foot crosscut was driven in the hanging wall. The main drift was in a dangerous condition from disuse and the winze was inaccessible. An examination of the face at the south end of the main drift showed no well-defined fracture zone. The material on the dump indicates that the deposit consists of chalcopyrite in a rather tight fracture zone. The chalcopyrite was accompanied in its introduction by quartz and calcite. Assays reported to the writer show a total yield in gold, silver, and copper of $4.84 to the ton, with copper at 18 cents. The value of this deposit depends on the persistence and size of the mineralized fracture zone. Little opportunity was afforded to examine it.

The prospects of Bolton & Wilson are 4 miles west of Tyrone, on the east side of Iron Gulch and on the headwaters of Whitewater Canyon. A number of prospect pits were examined. The country rock is pre-Cambrian granite cut here and there by dikes of quartz monzonite porphyry and by a few dark-colored dikes. None of the prospects were such as to give the impression that an ore body might be found. Ill-defined fissures or small fractures trend in general northward or northeastward, showing carbonate of copper near the surface and for a depth of 40 or 50 feet. Unaltered sulphides were struck near the surface. Pyrite, chalcopyrite, and quartz were the principal minerals of secondary introduction. Veinlets of chalcocite were seen and at one locality a little molybdenite filling fractures. Carbonate ores in paying bunches have been in the past extracted from some of the prospects.

The property of R. P. Thomson is about 1¾ miles west of Tyrone, in a small gulch running northward about one-fourth to one-third mile north of the quartz monzonite contact. A shaft 240 feet deep has been sunk in the granite and at 155 feet from the surface a crosscut has been driven for 96 feet southeast. The shaft was not accessible. The crosscut is reported to average 2 per cent of copper, mostly carbonates. The surface showings were very poor.

About 3 miles southeast of Leopold and 2,000 feet southwest of Cherry Creek a 200-foot shaft has been sunk by the Cherry Creek Copper Co. in the pre-Cambrian granite. A little carbonate of copper is visible in the dump. Much specular iron is present in the material, at first sight suggesting chalcocite.

Another shaft 70 feet deep, 6 miles almost due south of Leopold, was examined. Here a shear zone striking N. 75° E. and dipping

85° S. traverses the granite. At the bottom of the shaft several tight seams were seen carrying oxidized cupriferous pyrite. Values up to $43 a ton are reported by John F. Jefford. A few hundred feet south on this ridge a drusy quartz lead carrying much hematite strikes N. 22° W. and dips 30° S. It is said to pan well in free gold.

Other localities in the vicinity where prospect holes had been opened were seen, but the impression gained by a general survey of this pre-Cambrian area is not encouraging for extensive deposits. Undoubtedly gold-bearing sulphide-quartz stringers have been superficially enriched, but the level of unoxidized pyrite is shallow. Small stringers will not pay when the unoxidized pyrite is reached. None of the localities visited gives hope of a copper deposit of workable size.

SECONDARILY ENRICHED DEPOSITS OF DISSEMINATED CUPRIFEROUS PYRITE.

INTRODUCTION.

The type of secondarily enriched ore body, so well known in the Southwestern States, has already been the subject of a number of detailed researches by Lindgren and others. As compared with such work the following notes are but an outline indicating the important geologic and mineralogical relations. This type, in that it is dependent for its origin on sulphide mineralization of fractured porphyry, has much in common with the less important deposits just described; but in that the mineralization was far more thorough and the process of enrichment far more extensive, it is decidedly different. Likewise it differs in being associated with a rock type which is curiously prolific of such deposits at many other localities. For the sake of clarity, and in view of the fact that these ore bodies are more extensively developed than any others in the immediate region, a slightly more systematic treatment will be accorded them than has been followed in the preceding pages.

The chalcocite deposits of the Burro Mountains lie at the foot of and on the northeast side of the Big Burro Mountains. Four companies were developing the field at the time of the writer's visit—the Burro Mountain Copper Co., the Chemung Copper Co., the Savannah Copper Co., and the Mangas Development Co. The writer wishes to express his thanks for the courtesies extended to him by the operators. The information obtained from them was of special value in the preparation of this brief account of the chalcocite ore bodies.

The offices of the several operating companies are located at or near the mining camps of Leopold and Tyrone. The writer was fortunate in having an opportunity to examine the mines as well as to study a number of drill records. It is the purpose of this description to present those geologic relations which have a bearing on the distribution of this type of ore body in this region, without giving a detailed account of individual mines.[1] The facts which are presented, it is hoped, will aid in a clearer understanding of the principles that determine the locus of the ore. Needless to say, the larger operators are already in possession of such an understanding. It is therefore for those not yet acquainted with the region and for those who may not have had an equal opportunity to study the district that the facts are presented.

THE ROCKS.

The first and salient fact connected with the occurrence of the chalcocite ore bodies near Leopold and Tyrone is the intrusion of a mass of quartz monzonite of subcircular outcrop into a pre-Cambrian granitic complex (see map, Pl. IV, p. 132), for the important chalcocite ore bodies are connected with this intrusive rock.

The pre-Cambrian complex comprises various types of coarse to medium grained granites and associated porphyry and pegmatitic dikes, with still later rhyolitic dike and stocklike intrusions. The quartz monzonite is a medium to coarse grained granular rock of rather light appearance where fresh. Both even granular and porphyritic phases are present, and dikes of nearly the same composition as the main mass are locally abundant. These dikes are later than the main mass and are characterized by very large phenocrysts of feldspar, some an inch or more in length.

The quartz monzonite where coarsely granular is composed of quartz, oligoclase and orthoclase feldspar, and a subordinate amount of biotite and hornblende. The oligoclase crystals are fairly well formed and many of them are partly inclosed in crystals of orthoclase and quartz. Sphene, apatite, magnetite, and a little chlorite are present.

The porphyritic phases contain phenocrysts of oligoclase, with perhaps a little andesine and albite, and of biotite embedded in a fine mosaic of quartz and orthoclase with a little twinned feldspar. Quartz makes up about half of the groundmass. Apatite, sphene, and magnetite are accessory minerals.

In both the even-grained and porphyritic phases of the quartz monzonite the biotite mica is noticeable in hand specimens, its lustrous black color contrasting strongly with the otherwise light appearance of the rock. In the ore-bearing zone, however, the monzonite takes on a quite different appearance; it is iron stained, fractured, and silicified; the biotite has generally disappeared; kaolinization of the feldspars is prominent, and hills in this zone have a characteristic rough, jagged, gossan-like appearance.

[1] A description of this territory and an account of some of the mines operated in the past is published in Prof. Paper U. S. Geol. Survey No. 68, 1910, by Waldemar Lindgren, L. C. Graton, and C. H. Gordon.

FRACTURING.

The second important condition affecting the locus of the ore deposits is the intensity and distribution of the fracturing of the quartz monzonite. Where solid and unaltered this rock does not carry ore. Where intensely fractured it carries ore. There is a distinct and traceable gradation from the zone of intense fracture to the areas of essential solidity, and the surface exposure of the fractured mass has a comparatively definite form. It may be represented as a triangle pointing southwest, its point approximately 1½ miles southwest of Leopold and its base formed by a line passing from Tyrone to Oak Grove. The line of greatest fracture lies between Leopold and Tyrone and forms roughly the north side of the triangle. This north edge follows for a portion of the distance the contact between the quartz monzonite and the pre-Cambrian granites to the north, and present data seem to indicate that mineralization of this type is not extensive north of this contact. (See map, Pl. IV, p. 132.)

Southward from this zone of greatest fracture the rock gradually becomes more solid and less altered. The fracturing fades away toward the south in a manner suggesting the opening of a fan, placed parallel to the locus of greatest fracture, with its handle southwest of Leopold, and so opening that one edge of it swings as a radius, with the handle as a center, through the arc of the triangle. On the southern edge of the imaginary triangle the fractured rock merges very imperceptibly with the essentially solid quartz monzonite.

In the above description only the horizontal distribution of fracturing has been considered. There is reason to believe that certain elements affecting the depth of the ore bodies are directly due to the arrangement of the fractures.

A study of the mines shows clearly that the depth to which oxidation has penetrated the rocks increases in a northeasterly direction, viz, from Leopold to Tyrone—and, further, that toward the south the dip and strike of the fractures shift. In the region about Tyrone, for example, the strongest fractures observed in the mines strike northeasterly and dip at different angles to the south. There are, it is true, innumerable fractures which do not follow this rule, notably vertical ones which cut the eastward-dipping system, but the fracturing is dominantly northeast with a southerly dip. On the other hand, on the southern border of the fractured zone the dominant fractures strike east, with a northward dip, though here also many other fractures are found. It should be stated that some of the strong fissures in the mines represent fault planes and that the contact of the quartz monzonite with the granite between Tyrone and Leopold follows for a distance such a fault. (See Pl. IV.)

Considering a number of these fissures, then, as fault planes, we may readily see that a pyramid-shaped block is involved in the ore-bearing zone and that while the limiting fractures of this block (those near the northern and southern edges) will meet at the surface near the point of the pyramid, they will meet at increasing depths as distance from the point is gained. (See fig. 18.) It must not be understood that any such regular fractures exist as are shown in the diagram, but it is a fact that the dominant strikes and dips are so distributed as to suggest such a figure as is presented. It would be expected that percolating water under the influence of such a system of breaks would tend to migrate down the planes of the breaks and would move toward the zone of most intense fracture. Such seems to have been the case, for deepest oxidation has taken place near Tyrone.

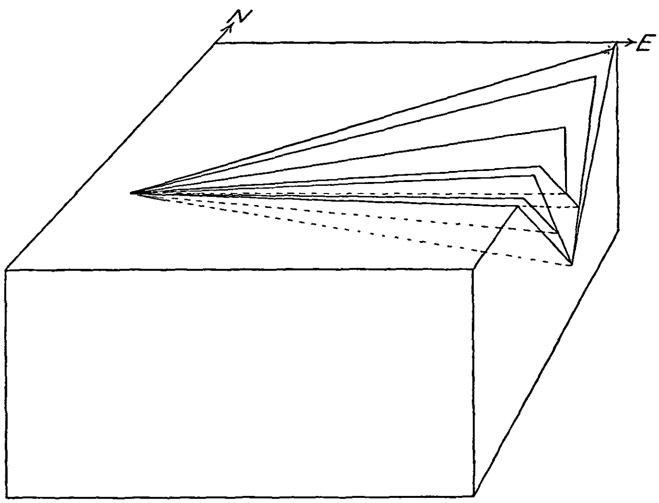


FIGURE 18.—Stereogram showing how the juncture of two systems of east-west and northeast-southwest fractures dipping toward each other will become lower to the east.

MINERALIZATION.

The present conditions of the ore bodies so far as mineralization is concerned may be attributed to three processes—primary mineralization, enrichment, and leaching.

Primary mineralization consisted in the deposition of cupriferous iron pyrite (probably finely intergrown chalcopyrite with pyrite) and locally quartz. The introduction of the pyrite followed the fracturing of the quartz monzonite. The solutions which carried the sulphides not only deposited their burden in the innumerable fractures but likewise soaked into the body of the rock. Deposition was greatest along lines of easiest passage, viz, in well-defined fissures. At the close of the period of deposition of the primary ore the mass of the rock consisted of a network of veins and veinlets of iron pyrite, with locally quartz and a little chalcopyrite. The feldspar of the rock was much altered to sericite and the ferromagnesian minerals were chloritized.

