THE GRAND GULCH MINING REGION, MOHAVE COUNTY, ARIZONA.

By James M. Hill.

INTRODUCTION.

Early in November, 1913, a few days were taken from a reconnaissance of some mining camps in eastern Nevada for a hasty trip to the Grand Gulch and Bronze L mines in northwestern Arizona. Mr. S. R. Callaway, superintendent of the Grand Gulch mine, supplied many details that have been incorporated in this report. To Mr. Whitehead, of Overton, and Messrs. Genty and Syphus, of St. Thomas, the writer is also indebted for courtesy in supplying information and for samples of ore.

GEOGRAPHY.

The Bently mining district is in that part of Mohave County, Ariz., which lies north of Colorado River and embraces the extreme western part of the Colorado Plateau. It forms a part of the region sometimes colloquially called the "Arizona Strip." So far as could be learned the boundaries of the district are indefinite. In the examination on which this paper is based only the Grand Gulch mine and the Bronze L mine, on the terrace above and immediately east of the Grand Wash, were visited. These mines are 8 miles west of Pigeon Spring, which, according to the edition of the General Land Office map of Arizona for 1912, lies near longitude 113° 45′ W. and latitude 36° 15′ N. The region is also represented on the Mount Trumbull topographic sheet of the United States Geological Survey. (See fig. 6.)

ECONOMIC CONDITIONS.

TRANSPORTATION.

The district is most easily reached from Moapa, Nev., on the main line of the San Pedro, Los Angeles & Salt Lake Railroad, 28 miles northwest of St. Thomas, Nev., the shipping and supply point for part of southeastern Nevada and northern Arizona. A branch railroad runs from Moapa to St. Thomas, but except in the summer during the cantaloupe season no regular service is maintained over this branch.