The formation of ore bodies from this stockwork of pyrite veins was clearly a result of secondary enrichment. An opportunity for such enrichment was afforded before and during the Quaternary cycle of erosion, in which were laid down those widespread deposits of gravels and sands which now fill the Mangas Valley and the country to the east and south. One standing on the summit of the Little Burros and looking toward Tyrone can easily recognize the dissected sloping rock-cut platform which circles the Big Burros and merges with the gravel deposits at its outer edge. (See fig. 19.)

FIGURE 19.—Sketch showing sloping plain at the foot of the Big Burros, now dissected, cut during the Quaternary cycle of erosion, and the gravels which fill the Mangas Valley. *a*, Big Burros; *b*, dissected sloping plain; *c*, gravel of Mangas Valley, formed in part by the erosion of the sloping plain.

The process of enrichment is well known, and consists first in the oxidation of the unaltered pyrite near the surface by surficial waters and second in the deposition of chalcocite at lower levels by downward-percolating water, which in the main carried copper in a sulphate solution. The junction of several fissure systems and the local damming of percolating waters against relatively impervious dikes have tended to produce enrichment.

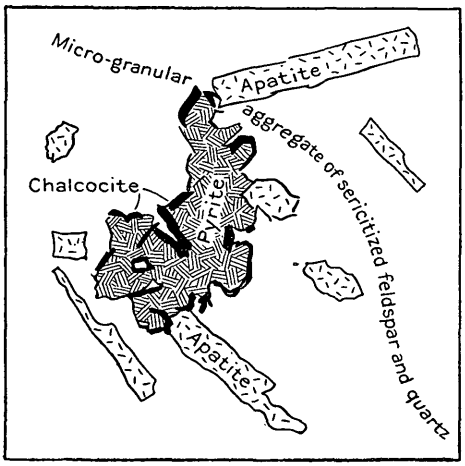


FIGURE 20.—Group of pyrite crystals, showing chalcocite along the edges, embedded in sericitized feldspar and quartz.

A microscopic examination of a number of thin sections cut from sulphide-bearing rocks in the mine of the Chemung Copper Co. shows rather plainly certain of the stages in the formation of the chalcocite. Figure 20 shows a small group of pyrite crystals embedded in a microcrystalline aggregate of sericitized feldspar and quartz. Much of the quartz is probably secondary. Abundant prisms of apatite are present. Chalcocite has formed on the edges of the pyrite. Figure 21 shows in addition the presence of kaolin associated with the pyrite. The parallel kaolin bands shown in the figure probably follow the twinning planes of a plagioclase feldspar phenocryst now almost entirely altered to a mass of sericite. Figure 22 shows a small veinlet, in sericitized feldspar, filled with chalcocite, pyrite, and a little quartz. Figure 23 shows another veinlet cutting feldspar in which a nodule of pyrite is surrounded by chalcocite; a little quartz is present. Near this veinlet may be seen grains of unaltered sulphide.

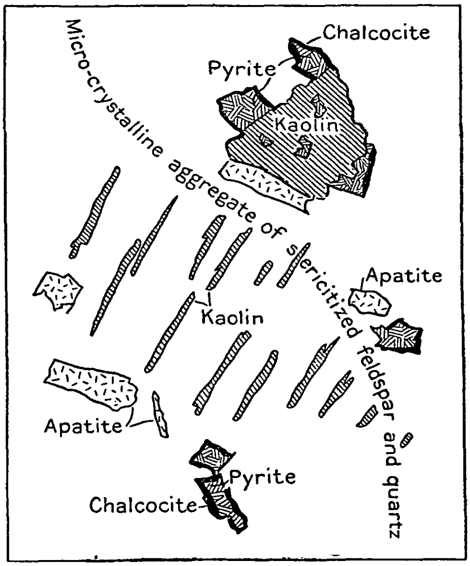


FIGURE 21.—Kaolin associated with chalcocitization of pyrite.

In other specimens the rock is speckled with grains of unaltered pyrite, near which are chalcocite grains, some without any signs of the original pyrite and some showing partial replacement.

It is a characteristic feature of this district that much of the ore-bearing territory has been thoroughly leached, near the surface, of its copper content; that is, all the copper has gone down and only a siliceous, ferruginous capping remains. Locally this leaching has been carried to great depths, 700 feet or more. This process of leaching, which is simply a step in the formation of a secondary chalcocite ore body, is unfortunately also capable of destroying an ore body and has done so in a number of places in the territory examined. Portions of strong veins of chalcocite are locally leached, nothing remaining of the original mineralization except a network of limonite veins. The disseminated stockworks also are locally so impoverished as to preclude their extraction at the present price of copper. This process of late leaching is well shown in some places where vertical fractures cut across eastward-dipping veins. (See fig. 24, p. 147.)

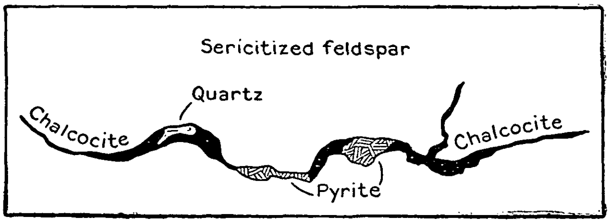


FIGURE 22.—Small veinlet in sericitized feldspar filled with chalcocite, pyrite, and quartz.

Although developments have shown that as a rule leached veins will lead at greater depths to enriched ore bodies, it is also clear that this is not always the case, for solutions may carry copper great distances, perhaps to such depths that it ceases to be profitable to continue a search. Definite prediction that a certain block of leached ground will yield an ore body at a given depth is impossible. To determine this point, a drill hole or a shaft is necessary.

The thickness of the blanket of barren ground overlying the ore bodies is extremely variable. In the country southeast of Leopold it varies from a few feet to 500 feet. Near Leopold there is reason to believe that the topography of the surface affects the upper limit of the ore. For example, an ore body to a certain level will pass horizontally into leached ground, as a gulch on the surface is approached—that is, locally leaching is at lower levels directly beneath stream channels. Near strong veins and faults, too, leaching is deeper than in the adjacent ground. The thickness of the chalcocite zone also is variable. Southeast of Leopold unaltered sulphides are struck locally at a depth of 380 feet, above which is 180 feet of secondarily enriched ground. The leached ground therefore is 200 feet deep. Again, a drill struck unaltered sulphides at 250 feet, and at another locality unaltered sulphides appear at 300 feet. The ground carrying chalcocite is locally 200 to 300 feet thick. In the Tyrone country leaching is locally very deep, 700 feet or more.

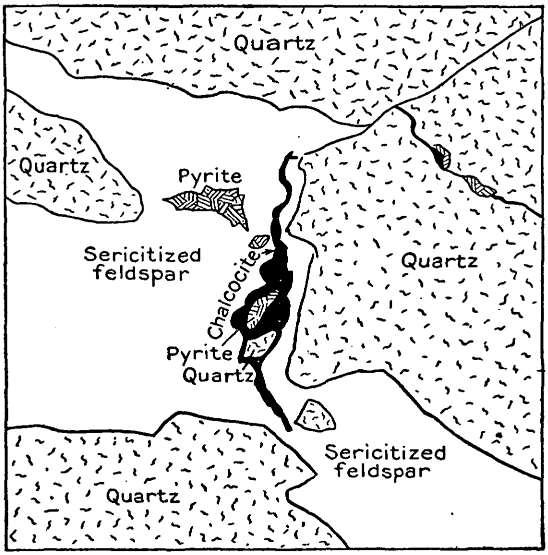


FIGURE 23.—Veinlet showing nodule of pyrite surrounded by chalcocite.

Permanent water level also is variable, standing 300 to 500 feet beneath the surface. It may vary as much as 200 feet in half a mile. The amount of water increases rapidly as the footwall fault near Tyrone is approached, indicating increased flowage near such breaks and accounting for the deeper leaching adjacent to them.

What has been said indicates that from their very nature irregularity is to be expected in the shape and size of the ore bodies, for the depth to which enrichment has penetrated is variable and also the amount of leaching which followed such enrichment.

Broadly considered, the ore bodies that have been best developed fall into two classes—those which are directly connected with veins and those which are not. Of the former several have been worked extensively in the territory southeast of Leopold, and much rich ore was extracted. In the mines near Leopold and Tyrone also much rich ore has been extracted from veins. The second class includes cigar-shaped masses of chalcocite ore and irregularly shaped blocks of ground grading off at the edges into rock too poor to be commercial. This grading off into lean material is in some places due to a change to unaltered sulphides, in others to a change to leached material. A number of these ore bodies are several hundred feet in length, breadth, and thickness.

The material considered ore in these mines varies in copper content from 2.5 to 3 per cent. As a rule the costs of mining and price of copper will determine when an ore body will cease to be profitable to work.

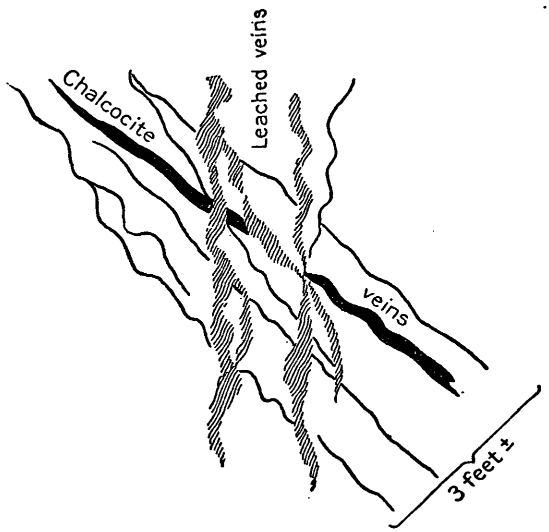


FIGURE 24.—Sketch showing leaching of eastward-dipping chalcocite veins along later vertical veins carrying only limonite.

DESCRIPTION OF THE MINES.

At the time of the writer's visit development by the Savannah Copper Co. was confined to drilling. A number of mines now closed but worked in the past are controlled by this company, but it was not practicable to study the underground workings. The more important shafts are located on Plate IV (p. 132), and the notes given below will indicate the character of the deposits. The Mangas Development Co. also confined its operations to drilling. Active development by drifting and shaft sinking was under way only on the property of the Burro Mountain Copper Co. and the Chemung Copper Co.

MINES OF SAVANNAH COPPER CO.

The offices of the Savannah Copper Co. are located half a mile nearly east of Leopold. The Boone shaft is 300 feet deep and connects underground with the Oquaqua shaft, about 900 feet to the north-northwest. The Boone shaft develops a nearly vertical vein trending north-northwest. The vein has not been worked above the 250-foot level. It varies from a few inches to 10 feet in width. All the ore was taken from the 250-foot level over a distance of about 600 feet. Stoping did not exceed 30 feet above the level. Winzes 15 to 20 feet deep were opened. The mine run yielded 5 per cent of copper, and hand-sorted stringers gave 10 or even 20 per cent values.

The Oquaqua shaft is 300 feet deep and opens about a mile of underground work. No ore was found in the workings except a vein 3 or 4 feet wide with enrichment in the walls up to 2 per cent for 15 to 20 feet. This vein, trending N. 80° E. and dipping 60° N., was followed for 600 feet and crosscut four times. A winze 40 feet below the level began to reach unaltered sulphides. Carbonates and iron gossan descend to 200 feet at this locality and unaltered sulphides are found at about 380 feet.