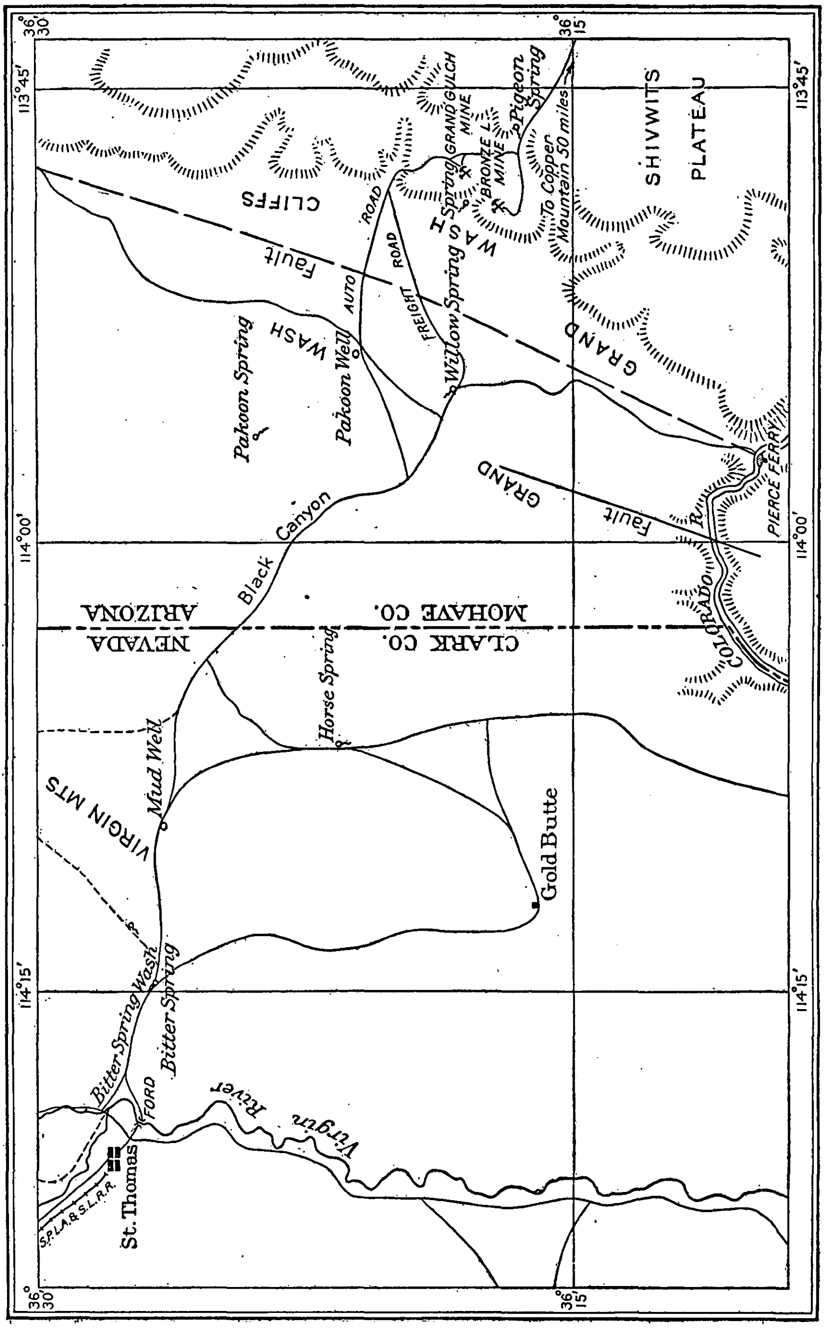

FIGURE 6.—Sketch map showing location of the Grand Gulch and Bronze L mines and the roads and watering places between St. Thomas, Nev., and Grand Gulch, Ariz. Adapted from St. Thomas and Mount Trumbull topographic sheets, United States Geological Survey.

The Grand Gulch mine is 54 miles by road east of St. Thomas. The road crosses Virgin River by a ford 2 miles east of St. Thomas, beyond which an ascent of 1,300 feet in 16 miles along the bottom of a narrow canyon carries it to the summit of Bitter Springs Pass over the Virgin Mountains. The road continues on the south bench of Black Canyon to a point about 2 miles from Grand Wash, which is crossed at either the Willow Spring or the Pakoon Well crossing. For about 6 miles east of the crossing the road passes over the low bench of Grand Wash to the base of the Grand Wash Cliffs, 1,250 feet high, which are ascended by a tortuous but well-constructed grade, up a narrow canyon that opens to the north. The mine is about 2½ miles south of the place where the road reaches the top of the first line of cliffs, but to avoid a deep canyon a detour of 4 miles is made to reach the camp.

The Bronze L mine is about 3 miles a little west of south of the Grand Gulch mine. To reach it the road goes about half way to Pigeon Spring around the narrow gorge known as Pigeon Spring Canyon.

For the most part these roads are rather sandy, and at the time of visit they were excessively dusty and cut by deep ruts and "chuck holes," owing to the lack of rain for many months. Freight teams take a week to make the round trip between the Grand Gulch mine and St. Thomas, hauling from 8 to 12 tons, at the rate of $10 a ton. From 6 to 10 horses are used, and usually the freighters travel in pairs, so as to double on steep hills. During the summer of 1913 a Sauer gasoline truck was successfully operated between the Grand Gulch mine and the east bank of Virgin River, but it was taken off in the fall because of the poor condition of the roads and the cost of keeping up the tires.

WATER.

Between Virgin River and the mine there are three springs. Bitter Spring, on the west side of the Virgin Mountains near the summit, is well named, for its waters are not palatable, though it is said that in the early spring, after the snows, they can be drunk without ill effects.

Willow Springs, at the mouth of Willow Canyon, issues from the deep, partly consolidated conglomerate fill of Grand Wash, where a buried flow of basalt dams the underground water and brings it to the surface.

Pigeon Spring, 8 miles east of the Grand Gulch mine, yields a stream of good water about a quarter of an inch in diameter. It has been developed by pipe and storage reservoirs to supply water for domestic uses at the Grand Gulch mine. All the water is hauled in barrels from the spring to the mine. Pigeon Spring issues below the light-colored limestone cap rock of the second terrace above the Grand Wash.

The Bronze L mine obtains its water supply from a spring near the base of the lower terrace, about three-fourths of a mile north of the mine.

Mud Well is located on the main road, at the summit of the Virgin Range. The waters are heavily charged with mineral and are not good, though used largely for watering the teams. About a quarter of a mile south of the well there is a small marshy area which is called a spring.

Pakoon Well is at the north crossing of the Grand Wash, where "rabbit grass" and mesquite indicate that water is not far distant. At the time of visit there was about 15 inches of water in a box 3 feet square, standing about 5 feet below the surface. It is said, however, that during the summer of 1913 the water here could not always be relied on to fill the radiator tank of the gasoline truck.