The Klondike shaft, about 1,800 feet nearly north of the Oquaqua shaft, is 300 feet deep. It cuts a north-south vein dipping 60° E. at 250 feet. At this depth a drift was driven 150 feet and some crosscutting done. But little ore was found. Unaltered sulphides were reached at 300 feet. Most of the values were in the carbonates and were taken out near the surface. Among the other properties idle at this time was the Virginia, located about one-third mile east-southeast of Leopold. Here a northeast lode, dipping 50° northwest, has been explored by a vertical shaft reported to be 200 feet deep. Some good ore was taken out previous to 1905, and the mine has had some production since that time.

There are a number of other old workings on the Savannah Co.'s ground, but they need not be mentioned here. The company is at present engaged in exploring its ground by churn drills.

MINES OF BURRO MOUNTAIN COPPER CO.

The property of this company has been operated since 1901 or 1902, and active production has been in progress from 1903 or 1904 to the present time. About 1905 the property was acquired by Phelps, Dodge & Co. The main shaft is in Leopold, and a second shaft, the Boston shaft, is located one-third of a mile east-northeast of town. The workings have attained a depth of about 400 feet, with a winze level at 500 feet. Four ore bodies have been more or less developed—the Protection, the West Sampson, the East Sampson, and the East. The first three of these bodies have a very definite orientation of their long diameters. They trend northeast, are arranged roughly en échelon, are longer than wide, and each shows to a greater or less degree that the mass of enriched material is lenticular in form. The East ore body has more noticeably the form of an irregular cone pointing downward and northeastward. It is connected with the East Sampson by a narrow neck.

While unaltered pyrite has been encountered at the extreme west end of this group, the bottom of the chalcocite zone has not been encountered elsewhere. The values in the lenses hold up well along vertical lines through their centers but fall gradually as the ends are approached.

In this mine the St. Louis vein, a well-defined fissure dipping east and considered the footwall fissure, as all the ore bodies are east of it, has produced much rich ore in the past. It is the only very strong fissure to be seen in the mine. The Protection ore body is said to be developed on this vein. There are numberless smaller veins, however, some of which are undoubtedly small faults. In one place a body of ore was sharply cut off by such a fault. Large ore reserves are present in the mine, as much of the work done is in the nature of development. The company is sinking a new shaft, about midway between the mines at Leopold and Tyrone. At Leopold a 300-ton concentrating mill has been operated at intervals for several years. Only development work was done in 1910.

MINES OF THE CHEMUNG COPPER CO.

The principal workings of the Chemung Copper Co., located at Tyrone, are opened by two shafts, No. 2 and No. 3. Shaft No. 1 is not connected with the main workings.

Shaft No. 2, 722 feet deep, is located about half a mile nearly south of Tyrone in a small gulch entering the gulch on which Leopold and Tyrone are located. Shaft No. 3, 421 feet deep, is one-fourth mile farther south, up the same small gulch. The underground workings include about 8 miles of tunnels, drifts, raises, and winzes. All the ore extracted is on the dumps, none having ever been shipped.

Ore in the Chemung mines occurs both in veins and in large blocks of more or less ore-bearing ground, the boundaries of the ore bodies depending on the degree of leaching which has taken place. From shaft No. 3 the ore zone pitches almost due east, spreading and splitting up as it gains depth. What is called the hanging-wall fault is a persistent break which has been developed in the mine over a horizontal distance of 2,750 feet. The fault dips from 45° to 50° E. and strikes about northeast. It is definitely enriched both in the fissure and in the adjacent walls, though locally it is thoroughly leached. The mine has developed a number of veins that are quite distinct from the disseminated ore bodies. In some of these veins values of 12 per cent or more are found. The presence of ore in disseminated bodies to the east of the hanging wall proves the possibilities east of that break.

West of shaft No. 2 the ground is leached, and as the so-called footwall fault is approached water increases noticeably—in fact, a very strong flow develops, sufficient to prevent for the present the development of the territory immediately adjoining the fault. The waters are highly impregnated with copper salts.

Though unoxidized pyrite is locally found in this mine, leaching reaches a remarkable depth, being proved to exist on the 800-foot level.

The ore which has been hoisted from the mine will average a little higher than 3¼ per cent. It is reported that by reducing the limit to 2½ per cent the ore reserves could be increased by one-half.

SUMMARY.

To summarize, the following geologic facts are important in their bearing on the extent and distribution of the chalcocite ore bodies near Tyrone and Leopold:

The ore is for the most part in the quartz monzonite. Though some granite is present in the Tyrone mines and though this rock contains ore, it may be said that the contact of the quartz monzonite with the granite marks the northern edge of the ore-bearing zone.

The distribution of the ore is directly dependent on a system of fractures. The fractures roughly take the form of a triangle whose point lies southwest of Leopold. The dips of the fractures to the south in the northern part of the area and to the north in the southern part of the area tend to make the fractures deeper toward the east. The more highly fractured region lies between Leopold and Tyrone. The number of fractures diminishes to the south, and there is a corresponding diminution in the richness of the disseminated ores, though not of individual veins.

The primary deposition of ore seemed to be governed principally by the fractures. Dikes within the ore-bearing zone, if fractured, carry ore; if not fractured they do not carry ore. The richest ore bodies are found in the zone of greatest fracture or along well-defined veins. The junction of several systems of veins tends to increase the value of the ores; dikes also have locally acted as dams to percolating waters and thus increased the precipitation of secondary ores. Ore of this type will probably not be found in areas of fairly solid, relatively unoxidized quartz monzonite.

The ore bodies are essentially secondarily enriched cupriferous pyrite deposits in veins and in stockworks.

The depth to unaltered sulphides is variable and in general increases to the east. When the level of unaltered primary pyrite is clearly reached, no enriched ore can be expected beneath it. Individual enriched veins may penetrate the general level of primary pyrite.

Leaching of the ore bodies has locally impoverished them; and though in general a leached area indicates commercial ore at greater depths, yet here and there leaching may extend to depths considerably below the principal ore horizon.

PRELIMINARY REPORT ON THE MINERAL DEPOSITS OF DUCKTOWN, TENNESSEE.

By W. H. Emmons and F. B. Laney.

INTRODUCTION.

The mineral deposits of Ducktown, Tenn., are located in the southeast corner of the State, near the North Carolina line, and extend southward into Georgia. The deposits were discovered in the late forties and, except during a brief interval in the early sixties and a longer one from 1877 to 1890, mining operations have been carried on continuously since their discovery. They had produced to the end of 1909 over 190,000,000 pounds of copper, about 1,500,000 tons of iron ore, and a relatively small amount of silver and gold. They yield at present, in addition to the metals, about 650 tons of sulphuric acid daily. Two companies are operating in the district, each having its own smelter, railroad, and acid plant. These are the Tennessee Copper Co., with headquarters at Copperhill, and the Ducktown Copper, Sulphur & Iron Co., with headquarters at Isabella, about 3 miles north of Copperhill. The production of copper in 1909 was 19,207,747 pounds.[1]

The district is included in the mountainous area of the southern Appalachians, and the greater portion of it is a small intermontane plateau about 1,600 feet above sea level, which is nearly surrounded by mountains that rise from 1,000 to 2,000 feet higher. This mountainous district is an area of complex geologic relations and extensive metamorphism. The region surrounding Ducktown has been mapped by Keith,[2] Hayes,[3] Hayes and Campbell,[4] La Forge and Phalen,[5]

[1] Butler, B. S., Mineral Resources U. S. for 1909, pt. 1, U. S. Geol. Survey, 1911, p. 171.

[2] Keith, Arthur, Knoxville folio (No. 16); Loudon folio (No. 25); Nantahala folio (No. 143), Geol. Atlas U. S., U. S. Geol. Survey.

[3] Hayes, C. W., Cleveland folio (No. 20), Geol. Atlas U. S., U. S. Geol. Survey, 1895; Physiography of the Chattanooga district in Tennessee, Georgia, and Alabama: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 2, 1899, pp. 1–58.

[4] Hayes, C. W., and Campbell, M. R., Geomorphology of the southern Appalachians: Nat. Geog. Mag., vol. 6, 1894, pp. 63–126.

[5] La Forge and Phalen, Ellijay folio (in preparation), U. S. Geol. Survey.

and others. The mineral deposits also have been described in several papers,[1] which together afford a great fund of useful data on the occurrence and genesis of the ores.

The work on which this paper was based was done in the summer of 1910, from May 1 to August 31. Mr. Laney was engaged during the greater portion of that period in areal mapping of the district and in stratigraphic studies in fields near by. The ore bodies were mapped and studied by Mr. Emmons. The result of the investigations will appear in a joint paper on the geology and ore deposits of the district. The present paper is simply a preliminary statement of the principal economic results, and it may be necessary to modify the conclusions when the study shall have been completed.

The writers wish to express their thanks to Mr. Waldemar Lindgren and to Mr. Arthur Keith for valuable suggestions in the field, and to Messrs. N. H. Emmons and M. A. Caine, of the Tennessee Copper Co., and Messrs. C. W. Renwick and J. H. Taylor, of the Ducktown Copper, Sulphur & Iron Co., for much valuable information and for many courtesies.

OUTLINE OF THE GEOLOGY OF THE REGION.

INTRODUCTION.

The region including the Ducktown district has been described in the several papers cited above. The folio describing the Nantahala quadrangle,[2] which is east of the Ducktown district, was published in 1907. In this folio are brought together in concise form the descriptions of the formations and the salient features of the geologic history of the province as a whole. The text of the folio has been freely drawn upon in the outline of the geology which follows.

The mountainous area of eastern Tennessee is composed of igneous, sedimentary, and metamorphosed rocks which range in age from pre-Cambrian to Carboniferous. These rocks have nearly everywhere been closely folded, at many places they have been complexly faulted, and some of them have been profoundly metamorphosed by pressure at great depths. The major faults, the axes of the folds, and the schistosity developed by metamorphism trend as a rule toward the northeast. The rock formations outcrop as parallel belts, and

[1] Safford, J. M., Geology of Tennessee, Nashville, 1869, pp. 469–482. Whitney, J. D., Remarks on changes which take place in the structure and composition of mineral veins near the surface, with particular reference to the east Tennessee copper mines: Am. Jour. Sci., 2d ser., vol. 20, 1855, pp. 53–57. Ansted, D. T., On the copper lodes of Ducktown in east Tennessee: Quart. Jour. Geol. Soc., vol. 13, 1857, pp. 245, 254. Heinrich, Carl, The Ducktown ore deposits and the treatment of the Ducktown copper ores: Trans. Am. Inst. Min. Eng., vol. 25, 1896, p. 173. Kemp, J. F., The deposits of copper ores at Ducktown, Tenn.: Trans. Am. Inst. Min. Eng., vol. 31, 1902, p. 244. Weed, W. H., Types of copper deposits in the southern United States: Trans. Am. Inst. Min. Eng., vol. 30, 1901, p. 480.

[2] Keith, Arthur, Nantahala folio (No. 143), Geol. Atlas U. S., U. S. Geol. Survey, 1907.

where the softer rocks have been eroded the lowlands and valleys are formed, leaving the more resistant rocks as ridges or mountain ranges, most of which trend northeastward like the major structural features of the country.

PRE-CAMBRIAN FORMATIONS.

The oldest formation is the Carolina gneiss, a great series of schists and gneisses which probably represent for the most part the metamorphosed equivalents of granite and other igneous rocks, though certain phases are regarded as metamorphosed sedimentary rocks.

The Roan gneiss is associated with the Carolina gneiss in relations which seem to imply that it is intrusive in that formation. It has been extensively metamorphosed, but certain phases of it are not so highly schistose as the Carolina. It is probable that most of this gneiss was diorite and gabbro. Both the Carolina and the Roan are intruded by granite which, though locally schistose, has not been subjected to the profound metamorphism that affected the gneisses.

CAMBRIAN FORMATIONS.

Hiwassee slate.—Resting unconformably upon the gneisses and the granite is a great series of sedimentary rocks consisting of graywackes, grits, conglomerates, shales, and limestones. Cambrian fossils have been found well toward the base of this series. The oldest formation of this series in the Nantahala quadrangle is the Hiwassee slate. This consists of banded slate and sandy shale, and its thickness is probably about 500 feet. It is much thicker than that where exposed in the Murphy quadrangle, in the gorge of Hiwassee River.

The Wilhite slate, the Citico conglomerate, and the Pigeon slate, of Hayes, which are exposed in the southeast corner of the Cleveland quadrangle, are regarded as the equivalents of the Hiwassee.[1] The Wilhite, though consisting in the main of dark slate, carries lenses of gray siliceous or argillaceous limestone[2] which grades into calcareous slate. Some limestone conglomerates are associated with the limestone and have evidently been derived from them. Interbedded with the slates are beds of sandstones and conglomerates and locally these attain considerable thickness. At most places in this area the Hiwassee is closely folded, and its thickness can not be stated with even approximate accuracy.

Great Smoky formation.—The Great Smoky formation is a thick series of rocks extensively developed in the Great Smoky Mountains.

[1] Keith, Arthur, Nantahala folio (No. 143), Geol. Atlas U. S., U. S. Geol. Survey, 1907, p. 11.

[2] Hayes, C. W., Cleveland folio (No. 20), Geol. Atlas U. S., U. S. Geol. Survey, 1895, p. 2.

Generally it overlies the Hiwassee slate, but in some places it overlaps the Hiwassee and rests directly upon the Carolina gneiss. The formation includes conglomerate, graywacke, grit, sandstone, quartzite, mica schists, garnet schist, and slate. The conglomerates, grits, and sandstones are greatly in excess of the more highly aluminous layers. These grade one into another along the beds and across them. The whole series may be described as an association of beds of the different sedimentary rocks. Feldspar is a prominent constituent of nearly all the gritty layers, although it is somewhat subordinate to quartz. In the Ducktown region few of the pebbles are more than one-fourth inch in shortest diameter, though some of them are half an inch long. Some of the conglomerate bands contain a few flakes and flat pebbles of dark slate, presumably derived from associated slates.

The slaty beds are composed of finely comminuted material of sedimentary origin. Even in these there is a very large proportion of quartz and some feldspar. There is probably not much clay in any of the beds and if they have been derived from muds, it would seem that such muds had not been greatly changed by weathering. The Great Smoky formation has been closely folded and at some places converted to schist. Some layers have been changed to bands containing large amounts of garnet, staurolite, and other metamorphic minerals. Those containing abundant staurolite crystals appear to be fairly persistent and some of them may be traced over great distances.

Deformation is such that the thickness of the Great Smoky formation can not be accurately measured, but the best estimate available places it at nearly 6,000 feet.

Nantahala slate.—The Nantahala slate, which overlies the Great Smoky formation, is composed of black and gray slates and of schists containing mica, garnet, staurolite, and ottrelite. Near the base these strongly resemble the slate and schist beds in the Great Smoky. The basal part of the Nantahala resembles the Great Smoky in that it carries many sandstones and conglomerates. Higher up in the formation there are also unimportant layers of graywacke and conglomerate. The thickness of the formation in the Nantahala quadrangle is from 1,400 to 1,800 feet.

Tusquitee quartzite.—The Tusquitee quartzite, which lies conformably above the Nantahala slate, consists chiefly of white quartzite which contains locally a few seams of fine conglomerate. At some places the component minerals are mashed and recrystallized. This formation is in general from 50 to 200 feet thick, but locally it reaches a thickness of 500 feet.

Brasstown schist.—The Brasstown schist overlies the Tusquitee quartzite and consists mainly of black or bluish-gray ottrelite schist, with a varying thickness of banded slate containing little or no ottrelite. The schist has been subjected to various degrees of metamorphism. Locally garnet and staurolite are developed.

Valleytown formation.—The Valleytown formation, which overlies the Brasstown schist, consists of graywacke and fine-grained gneiss interbedded with dark garnet and ottrelite schists. In the basin of Valley River mica schist and fine-banded gneiss constitute practically all of the formation. The beds are most uniform along Nantahala River, where they are apparently from 1,000 to 1,200 feet thick.

Murphy marble.—The Murphy marble, which overlies the Valleytown formation, is a white, blue, or white and blue recrystallized limestone. Where the base is exposed it passes downward into the Valleytown by interbedding with the slates of that formation. It passes into the overlying Andrews schist through interbedded marble and schist. The thickness ranges from 150 to 500 feet.

Andrews schist.—The Andrews schist consists of a bed of calcareous schist from 200 to 350 feet thick. It contains ottrelite, muscovite, biotite, and other minerals. Brown hematite is interbedded with the schists and occurs also as lumps and masses in the residual clay.

Nottely quartzite.—The Nottely quartzite, which is the highest Cambrian formation exposed in the Nantahala quadrangle, originally consisted of quartz sand and feldspathic material. During metamorphism this was replaced by secondary quartz and muscovite. In some places the mica flakes become coarse and the rock approaches quartz schist in appearance. The formation is at least 150 feet thick.

LATER PALEOZOIC FORMATIONS.

All the Paleozoic formations which have been described are of Cambrian age and all are exposed in the Nantahala quadrangle, which joins the Murphy quadrangle on the east. It is not known that the Nottely quartzite is the last formation deposited in that area, for the record of sedimentation may not be complete in the Nantahala quadrangle. Keith[1] has correlated the Valleytown formation of the Nantahala quadrangle with the Hesse sandstone of the Loudon and other quadrangles. In the Loudon quadrangle, which is just north of the Murphy quadrangle, there are above the Hesse about 1,500 feet of Cambrian limestone, sandstone, and shale, exclusive of the Knox dolomite, about 3,500 feet thick, which is regarded as in part of Cambrian age. Above the Knox in the Loudon region is a considerable thickness of Silurian, Devonian, and Carboniferous strata which have been almost if not completely removed in the mountainous area. From the base of the Cambrian

[1] Nantahala folio (No. 143), Geol. Atlas U. S., U. S. Geol. Survey, 1907, p. 11.

to the top of the Great Smoky conglomerate the thickness of strata is about 6,000 feet; from the top of the Great Smoky to the Nottely quartzite it is about 5,300 feet; and from the Nottely quartzite to the top of the Carboniferous it is about 9,600 feet. These figures are not accurate, for the several formations feather out here and there, and there is no certain record that some of them ever covered the Ducktown district,[a] but they convey an idea, probably not exaggerated, of the great thickness of the Paleozoic rocks in this region. As the contacts of the various formations are not known to show angular unconformities, it is assumed that the beds were approximately horizontal one above another when the great Appalachian revolution took place near the close of Paleozoic time. This revolution was accompanied by folding, faulting, mountain building, and metamorphism.

GEOLOGIC STRUCTURE OF THE APPALACHIAN PROVINCE.

Three kinds of geologic structure are developed in the southern Appalachians, each one prevailing over an area corresponding to one of the geographic divisions. In the Cumberland Plateau and in the region west of it the rocks are nearly horizontal and not much altered. In the valley region they are steeply tilted, folded, and faulted and some of them are altered to slates. In the mountain district, which includes the Ducktown region, faults and folds are numerous, and slaty cleavage, schistosity, and other results of great dynamic metamorphism are conspicuously developed.

In the folded and faulted regions the major structures trend northeastward. Keith[1] says:

> The crests of most folds continue at the same height for great distances, so that they present the same formation. Often adjacent folds are of nearly equal height and the same beds appear and reappear at the surface.

Hayes,[2] describing the structure in the Cleveland quadrangle, which borders the Murphy quadrangle on the west, says:

> The folding is greater in thin-bedded rocks, such as shale and shaly limestone, because the thin layers were most readily bent and slipped along their bedding planes. Perhaps the most striking feature of the folds is the prevalence of southeastward dips. In some sections across the southern portion of the Appalachian Valley scarcely a bed can be found which dips toward the northwest.

The faults are mainly of the reverse type and practically all of them dip toward the east. Some are simply ruptured folds and, as

---

[1] Op. cit., p. 6.

[2] Hayes, C. W., Cleveland folio (No. 20), Geol. Atlas U. S., U. S. Geol. Survey, 1905, p. 3.

stated by Keith, many of them are on the northwest sides of the anticlines.

Although the folds and faults characterize both the valley region and the mountain area, slaty cleavage is more generally developed in the mountain area, and in many places it obscures all other structures. Keith[1] says:

> All rocks were subjected to this process, and the final products of the metamorphism of very different rocks are often indistinguishable from one another. * * * There is a great increase of metamorphism toward the southeast, until the resultant schistosity becomes the most prominent of the mountain structures. Formations there whose original condition is unchanged are extremely rare, and frequently the alteration has obliterated all the original characters of the rock. Many beds that are scarcely altered at the border of the valley can be traced southeastward through greater and greater changes until every original feature is lost. * * *
>
> Along these planes or zones of localized motion the original texture of the rock was largely destroyed by the fractures and by the growth of the new minerals, and in many cases this alteration extends through the entire mass of the rock. The extreme development of this process is seen in the mica schists and mica gneisses, the original textures of which have been entirely replaced by the schistose structure and parallel flakes of new minerals. The planes of fracture and schistosity are inclined toward the southeast through most of the mountains, although in certain belts * * * northwesterly dips prevail.
>
> * * * These structures * * * were chiefly the result of compression which acted most effectively in a northwest-southeast direction, at right angles to the general trend of the folds and of the planes of schistosity. Compression was also exerted, but to a much less extent, in a direction about at right angles to that of the main force. To this are due the cross folds and faults that appear here and there throughout the Appalachians.

GEOLOGY OF THE DUCKTOWN MINING DISTRICT.

CHARACTER AND OCCURRENCE OF THE ROCKS.

The Ducktown district lies in the heart of the mountain country of the southern Appalachian province. The prevailing rocks are sandy schists and graywackes with interbedded mica schists. The dominant series is the metamorphosed product of an association of sedimentary beds, including conglomerate, grits, sandstones, and shales. These beds grade one into another along the strike and across the bedding. The gritty, conglomeratic, and sandy layers are highly siliceous, fragmental quartz being their most important constituent. Feldspar is prominent in the coarser layers and is present in nearly all the beds. The fine-grained layers interbedded with the sandstones and grits, where they are not highly metamorphosed, are dark, even-grained slates, but in the central and southeastern portions of the area, where changes are greater, they have been converted to mica and chlorite

[1] Keith, Arthur, op. cit., p. 8.

schist. Even these contain a very high proportion of extremely small quartz grains and a smaller proportion of feldspar. Quartz, feldspar, biotite, chlorite, and muscovite are present in all the beds, but the micas and chlorite predominate in the finer ones and quartz and feldspar are more conspicuous in the coarser beds. The most characteristic feature of the whole series is the lack of effective sorting of the material both as to size and composition.