CLIMATE.

The climate of this region is typical of the desert country of the Southwest, showing wide daily and yearly ranges. The highest summer temperature is said to be about 105°. The winters are rarely severe, though occasionally the thermometer records a temperature as low as −12° F.

TIMBER.

An open growth of fairly large juniper or "cedar" covers the mesa on which the Grand Gulch and Bronze L mines are located. Interspersed with the cedars are piñon trees, which here and there form small groves. The soil supports a scant cover of desert grass throughout the year. In the spring, after the light snows melt, this growth is said to be luxuriant.

The timbers used at the Grand Gulch mine are obtained from the Shivwits Plateau, 25 miles east of the mine, where there is said to be an open forest of "jack pine" with some "red-pine" trees, some of which are 3 to 4 feet in diameter. This timber, square sawed for mining use and laid down at the mine, is said to cost $30 a thousand feet.

LABOR.

St. George, Utah, 129 miles by road north of Grand Gulch, supplies most of the labor employed at the mine, which is all white. In the fall of 1913 about 50 men were employed by the Grand Gulch Co., most of them at the mine, but some at the lumber camp maintained by the company 25 miles east of the mine. At the Bronze L mine five men were at work.

HISTORY.

According to Mr. Callaway, the Grand Gulch ore deposit was discovered about 1853, though it seems probable that it was known to the Indians before that time. The prospect was bought from the Indians for a horse and some flour by a Mr. Adams, employed by Bishop Snow, of St. George, Utah. Adams patented one claim and located eight adjoining claims. The original claim, the Adams, is patent No. 37. For a number of years the ore was hauled to St. George. In 1870 an adobe smelter was built, which evidently did not meet with marked success, as the small slag dumps have since been shipped for their metal content. An adobe and stone stack now standing near the shaft does not seem to have been used.

After several unsuccessful attempts had been made to operate the Adams mine it was acquired in 1890 by the Jennings brothers, who worked it intermittently for 16 years. Since 1906 it has been a continuous producer. It is impossible to obtain accurate figures of production, though Mr. Callaway estimates the total at $500,000. Since 1906 no ore carrying less than 14 per cent of copper has been shipped. In the fall of 1913 an average of 120 tons of ore was sent to the Salt Lake smelters each month.

The Bronze L mine, formerly known as the Savanic, is controlled by Harry Gentry and Levi Syphus, of St. Thomas, Nev., who took over the property in 1906. It also is an old claim and has had as varied a career as the Grand Gulch. Its production is not known but is probably very much smaller than that of the Grand Gulch mine.

PREVIOUS DESCRIPTIONS.

So far as known there are no published descriptions of the mines of this region, though the presence of the prospects was evidently known to the geologists of the Wheeler Survey, for their position is shown on atlas sheet 66 accompanying the Wheeler reports. The geologic facts concerning this region contained in the preliminary reports of the Wheeler Survey are brought together in part 2 of volume 3 of the final report, issued in 1875. General information on the plateau region is given in C. E. Dutton's "Tertiary history of the Grand Canyon district," issued in 1882 as Monograph II of the United States Geological Survey.

GEOLOGY.

The bold cliffs on the east side of Grand Wash, at the west end of the Colorado Plateau province, as pointed out by Gilbert,[1] lie along a profound fault, which is shown in figure 7. West of this fault zone the sedimentary beds rest in an inclined position along the eastern part of the Virgin Range, dipping at moderately steep angles toward Grand Wash. The wash is from 8 to 12 miles wide where crossed by the road and is filled with coarse, partly consolidated conglomerates and cross-bedded sandstones. The gravels represent two

[1] Gilbert, G. K., U. S. Geog. Surveys W. 100th Mer., vol. 3, p. 54, 1875.

periods of deposition, as is shown near the mouth of Black Canyon, where there is a distinct erosion surface about 30 feet below the top of the gravels. The presence of these two conglomerates was noted by Marvine.[1]

At least two flows of augite basalt are intercalated with the gravel fill. They are confined to the west side of the valley, and the upper flow is at most places thinly covered with gravels. These gravels, in which are interbedded flows, are probably to be correlated with the Temple Bar conglomerate described by Lee.[2] East of the wash the low flat-topped ridges, cut by many canyons, are underlain with soft dull reddish-brown shales and sandstones that are probably part of the lower division of the Redwall limestone.

The great wall forming the east side of the valley is composed of apparently horizontal sedimentary beds of dull-red color. At the base of the cliffs the wagon road turns south behind a ridge composed of westward-dipping limestones similar to the horizontal beds at the east. This fold is local, only a small section of the cliff face about a

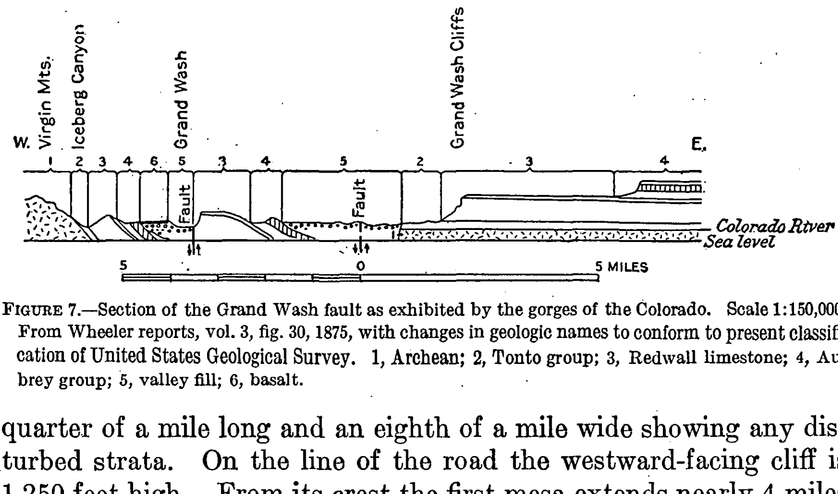

FIGURE 7.—Section of the Grand Wash fault as exhibited by the gorges of the Colorado. Scale 1:150,000. From Wheeler reports, vol. 3, fig. 30, 1875, with changes in geologic names to conform to present classification of United States Geological Survey. 1, Archean; 2, Tonto group; 3, Redwall limestone; 4, Aubrey group; 5, valley fill; 6, basalt.

quarter of a mile long and an eighth of a mile wide showing any disturbed strata. On the line of the road the westward-facing cliff is 1,250 feet high. From its crest the first mesa extends nearly 4 miles eastward and is bounded on the east by a second cliff at least 1,000 feet high. The lower step is composed of alternating beds of dull brownish-red, red, and pink thick-bedded limestones, sandy limestones, and massive cross-bedded calcareous sandstones. The upper step displays, in its lower portion, brilliant red and yellow shales and sandstone, overlying which is a bed of yellowish massive cross-bedded sandstone, capped by light-colored cherty limestone. This succession of rocks can be correlated with the upper half of the section examined at the mouth of the Grand Canyon by G. K. Gilbert. That section, with the changes necessary to make it conform to the stratigraphic nomenclature now in use, is shown in figure 8.

[1] Marvine, A. R., U. S. Geog. Surveys W. 100th Mer., vol. 3, p. 197, 1875.

[2] Lee, W. T., Geologic reconnaissance of a part of western Arizona: U. S. Geol. Survey Bull. 352, pp. 17-18, 1908.