Bands of garnet or of garnet and staurolite are developed at many places in the schists, and in general they are more common in the finer beds. The garnet layers are found in stringers and bands scattered widely at many horizons, but the staurolitic layers are fairly persistent and many of them may be traced almost continuously for miles. They make up as much as 40 per cent of certain beds, but as a rule they constitute less than 10 per cent of the mass. The highly staurolitic beds may be traced by every gradation into beds containing staurolites only here and there. That the staurolite bands represent sedimentary beds which were of different composition from the main mass of the rock is inferred from the fact that they are so closely confined to the narrow parallel zones. In some of the rocks zones free from staurolite, perhaps 6 inches wide, alternate with somewhat narrower zones that are composed almost entirely of staurolites. These zones do not lie everywhere with the schistosity of the rock, but at some places the staurolitic bands, which are assumed to represent the bedding planes, lie directly across the schistosity, showing that their presence is not due to different degrees of pressure or to other incidents of metamorphism.

The schists of the Ducktown area are clearly metamorphosed sediments. Pure staurolite contains 55.9 per cent of alumina and 15.8 per cent of ferrous oxide. It is possible, therefore, that the staurolitic layers represent beds for which the material contained a considerable but variable proportion of clay, and unless iron was added during metamorphism the clay was ferruginous. Several of the staurolitic bands may be followed for great distances across the area. It is not supposed that each of these represents a separate stratigraphic horizon, for the rocks have been folded closely and eroded so that the same strata are repeated many times.

Thin lenses of limestone were deposited in the great series of sedimentary rocks whose metamorphosed equivalents occupy the Ducktown area. These are neither extensive nor persistent and are not known to be exposed on the surface at any place in the district. In the lower levels of the East Tennessee mine the relatively pure marmarized limestone is exposed at several places, and in several other mines masses of nearly pure white marble are inclosed in the ore. In the East Tennessee mine the marmarized limestone contains layers of biotite and muscovite that are clearly parallel to the bedding planes of the rock which incloses it. The mica bands are assumed to represent aluminous layers in the original limestones which were changed to micas by dynamic metamorphism. The limestone is at the same stratigraphic horizon as the mineral deposits of the Ducktown district, and if it is followed on the dip it is found to grade into a rock composed of the gangue minerals of the ore zone with metallic sulphides. In practically every mine in the district coarsely crystalline marble grades into the massive sulphide ore; hence it is inferred that the mineral deposits and the associated low-grade rock composed of the minerals of the gangue of the ores represent limestone which has been replaced by ore. Volume for volume the ore bodies carry about 16 per cent as much lime as a relatively pure limestone, and the lower-grade ores with relatively small amounts of the sulphide about 24 per cent as much. The gangue is composed mainly of actinolite, garnet, tremolite, pyroxene, zoisite, and other lime-bearing minerals which are known to have formed in a great many mining districts where limestone is replaced by ore. The thickness of the limestone, as indicated by its remnants or by the ore which is assumed to have replaced it, varies from less than 10 feet to more than 200 feet. At most places where it is thick there are indications of close folding or thrust faulting which have had the effect of increasing its thickness.

The ore bodies lie in parallel groups or belts and not all the deposits of a single belt are connected by ore. No limestone is exposed in the intervals between the deposits; consequently it is inferred that the limestone lenses were not continuous. Although there are several such disconnected belts of ore bodies it is not supposed that the limestone lenses which they replaced were deposited at an equal number of horizons in the schist. The horizon of the replaced limestone is approximately that of the staurolitic beds that occur in the mineralized area. These beds are not found in the walls of every ore body, but they outcrop locally along or near every important lode. They are present on both sides of the Isabella-Eureka lode and in or along the continuation of the beds that form the walls of the Polk County, Old Tennessee-Cherokee, Burra Burra, London, East Tennessee, and Mobile lodes. The outcrops of the staurolite beds and limestone have probably been repeated by close folding and erosion.

The sedimentary series contains here and there small veinlets of quartz-feldspar pegmatite and short, narrow lenses and layers of a rock composed of quartz, feldspar, hornblende, garnet, and zoisite. It is intruded by gabbro dikes, which generally follow the bedding of the schists.

The age of the sedimentary series which occupies the Ducktown region can not be definitely stated, but there are many reasons for correlating this series with the Great Smoky formation described by Keith and others as occurring in the quadrangles surrounding the Ducktown district. Certain phases of the Carolina gneiss, however, are closely similar to the most intensely metamorphosed phases of the Great Smoky formation. A granite gneiss is known to outcrop in the Dalton quadrangle, southwest of the Ducktown district, and it is possible that this or equivalent formations may extend eastward and northeastward into the Ducktown region. Although the great mass of lithologic and structural evidence seems to admit the correlation of the schists at Ducktown with the Great Smoky formation, there is a possibility that the Carolina gneiss may also be represented in the district. The correlation can not be conclusive until more detailed mapping has been done in the Dalton quadrangle, southwest of the Ducktown district.

Gabbro is intruded in the schists at several places. The largest body is a relatively narrow dike about 4 miles long, which extends from a point on Fightingtown Creek, half a mile southeast of the Mobile mine, northeastward to a point half a mile east of Coletown. A small mass of gabbro occurs near the wagon road between the Boyd mine and Ducktown. The gabbro is a dark granular rock not so highly schistose as the inclosing beds, and is later than the more profound dynamic metamorphism which converted the sedimentary rocks into schist.

DYNAMIC METAMORPHISM.

In late Paleozoic time the great series of sedimentary rocks was subjected to enormous lateral pressures. These pressures, which may be considered as forces operating tangentially to the earth's crust, were not all equal and those which were greatest operated in northwest and southeast directions. As results of these differences the rocks were shortened in the direction of greatest pressures and thrown in many closely spaced parallel folds. Nearly all these, as already stated, trend northeastward.[1] The tops of many of the folds or crests of the anticlines are formed of the same beds and are at approximately the same elevations. The same bed, exposed by erosion, will consequently outcrop as a number of closely spaced parallel belts, some of which are traceable for great distances. In every quadrangle surrounding the Ducktown area the reduplication of beds is a most conspicuous geologic feature. Not all the beds are everywhere parallel; some of them outcrop as sharp S-shaped folds,

[1] Keith, Arthur, Nantahala folio (No. 143), Geol. Atlas U. S., U. S. Geol. Survey, 1907.

but at many places the beds continue at either end of the S in a northeast or southwest direction parallel to the general strike. Reverse faulting accompanied the folding of the rocks.

DEVELOPMENT OF SCHISTOSITY.

The deformation of the beds which resulted in close folding was accompanied also by mashing, recrystallization, and the development of slaty cleavage and schistosity. The small quartz grains in the sediments were revolved so that the longer axes were oriented parallel to the direction of least pressure. Muscovite, biotite, chlorite, and other flat minerals were crystallized and these were oriented so that the longer dimensions were likewise in the direction of least pressure and parallel to the longer axes of quartz fragments. As a result of these processes a high degree of schistosity was developed in the rocks, especially in the finer-grained members and in those that contained considerable material from which it was possible to form platy minerals like the micas and chlorite.

THE ORE BODIES.

GEOGRAPHIC DISTRIBUTION AND GEOLOGIC RELATIONS.

The deposits are included in an area 6 miles long and 4 miles wide, and all are located on the dissected peneplain which occupies the central portion of the Ducktown Basin. The outcrops are composed of iron oxides and quartz and contrast strongly with the country rock. All the lodes have a general northeastward strike. South of the Culchote mine, which is near the center of the productive area, they strike more nearly north than east; north of the Culchote they strike more nearly east than north. In general the lodes dip southeast, but some dip northwest. The deepest development underground is about 800 feet below the surface. The distribution of the lodes is shown in figure 25.

In the main the deposits are roughly tabular. Some of them are lens shaped and most of them are at places curved. All are included in metamorphosed sedimentary rocks and, except where faulting or close folding is apparent, the beds are parallel to the contacts of ore and country rock.

The primary ore consists of pyrrhotite, pyrite, chalcopyrite, zinc blende, bornite, specularite, magnetite, actinolite, calcite, tremolite, quartz, pyroxene, garnet, zoisite, chlorite, micas, graphite, titanite, and feldspars. The minerals are generally intergrown and of contemporaneous age. Essentially the same minerals are found in all the deposits, but they appear in varying proportions at different places in the lodes. Where the content of copper is above 1.5 per cent, or where sulphur is high, the material is ore, but where the proportion of actinolite and other lime silicates is greater and the sulphides less abundant the material, though containing copper and

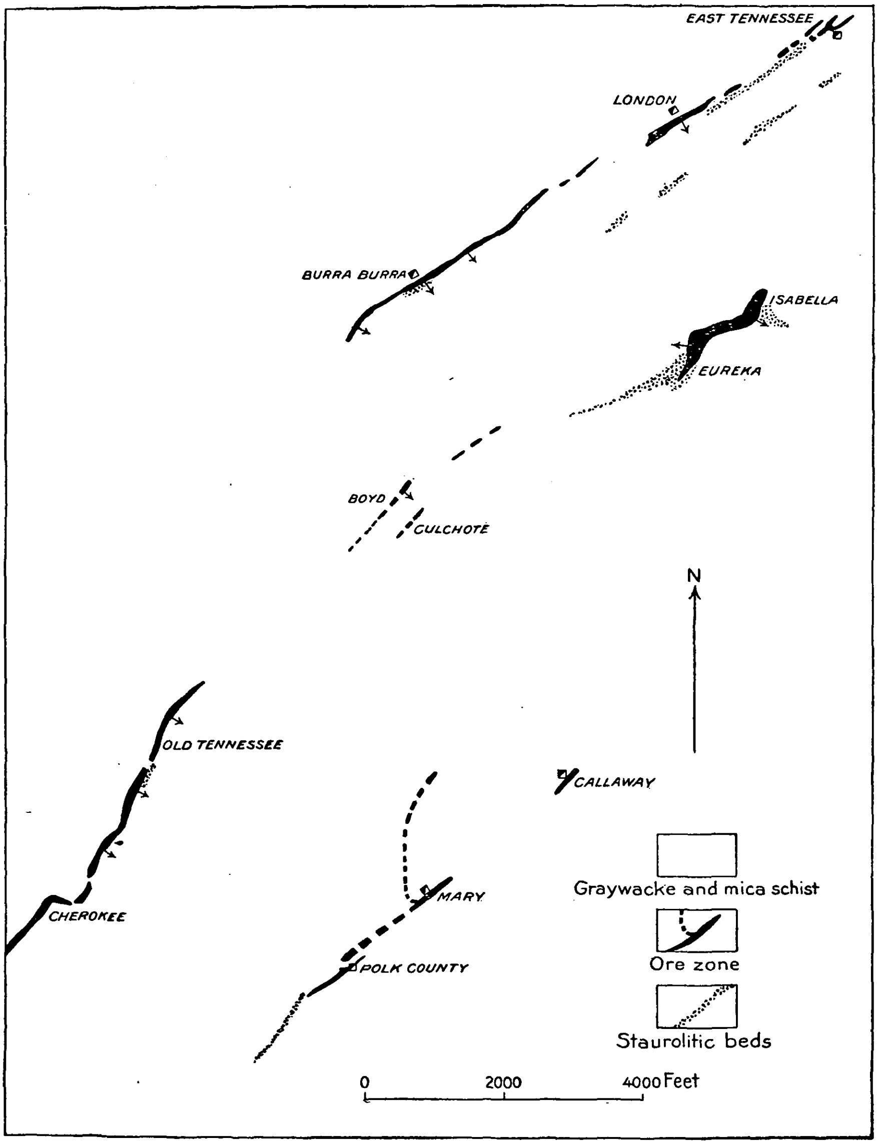


FIGURE 25.—Sketch map showing the location of the principal ore deposits in the producing portion of the Ducktown district. The arrows indicate dips of lodes.