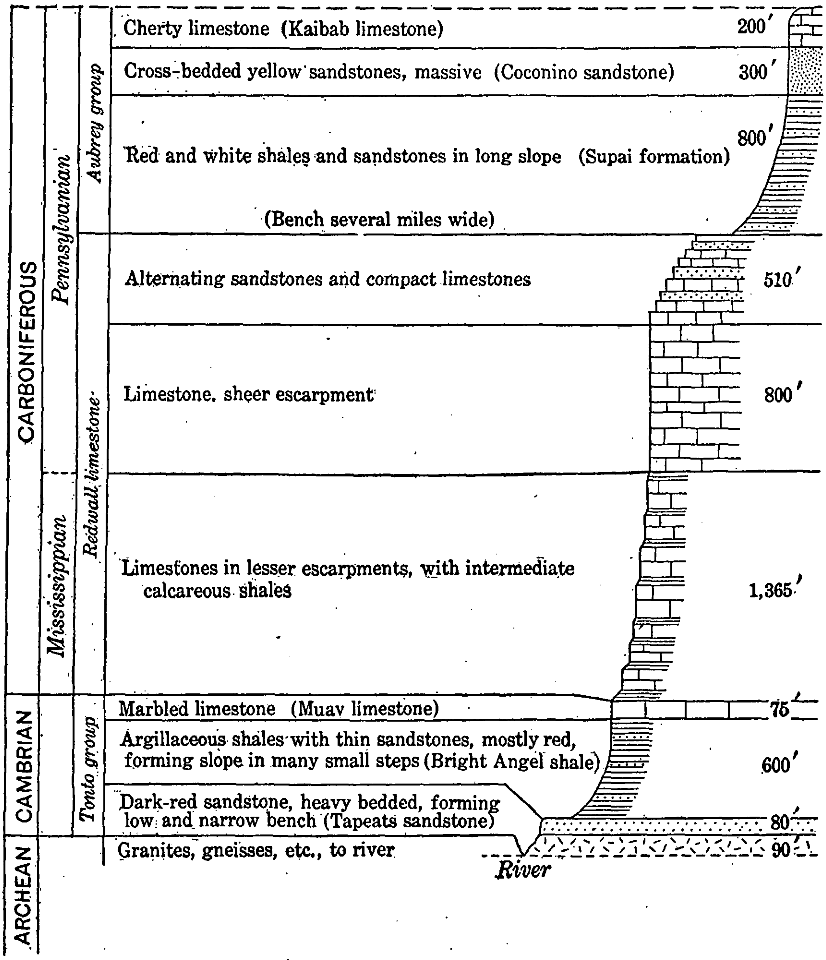

FIGURE 8.—Section of the sedimentary series at the mouth of the Grand Canyon. After Gilbert, G. K., op. cit., fig. 82, opp. p. 196.

The following section was measured barometrically by the writer in ascending the road from the base to the summit of the lower cliff:

Section of lower cliff at east side of Grand Gulch, on road between St. Thomas and Grand Gulch mine, beginning at top but 150 feet below the actual rim.

	Feet.
1. Buff sandstone	50
2. Pinkish arenaceous limestone	100
3. Brownish-red sandstone, massive and cross-bedded, grading into arenaceous limestone at top	200
4. Limestone, fine grained and pink at top, grading into coarse grained and red at bottom	500
5. Brownish-red sandstone and calcareous sandstone	50
6. Reddish-white crystalline limestone with some dark-colored cherty beds; grades into sandy lime at top	650
Base not exposed.	
	1,100

A few fossils were found near the Grand Gulch shaft in the pinkish limestone (No. 2 of the above section), and among them G. H. Girty, of this Survey, determined the following species:

Zaphrentis sp.	Pugnax utah.
Echinocrinus sp.	Squamularia perplexa?
Productus sp.	Composita subtilita.
Dielasma? sp.	Naticopsis? sp.

Mr. Girty says: "This lot is clearly Carboniferous, and though the fossils are very fragmentary and the fauna which they compose is far from diagnostic the geologic age may, with high probability, be assigned to the Pennsylvanian or the Permian."

GRAND GULCH MINE.

EQUIPMENT AND DEVELOPMENT.

Grand Gulch camp lies in a small depression and is not visible from a distance. The first view from the road shows a frame engine house, surrounded by dumps and ore houses, with two long masonry buildings in the background. The shaft is equipped with a 22-horsepower gasoline hoist, whose engine also operates a 10 by 10 inch air compressor capable of running three drills, and with a crosshead and bucket.

From the shaft, which is vertical and 500 feet deep, levels have been run at 100, 200, 300, and 400 feet below the collar. These levels, owing to the peculiar shape of the ore body, presently to be described, are generally of circular plan. At the 100-foot level the ore zone is only a few feet from the shaft. Between the surface and this level there are sublevels in ore at 28, 40, and 60 feet. The 200-foot level has been driven nearly around the circle, though the connection has not been made. On the northwest side of the circle there are four sublevels between the 100 and 200 foot levels, and short sublevels have been driven between these main levels at other places. On the 300-foot level, at the time of visit, a drift around the east and southeast sides of the circle was being pushed to the west at the south side, to connect with an underhand stope in ore on the 200-foot level. On the 400-foot level there is a crosscut to the east and short drifts on the east side of the circle. A station has been cut at the 500-foot level, but no drifting has been done.

GEOLOGIC RELATIONS OF THE ORE BODIES.