sulphur, is unworkable. Along the strike and down the dip the ore grades into this lime-silicate rock, and in some places it grades into marmarized limestone. The ore zones may be considered therefore as tabular bodies composed of ore, of lime-silicate rock, and of marble. As thus defined these zones vary from a few feet to nearly 200 feet in width and average probably between 50 and 75 feet. The amount of ore is about equal to that of the lime-silicate rock and marble. At some places the ore, the lime-silicate rock, and the limestones have schistosity or banding which is parallel to the boundaries of the ore zone, and wherever bedding planes have been made out in the marble and in the lime-silicate rocks these are likewise parallel to the boundaries

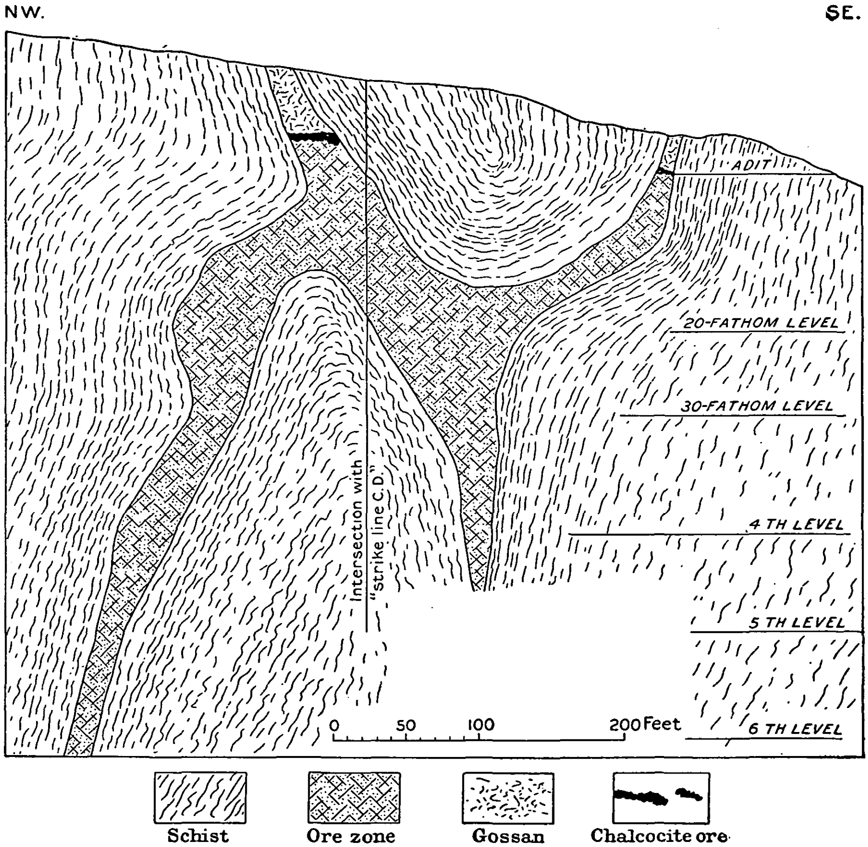


FIGURE 26.—Cross section of the Mary mine, chamber 3 S.

of the ore zone and country rock. Some of the layers of sandy schist included in the ore zone are believed to represent beds that were deposited with the limestones.

TEXTURES OF THE ORE.

The ore minerals are not arranged in layers or crusts one upon another, like the minerals deposited from solutions in an open cavity, but are intergrown and are assumed to have formed at the same time.

At some places the silicates inclose the sulphides, at others the sulphides inclose the silicates, and at still others the two are intimately intergrown so that neither set of minerals may be said to inclose the other. The oxides, magnetite and specular hematite, are not abundant, but both have been recognized, and where they are developed they are intergrown with the sulphides and with the lime silicates. Where the purer limestones are recrystallized into marble the bedding is not apparent, but in the aluminous phases it is clearly shown.

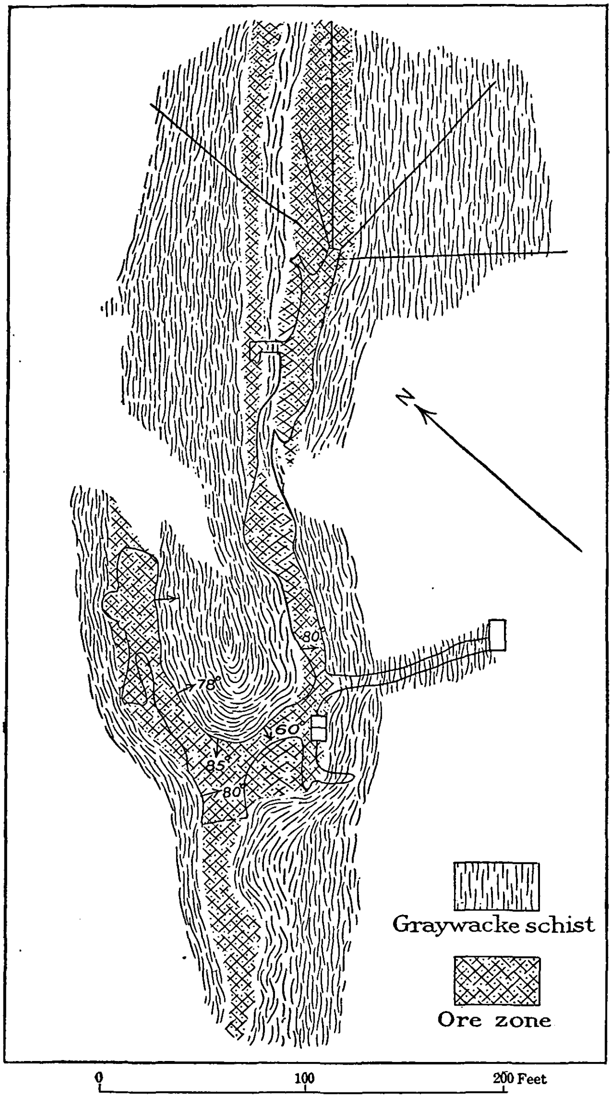


FIGURE 27.—Plan of 20-fathom level, East Tennessee mine. The solid lines indicate mine workings and drill holes. The arrows show the dip of the ore zones.

Veinlets of pyrrhotite and chalcopyrite cut the hornblende and zoisite in some of the ore and fill cracks along the cleavage of the silicates. At many places the sandy schists near the ore zone are heavily impregnated with iron and copper sulphides, but this material is generally not workable. Along fault zones, where drag of ore and schist have been replaced and impregnated, workable ore is locally developed.

FOLDS AND RUPTURED FOLDS OF THE ORE ZONE.

In the Mary mine, near the Baxter shaft, the ore zone is clearly folded. This fold, which is shown in figure 26, is exposed on several levels. The thickening of the ore on the crest of the anticline is conspicuous in this section, but not all sections of anticlines show this feature. Figure 27 is a plan of the 20-fathom level of the East Tennessee mine. At the Thomas shaft the ore zone bends, making a horseshoe curve, with ore extending from the center of the curve southwestward at least 125 feet. On the inner side of this curve, as elsewhere, the schistosity conforms with the ore body. This contact is very well defined and the walls are smooth, suggesting that movement has taken place on both flanks of the curved ore body. The walls dip to the southeast at high angles, except at the sharp curve, where they dip about 85° SW. This curved plane and the bent ore body are exposed on several levels.

Other faults cut the ore bodies, but they follow the strike approximately, and as horizon markers are not always available the positions of the greater number of these faults can not be accurately shown.

GENESIS OF THE PRIMARY ORES.

(1) The conclusion that the ore bodies are replacement deposits is supported by several lines of evidence. All the lodes are inclosed in sedimentary rocks and, except where faulting has taken place, the deposits are oriented parallel to the bedding. Along the horizons of the replaced rock there are aluminous beds, in places staurolitic, which are probably metamorphosed products of strata of a composition unlike that of the associated beds. The staurolitic layers are confined to certain beds, and where they are present they serve as reliable markers of the bedding. These beds parallel some of the lodes for great distances.

At some places the exposures of the ore zone are over 200 feet wide. Although fissure veins as wide as these are not unknown, they are in the main, if not altogether, replacement veins or fractured zones, not clean-cut filling deposits such as those which occupy wide spaces. The association of ore and gangue minerals in the Ducktown lodes is characteristic of deposition at considerable depth and under pressure. It seems improbable that spaces of great size would remain open at the depths at which these minerals are assumed to have formed.

The internal structural features of fissure fillings are lacking in the Ducktown lodes. Fissure fillings as a rule show well-defined comb structure here and there, with open spaces or druses lined with banded crusts. Such features are nowhere developed in the Ducktown deposits except in the small calcite or quartz seams and veinlets which cross the ore bodies and which are clearly later than the ore. Locally crystals of amphiboles, garnet, and other heavy silicates project into open spaces in the lodes, but these minerals are not crustified, and in all cases observed in the course of this investigation calcite is intergrown with the projecting heavy silicates. It is believed that in all such relations the cavities represent spaces from which calcite or some other readily soluble mineral has been removed.

There is little evidence of premineral fissuring along the walls of the lodes. The contact between the ore and mica schist is at many places tightly frozen. At some places slickensided planes cut the ore and the country rock, but these planes do not limit the ore bodies and are clearly of later age than the ores. Here and there veinlike deposits of ore make off from the main ore zone, but these are so small that they are not mined. They are probably calcite veins formed during the intense metamorphism of the limestone and associated rocks and subsequently replaced by ore. The minute fractures filled with chalcopyrite, which here and there cut the ore and the siliceous wall rock, are believed to have been formed by a transfer of material after the primary ores had been deposited and shattered by movement.

(2) The ores replace limestone. All the abundant gangue minerals except quartz contain considerable lime. These include calcite, actinolite, tremolite, pyroxene, garnet, and zoisite. The lime silicates are known to be developed at many places and in widely separated districts by replacement of limestone. These minerals are intimately intergrown with the sulphides and are of contemporaneous age. Almost every piece of ore which one may examine will be found to contain one or more of the lime silicates. They constitute a considerable proportion of the great masses of ore and even the small pieces of ore which at first appear to be composed solely of iron sulphides are found on close examination to contain them. The ore mined from the Burra Burra mine for a period of 12 months averaged 6.32 per cent of CaO; that mined from the London mine for the same period averaged 6.82 per cent; and that from the Polk County mine 6.30 per cent.