The Grand Gulch mine is about a mile and a half east of the mesa rim and a mile north of the deep Pigeon Canyon. In this vicinity the calcareous sandstone forms the surface rock, lying essentially horizontal and covered at most by a few inches of red sandy soil. The shaft is at the head of a small branch of Pigeon Canyon, where the structure is well exposed. There are apparently no faults near the mine, the only fractures being an irregular system of joints.

The ore bodies occur around the sides of a vertical pluglike mass of rock, which is sedimentary but is entirely different from the stratified rocks that inclose it and will in this paper be called the filling. This mass is roughly elliptical in cross section where exposed at the surface over an area about 300 feet long and 180 feet wide. It increases in size to a depth of 250 feet, and from that depth downward it apparently grows smaller, so that on the whole the mass is roughly pear shaped. (See fig. 9.)

The outcrop of the ore is of annular form. To the north and west the croppings are covered by dumps so that details of structure are concealed, but along their northeast side blocks of sandstone for about 4 to 5 feet away from the circular outcrop dip toward the center and are separated from the solid formation by open cracks.

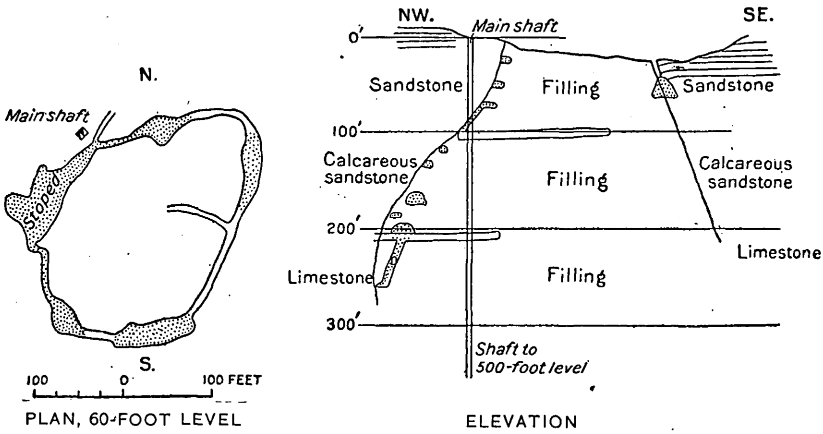

FIGURE 9.—Plan and elevation of the Grand Gulch mine, Mohave County, Ariz.

Underground no such slumping of the beds was noted. As seen in the mine, the beds end abruptly against the outer wall of the filling. This wall is in some places marked by slickensides, but as a rule is merely a close, irregular surface of separation.

At the 80-foot level the vertical shaft, whose collar is 40 feet northwest of the ellipse, cuts into the ore zone, which on all sides at this level appears to dip outward. (See elevation, fig. 9.) At the 200-foot level the ore zone is nearly circular in horizontal section and about 300 feet in diameter. It seems fairly well established that below a depth of 250 feet the walls of the ore zone tend to slope inward instead of outward, though the development on the 300 and 400 foot levels is not extensive enough to determine this matter absolutely.

To a depth of 60 feet the inclosing rock is a calcareous sandstone. Below this depth the proportion of lime increases, so that at the 200-foot level the rock is a slightly arenaceous limestone.

The nature of the wall rock below the 400-foot level is not known, but it would seem that this level should be near the top of the massive cross-bedded sandstone that was noted in the section measured along the road up the cliff. (See p. 45.)

The filling is composed of a very fine-grained pinkish-yellow sandstone in which there can occasionally be recognized small pieces of unaltered country rock. As the filling has not proved ore bearing, there are only a few underground openings in which its character could be studied. This rock shows no stratification, so far as noted, for a depth of 500 feet. As seen in thin sections under the microscope it is composed of finely comminuted quartz grains with a very few feldspar grains in a cloudy, slightly ferriferous matrix that contains a considerable quantity of calcite. The explanation here advanced for the origin of the filling is speculative, but is thought to accord with the facts ascertained.

According to Dutton,[1] during Eocene and Miocene time this region was being elevated. There was abundant rainfall, and erosion was rapidly wearing away the younger sediments. The great faults were initiated near the close of the Miocene, effecting differences in elevation of 2,000 to 3,000 feet. The Pliocene he conceives to have been marked by aridity, though the drainage was sufficient to carve out the upper terrace of the Grand Canyon, underlain by Carboniferous rocks, in which the Grand Gulch mine is located. A second upheaval and faulting, amounting to 3,000 to 4,000 feet, he thinks took place at the end of the Pliocene. The inner gorge of the canyon has been cut during this last orogenic movement and in Pleistocene and Recent time.