As already stated, the lodes are everywhere inclosed in graywacke or in mica schist. Near the lodes this rock generally carries sulphides, but the mineral associations of schist and of ore zone are distinctly different. At many places the contact between the ore zone and the schist is gradational, but the zone of gradation is in general not more than a few inches wide. There are relatively few places where the contact zone is more than a foot wide. If the ore had been deposited along a crushed zone, replacing the schist, the boundaries would presumably be less sharply defined. Along the strike, however, the ore grades here into a rock composed almost entirely of actinolite, tremolite, and calcite; there into one composed essentially of actinolite or of calcite. These masses of actinolite or of actinolite and tremolite in the Polk County, Mary, and other mines constitute about half of the ore zone. In some of these mines the ore may be regarded as irregular masses of sulphides spaced apparently haphazard in a relatively narrow zone of actinolite rock, which is inclosed between walls of graywacke. The actinolitic phase of the ore zone carries about 12 per cent of calcium oxide, but the average of several analyses of the country rock shows less than 1 per cent of lime.

At certain places in nearly all the mines masses of marmarized limestone are inclosed in the ore or in tremolite or actinolitic rock. These masses have not been found outside of the ore zone. Generally they contain a few shreds of the calcareous amphiboles, of pyroxene, or of garnet and a few minute grains of pyrite or of chalcopyrite. In all the mines except the East Tennessee these masses of limestone are small and may easily escape the attention of one who is not looking for them. In the East Tennessee mine, however, masses of marmarized limestone for 20 feet or more along the strike occupy almost the entire width of the ore zone. On the ninth level of this mine the bedding planes of the limestone are clearly shown. They are parallel to the walls of the limestone lens and to the bedding planes of the inclosing quartz-biotite schist.

As the East Tennessee lode is at the same stratigraphic horizon as the London and Burra Burra lodes, and as it is clearly a replacement of limestone, it is rational to suppose that the rock replaced in the London and Burra Burra is also limestone. As already stated, the same minerals are present in all the ore bodies developed in the district. The ore bodies differ in chemical composition because these minerals are present in different proportions in the several lodes. On every large mine dump in the district one may obtain a suite of specimens showing all gradations from a marmarized limestone, composed almost entirely of calcite, to the typical sulphide ore.

(3) The limestones were probably replaced by magmatic waters. The minerals of the ore zone are those typically associated with ores which have been deposited by the replacement of limestone along or near intrusive masses. With the exception of quartz and calcite, the gangue minerals, abundant in the ore zone, are all lime silicates. They include actinolite, tremolite, pyroxene, garnet, and zoisite, all of which are characteristic of igneous metamorphism. The ore minerals include pyrrhotite, pyrite, chalcopyrite, zinc blende, galena, magnetite, and specularite. These are intergrown with calcite and with the heavy silicates and must have formed simultaneously with them.

It has been shown that at many widely separated places in North America[1] similar associations of ore and gangue minerals have been formed as a result of the metamorphism of limestone by hot solutions from igneous bodies. The mineral associations in these deposits are so nearly constant that they appear to have a genetic significance. It is assumed, therefore, that the deposits of Ducktown were formed by similar agencies, although the source of the solutions is not known. The schists near the ores are intruded by gabbro and contain small bodies of pegmatite, and either of these rocks may be evidence of the same igneous agencies that deposited the ores. When it is recalled, however, that other and larger masses of intruded igneous rock are present in the southern Appalachian region at places more remote from the Ducktown district, the correlation of the deposits with the intrusion of any particular igneous body is obviously a matter of conjecture.

(4) The forms of the ore bodies and their relations to other beds show that the rock which the ores replaced, or the ore bodies themselves, have been involved in all of the deformation by dynamic metamorphism to which the country rock has been subjected. The major portion of the dynamic metamorphism, resulting in the development of slaty cleavage and close folding of the beds, may have taken place before the mineralization, but some deformation has occurred since the ores were deposited. The gangue minerals which are included in the sulphides are generally broken and crushed, and in some thin sections of the ore the pyrrhotite shows minute crinkling of closely spaced planes. Pyroxene and zoisite crystals are bent and twisted. At many places the ore appears brecciated, and small balls consisting predominantly of actinolite, garnet, and quartz with a subordinate amount of sulphides are surrounded by heavy sulphide ore containing numerous broken fragments of hornblende. In the No. 20 mine some of these balls are elongated ellipsoids. At some places the minerals of the gangue are oriented in parallel layers, like the minerals of a schist, but in general the gangue of the ores is not schistose. Recrystallization, following deformation, may have obscured certain metamorphic structures. Little is known regarding the behavior of metallic ores in differential stresses under heavy load, and the data are insufficient to warrant a statement regarding the degree of the deformation of the ores or the depth at which they were deformed.

---

[1] Lindgren, Waldemar, Copper deposits of the Clifton-Morenci district, Arizona: Prof. Paper U. S. Geol. Survey No. 43, 1905, p. 218. Kemp, J. F., Ore deposits at the contacts of intrusive rocks and limestone and their significance as regards the general formation of veins: Econ. Geology, vol. 2, 1907, p. 1.

CORRELATION OF THE LODES.

It has been shown that the lodes are replacements of limestone lenses. Throughout this portion of the mountainous area of southeastern Tennessee the outcrops of beds are repeated again and again by close folding, a reverse faulting, and subsequent erosion. It would be a natural inference that the lenses which the several lodes replace were all formed at the same stratigraphic horizon, and that the ore zone was likewise repeated by close folding. The close association of staurolite with the ore zone and its common occurrence on the hanging-wall side would seem to be in harmony with this interpretation. In certain places in the area, however, the staurolite bed is lacking. The evidence that all the ore bodies are at the same stratigraphic horizon is therefore incomplete, and the correlation of the several deposits can not be made on the basis of the data at hand. Where the rocks are closely folded and much faulted, as they are in the Ducktown district, a number of interpretations are possible, and because continuous separable beds are rare, it is not always possible to show which one is true. It is hoped, however, that certain working hypotheses may be suggested when all the data shall have been assimilated.

SURFICIAL ALTERATION AND SECONDARY ENRICHMENT.

DISTRIBUTION OF THE ORES IN DEPTH.

General statement.—The Ducktown lodes are composed of three kinds of ore. The outcrops consist of hydrous iron oxides with smaller proportions of other minerals, chiefly kaolin and quartz. This ore extends from the surface downward to a maximum depth of about 100 feet. Below the iron ore there is generally a few feet of chalcocite ore, which in most of the deposits lies like a floor below the gossan iron ore. Below the chalcocite zone is the yellow sulphide ore which has already been described. This ore extends downward as far as exploration has gone and is assumed to be the primary ore from which the chalcocite zone and the gossan have been derived. In all the deposits now mined the chalcocite was almost completely exhausted years ago and a large portion of the gossan ores has been shipped to iron furnaces. The opportunities for studying these ores are now meager. The workings in black ore are accessible in some of the mines, but even where the ores have not been removed extensive changes have doubtless taken place as a result of leaching after the ground-water level was depressed by mining and pumping in levels below.

Distribution and character of the iron ore.—The deposits of gossan ore vary in width from a few feet, as shown in the narrow openings along the Cherokee lode, to 250 feet in the Isabella and Eureka pits.

Few of them extend downward from the surface more than 100 feet. The greatest depths are below the hilltops, and where the lodes are crossed by running streams the gossan ores are thin or lacking.

The iron ore is porous and earthy. It carries from 40 to 50 per cent of iron and on account of its low content of phosphorus it is especially desirable for mixing with lower grade high-phosphorus ores to bring the mixture within the Bessemer limit. Silica and alumina together are generally less than 12 per cent, although in some of the ores they are as high as 17 per cent. Copper varies from 0.3 to 0.7 per cent.

Hydrous iron oxides are the most abundant minerals. Silica is present in varying amounts. Some of it is quartz residual from the primary ore, but a red siliceous mineral resembling jasper was noted

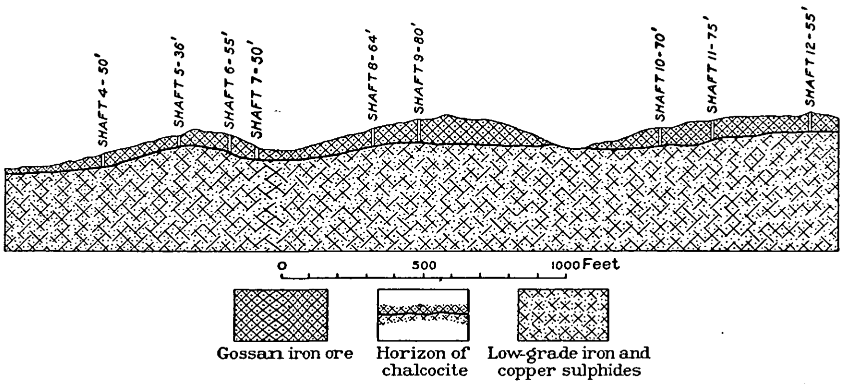


FIGURE 28.—Side elevation of a portion of the Old Tennessee-Cherokee lode, looking N. 55° W.

in several of the deposits. Some of this is an intimate mixture of hydrous silica and iron oxide which has formed presumably by the solution and precipitation of silica during weathering of the deposits. A small amount of kaolin is generally present. It is developed by reactions of sulphate water on the aluminous minerals of the ore and wall rock. Cuprite has been noted in the oxidized ores and it is probably the principal copper mineral. Native copper has been reported. A small amount of sulphur, less than 1 per cent, is present. It occurs as native sulphur, in pyrite, and in sulphates.

Distribution and composition of the zone of secondary copper ore.—Below the gossan iron ores is a zone of dark, rich copper ores, consisting of chalcocite and other copper minerals in a gangue of sulphates, quartz, and decomposed silicates. Under the higher portions of the outcrops of the lodes the top of this zone is about 100 feet below the surface, but the depth decreases down the slopes and where the lodes are crossed by running streams the secondary copper ores are exposed at the surface. The upper limit of the chalcocite zone follows the level of ground water, which, in turn, follows the contour of the country but is less accentuated. Figure 28 is a longitudinal projection along the Old Tennessee-Cherokee lode based on data supplied by the Virginia Iron, Coal & Coke Co., which mined the gossan ores of this deposit. The heavy black line has been added to indicate the horizon and approximately the extent of the secondary ores. Below the chalcocite zone is the lower-grade primary ore.

The rich secondary copper ore is a mixture of the primary minerals and minerals that have been deposited by sulphate waters since the deposits were exposed to weathering. Not much of the secondary ore was available for study in the course of this investigation, and the list of minerals and the facts ascertained as to their occurrence and relations are obviously incomplete and unsatisfactory.

The following minerals have been recognized by different writers: Alisonite, allophane, alums, argentite, azurite, bornite, chalcanthite, chalcedony, chalcocite, chalcopyrite, chrysocolla, covellite, cuprite, ducktownite(?), gypsum, harrisite(?), iron sulphate, jasper, kaolin, limonite, malachite, marcasite, melaconite, native copper, rahtite(?), sulphur, talc, turgite. The secondary ore contains also pyrite, chalcopyrite, pyrrhotite, zinc blende, and galena, with actinolite, quartz, tremolite, garnet, and other gangue minerals of the primary ore.

Four analyses of the mine waters made by Dr. R. C. Wells are stated below.

No. 1 represents a sample from the East Tennessee mine taken on the 30-fathom level. The water is flowing in a small stream over the primary sulphide ore and is exposed freely to the atmosphere. In this water only does zinc exceed copper.

Analysis No. 2 represents a sample taken from the Burra Burra mine in the first level below the black copper workings. This water seeps through the workings in the chalcocite zone along a fissure which extends downward into the pyrrhotite ore and was caught from a stream dripping from the roof. The high content of copper, zinc, and ferrous iron is noteworthy. Although the sample was taken in the open air, none of the iron is oxidized to the ferric state. This is remarkable, because no precautions were taken to prevent the oxidation of this sample.

Samples 3 and 4 were taken from the Callaway shaft. Sample 3 was taken from the top of the water column in this shaft and sample 4 was taken 37 feet below. A special device was used to filter sample 4 under the 37 feet of water pressure.

Analyses of mine waters from Ducktown district.

	1	2	3	4
Acidity as H_2SO_4[a]	406.5	129.6	210.2	97.5
SiO_2	78.9	55.6	37.0	49.9
Al	165.0	433.0	14.5	19.1
Fe'''	186.3	.0	20.3	55.9
Fe''	1.3	2,178.0	71.4	89.2
Mn	.3	.2	.2	.1
Zn	54.3	199.8	2.4	2.9
Cu	40.8	312.1	28.1	11.0
Na	5.9	23.4	5.2	5.5
K	7.8	19.8	2.7	2.2
Ca	238.0	67.6	19.7	30.4
Mg	63.3	40.6	5.2	6.2
SO_4	2,068.0	6,664.0	415.8	476.8
Cl	2.2	.1	.7	.4

[a] Determined after shipping, when partial hydrolysis had occurred.

Chalcocitization.—Weathering and related processes operating on an ore composed of iron and copper sulphides generally result in the enrichment of a certain zone. As a rule, the top of this zone is near the water level and it extends downward for varying distances below the water level. As shown by the analyses, the waters are sulphate solutions, and in the zone above the water level, where air is admitted, acid or ferric sulphates predominate. In such solutions copper is readily dissolved. Below the water table the acid reacts with sulphides that precipitate copper sulphide from sulphate solutions. From the sulphides hydrogen sulphide is formed. The sulphuric acid is used up also by reactions with gangue minerals, some of which result in the production of calcium sulphate, alkali sulphates, and other inert salts. The solutions below the water level are consequently less acid and probably do not dissolve copper. It is noteworthy that the solution taken 37 feet below the water level in the Callaway mine contains less than half the free acid stated in the analyses of the sample taken at the water level.

The secondary zone in the Ducktown district is less extensive vertically than most chalcocite zones elsewhere. The lodes are comparatively impervious to downward circulation, and it is believed that the reactions were brought near to completion before the descending oxidized solutions had moved downward great distances. It is thought also that the reactions precipitating copper sulphide take place more rapidly with pyrrhotite than with pyrite or chalcopyrite. Experiments planned to show the rate of solution of different minerals in acid sulphate waters and the rate at which hydrogen sulphide is liberated by these minerals in dilute acid solutions are being made by Dr. R. C. Wells, of the Geological Survey. It is hoped that quantitative data may soon be available for the discussion of these reactions.

SURVEY PUBLICATIONS ON COPPER.

The following list includes the principal publications on copper by the United States Geological Survey or by members of its staff. In addition to the publications cited below, certain of the geologic folios listed in the " Introduction " contain discussions of the copper resources of the districts of which they treat.

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. The one marked " Exhausted " is not available for distribution, but may be seen at the larger libraries of the country.

BAIN, H. F., and ULRICH, E. O. The copper deposits of Missouri. In Bulletin 260, pp. 233–235. 1905. 40c.

BALL, S. H. Copper deposits of the Hartville uplift, Wyoming. In Bulletin 315, pp. 93–107. 1907.

BANCROFT, HOWLAND. Reconnaissance of the ore deposits in northern Yuma County, Ariz. Bulletin No. 451.

BOUTWELL, J. M. Ore deposits of Bingham, Utah. In Bulletin 213, pp. 105–122. 1903. 25c.

——— Economic geology of the Bingham mining district, Utah. Professional Paper 38. 413 pp. 1905.

——— Ore deposits of Bingham, Utah. In Bulletin 260, pp. 236–241. 1905. 40c.

BUTLER, B. S. Copper. In Mineral Resources U. S. for 1909, pt. 1, pp. 151–180. 1911.[1]

COLLIER, A. J. Ore deposits of the St. Joe River basin, Idaho. In Bulletin 285, pp. 129–139. 1906.

DILLER, J. S. Copper deposits of the Redding region, California. In Bulletin 213, pp. 123–132. 1903. 25c.

——— Mining and mineral resources in the Redding district in 1903. In Bulletin 225, pp. 169–179. 1904. 35c.

EMMONS, S. F. Geological distribution of the useful metals in the United States—Copper. Trans. Am. Inst. Min. Eng., vol. 22, p. 73. 1894.

——— Economic geology of the Butte (copper) district, Montana. Geologic Atlas U. S., folio No. 38. 1897.

---

[1] See also Gold, silver, copper, lead, and zinc (mine production) in Western, Central, and Eastern States, by various authors. In Mineral Resources U. S. for 1909, pt. 1, pp. 221–547. 1911.

EMMONS, S. F. Copper in the red beds of the Colorado Plateau region. In Bulletin 260, pp. 221–232. 1905. 40c.

——— The Cactus copper mine, Utah. In Bulletin 260, pp. 242–248. 1905. 40c.

EMMONS, W. H. The Cashin mine, Montrose County, Colo. In Bulletin 285, pp. 125–128. 1906.

——— Some ore deposits of Maine and at the Milan mine, New Hampshire. Bulletin 432. 62 pp. 1910.

GALE, H. S. Geology of the copper deposits near Montpelier, Bear Lake County, Idaho. In Bulletin 430, pp. 112–121. 1910.

GRATON, L. C. Copper. In Mineral Resources U. S. for 1906, pp. 373–438. 1907. 50c.

——— Copper. In Mineral Resources U. S. for 1907, pp. 571–644. 1908. $1.

——— The occurrence of copper in Shasta County, Cal. In Bulletin 430, pp. 71–111. 1910.

HOWE, H. M. Copper smelting. Bulletin 26. 107 pp. 1885. Exhausted.

IRVING, R. D. The copper-bearing rocks of Lake Superior. Monograph V. 464 pp. 1883. $1.85.

LINDGREN, WALDEMAR. The copper deposits of the "Seven Devils," Idaho. In Min. and Sci. Press, vol. 78, p. 125. 1899.

——— The copper deposits of the Seven Devils. In Twentieth Ann. Rept., pt. 3, pp. 249–253. 1900.

——— Copper deposits of Snake River and Powder River, Oregon. In Twenty-second Ann. Rept., pt. 2, pp. 551–776. 1901.

——— Copper deposits at Clifton, Ariz. In Bulletin 213, pp. 133–140. 1903. 25c.

——— Copper deposits of Clifton-Morenci district, Arizona. Professional Paper 43. 375 pp. 1905.

——— Notes on copper deposits in Chaffee, Fremont, and Jefferson counties, Colo. In Bulletin 340, pp. 157–174. 1908.

——— Resources of the United States in gold, silver, copper, lead, and zinc. In Bulletin 394, pp. 114–156. 1909.

LINDGREN, W., and GRATON, L. C. A reconnaissance of the mineral deposits of New Mexico. In Bulletin 285, pp. 74–86. 1906. 60c.

LINDGREN, W., GRATON, L. C., and GORDON, C. H. The ore deposits of New Mexico. Professional Paper 68. 361 pp. 1910.

PHALEN, W. C. Copper deposits near Luray, Va. In Bulletin 285, pp. 140–143. 1906.

RANSOME, F. L. Copper deposits of Bisbee, Ariz. In Bulletin 213, pp. 149–157. 1903. 25c.

——— The Globe copper district, Arizona. Professional Paper 12. 168 pp. 1904. 70c.

——— Geology and ore deposits of the Bisbee quadrangle, Arizona. Professional Paper 21. 168 pp. 1904.

——— The Yerington copper district, Nevada. In Bulletin 380, pp. 99–119. 1909.

——— Geology at Globe, Ariz. In Min. and Sci. Press, vol. 100, No. 7, pp. 256–257. 1910.

RANSOME, F. L., and CALKINS, F. C. The geology and ore deposits of the Cœur d'Alene district, Idaho. Professional Paper 62. 1908. 85c.

SPENCER, A. C. Mineral resources of the Encampment copper region, Wyoming. In Bulletin 213, pp. 158–162. 1903. 25c.

——— Reconnaissance examination of the copper deposits at Pearl, Colo. In Bulletin 213, pp. 163–169. 1903. 25c.

SPENCER, A. C. Copper deposits of the Encampment district, Wyoming. Professional Paper 25. 107 pp. 1904. 15c.

STOSE, G. W. The copper deposits of South Mountain in southern Pennsylvania. In Bulletin 430, pp. 122–131. 1910.

VARIOUS AUTHORS. Gold, silver, copper, lead, and zinc (mine production) in Western, Central, and Eastern States. In Mineral Resources U. S. for 1909, pt. 1, pp. 221–547. 1911.

VAUGHAN, T. W. The copper mines of Santa Clara Province, Cuba. In Eng. and Min. Jour., vol. 72, pp. 814–816. 1901.

WATSON, T. L. Notes on the Seminole copper deposits of Georgia. In Bulletin 225, pp. 182–186. 35c.

WEED, W. H. Types of copper deposits in the southern United States. In Trans. Am. Inst. Min. Eng., vol. 30, pp. 449–504. 1901.

——— Copper mines of Las Vegas, Chihuahua, Mexico. In Trans. Am. Inst. Min. Eng., vol. 32, pp. 402–404. 1902.

——— Copper deposits near Jimenez, Chihuahua, Mexico. In Trans. Am. Inst. Min. Eng., vol. 32, pp. 404–405. 1902.

——— Copper deposits of Cananea, Sonora, Mexico. In Trans. Am. Inst. Min. Eng., vol. 32, pp. 428–435. 1902.

——— Ore deposits at Butte, Mont. In Bulletin 213, pp. 170–180. 1903. 25c.

——— Copper deposits of the Appalachian States. In Bulletin 213, pp. 181–185. 1903. 25c.

——— Copper deposits in Georgia. In Bulletin 225, pp. 180–181. 1904. 35c.

——— The Griggstown, N. J., copper deposit. In Bulletin 225, pp. 187–189. 1904. 35c.

——— Notes on the copper mines of Vermont. In Bulletin 225, pp. 190–199. 1904. 35c.

——— The copper production of the United States. In Bulletin 260, pp. 211–216. 1905. 40c.

——— The copper deposits of eastern United States. In Bulletin 260, pp. 217–220. 1905. 40c.

——— The copper mines of the United States in 1905. In Bulletin 285, pp. 93–124. 1906.

——— Copper deposits of the Appalachian States. Bulletin 455. 166 pp. 1911.

WEED, W. H., and PIRSSON, L. V. Geology of the Castle Mountain mining district, Montana. Bulletin 139. 164 pp. 1896. 15c.

WEEKS, F. B., and HEIKES, V. C. Notes on the Fort Hall mining district, Idaho. In Bulletin 340, pp. 175–183. 1908.