It is possible that during the periods of denudation at least part of the drainage of this area was subterranean and that the space now occupied by the Grand Gulch filling represents an old sink hole.

Whether the sink hole was formed entirely by solution,[2] or in part by caving of the roof, is not fully demonstrated. The absence of any great number of blocks of rock from the side walls, however, and the small size of those seen, together with the fact that the opening tends to expand more in the easily soluble limestone than in the calcareous sandstone, lead to the conclusion that at least this portion of the channel is the result of solution rather than of caving.

[1] Dutton, C. E., Tertiary history of the Grand Canyon district: U. S. Geol. Survey Mon. 2, pp. 208–288, 1882.

[2] Discussions of formations of sink holes will be found in the following papers:

Matson, G. C., and Clapp, F. C., A preliminary report on the geology of Florida, with special reference to the stratigraphy: Florida Geol. Survey Second Ann. Rept., pp. 25–197, 1909.

Matson, G. C., and Sanford, Samuel, Geology and ground waters of Florida: U. S. Geol. Survey Water-Supply Paper 319, pp. 26–28, 1913.

Purdue, A. H., On the origin of limestone sink holes: Science, new ser., vol. 26, pp. 120–122, 1907.

Sellards, E. H., Some sink-hole lakes of north-central Florida: Science, new ser., vol. 23, pp. 289–290, 1906; Origin of sink holes: Idem, vol. 26, p. 417, 1907; Some Florida lakes and lake basins: Florida Geol. Survey Third Ann. Rept., pp. 43–76, 1910.

This sink hole, in consequence of a change in the drainage or a clogging of its outlet, may subsequently have been filled with an unstratified accumulation of fine sandy mud, which by the normal processes of induration would harden into the rock of which the filling is composed.

Mr. Callaway, superintendent of the mine, told the writer that the body had been explained by some as the filling of the vent of a hot spring, and the material is locally referred to as "tufa." This explanation, however, does not seem in harmony with the observed facts. The material, even at its margin, carries none of the minerals characteristic of hot-spring action. Further, there are no accumulations of sinter or travertine anywhere in this vicinity. It is true that such deposits might have been attacked by erosion, but it would seem that some remnants should be found near the orifice of such a spring.

THE ORES.

OCCURRENCE.

At the Grand Gulch mine the ore bodies are distributed all around the outside of the filling, but are not continuous around it at any level, and so far as known there are no ore bodies within the filling. As a rule, the larger bodies appear to be on the northwest and southeast sides. So far as development shows, the ore bodies do not extend below a depth of about 250 feet, no ore having been found on the 300 and 400 foot levels, though what is termed "ledge matter" is opened by the drifts on both of these levels on the east side of the filling.

No other ore bodies have been found in the vicinity of the Grand Gulch mine, except at the Bronze L and at a prospect near it.

The ore bodies are lenslike replacements of portions of the stratified rock in which they lie. The larger ore shoots range in shape from stout irregular pods or lenses, in various attitudes between the horizontal and the vertical, to slender, nearly vertical pipelike bodies.

Between the 200-foot level and the surface there are several large stopes at different points around the circle, which range from 20 to 30 feet in width, 20 to 40 feet in length, and 40 to 60 feet in height. Not all the material removed from these stopes was shipping ore, though much of it that still lies on the dump is said to carry as much as 5 per cent of copper. In these ore bodies the replacement was not everywhere complete and there were probably some inclosed masses of waste. This waste is in some places very soft and sandy, the cementing material having been largely removed, while in other places it is the ordinary unaltered, more or less quartzose limestone.

The ore exposed in these stopes consists largely of malachite, azurite, and brochantite, with small bunches of chalcocite scattered irregularly through it. The carbonate ore, even where it appears to be a solid mass of malachite or azurite, is deceptive, for a varying proportion of the mass is shown by the microscope to consist of quartz grains. In other words, ore of this kind is a replacement of the matrix and of some of the feldspar particles of the original rock, and it is questionable whether any of the original quartz grains were replaced.

The lighter-green ores are apparently all malachite, but certain darker-green and heavier ores, particularly near masses of chalcocite, contain brochantite, a basic copper sulphate, mixed with carbonate. A very little light bluish-green chrysocolla is present in some varieties of the ore. The blue ores are apparently all azurite, part of which has been formed from malachite, while some of it appears to have replaced the matrix of the rock directly.

Some of the bodies of carbonate ore are, with little question, formed from the direct alteration of chalcocite in place, but others, in places where there is not a particle of the sulphide, are believed to have been deposited as such from solutions which may have obtained their copper from a higher part of the ore zone, perhaps from portions that have since been eroded away.

Where chalcocite occurs in the carbonate ore bodies, very few sand grains, if any, are inclosed by it. One thin section of chalcocite ore appears to show that the copper sulphide replaces the quartz, the replacement starting from the edges of the grains or from cracks through them. A specimen of chalcocite from the carbonate bodies was found to contain veinlets of a nearly white, waxy mineral which on polished faces appears slightly pinkish gray and has a nonmetallic luster. This mineral is soft and brittle. Chemical tests show it to contain lead, chlorine, and some carbonate. The carbonate, however, is thought to be in the form of malachite, which, in one of the thin sections, is seen to be replacing the chloride mineral. The gray mineral is probably cotunnite. In the alteration of chalcocite, malachite appears to form first, and subsequently it changes to azurite. It is possible, however, that the chalcocite first alters to brochantite and that this mineral then alters very quickly to malachite. Both minerals occur with chalcocite, but no definite zone of the sulphate between the sulphide and carbonate was seen.

The most interesting ore bodies in the mine were those stoped between the 100 and 200 foot levels, at the northwest side of the circle, in the Pancake, Slap Jack, and Hot Cake stopes, situated 15, 27, and 39 feet, respectively, above the 200-foot level. In these stopes the ore occurred as thin horizontal layers parallel to the bedding of the limestone. The Pancake stope extends for 300 feet around the circle, and the workable ore in it was from 20 to 30 feet wide and from 3 inches to 3 feet thick. The Slap Jack stope is 20 by 40 feet in horizontal dimensions, and the ore in it was 2½ to 3 feet thick. The Hot Cake stope was 100 feet long and averaged 40 feet in width, and the ore in it was apparently 2 feet thick. The floor of the Pancake stope is flat, but the roof is irregular in detail. In the Slap Jack stope both the floor and roof are relatively smooth, and in the Hot Cake stope the roof is smooth and the floor is irregular.

The ore has been removed from these stopes except in a very few pillars and along the edges, where it is too thin to mine. In all these stopes the larger part of the ore is said to have consisted of massive chalcocite, though a little malachite and azurite are present at both the upper and under surfaces and are seen lining vugs and fractures in the chalcocite.

These chalcocite bodies apparently occur along beds of arenaceous limestone in which the proportion of sand to lime is less than in the adjoining beds. Locally the replacement is not entirely complete, and small portions of the mass carry a considerable quantity of sand grains; elsewhere the replacement has been complete and the chalcocite mass is nearly pure, containing only a little malachite along cracks. Under the microscope polished faces of the chalcocite show interlocking intergrowths of very small crystals. Some microscopic bands through the chalcocite show a crystalline structure resembling that of comb quartz. Other polished sections show radiating growths of chalcocite crystals. Blowpipe tests indicate that this chalcocite contains no lead or silver.

Limonite is present in the carbonate ore bodies and is the only metallic mineral found on the 300 and 400 foot levels, where it occurs as thin coatings along open crevices and in the matrix of the arenaceous limestone.

ORE MINERALS.

The following minerals, identified in part by W. T. Schaller, of this Survey, were found in ores from the Grand Gulch mine collected by the writer:

Azurite, $(CuOH)_2.Cu(CO_3)_2$; dark blue. Occurs as a replacement of the matrix of calcareous sandstone and arenaceous limestone in the Grand Gulch mine.

Brochantite, $CuSO_4.3Cu(OH)_2$; dark green. Occurs intimately mixed with malachite in the darker-green ores, especially near bodies of altering chalcocite. Has not been separated from the carbonate, but its presence is shown in the dark-green ore by the test for sulphate.

Chalcocite, Cu_2S; black. Metallic. Occurs as remnants in masses of carbonate ore and was found practically pure in the flat stopes near the 200-foot level on the northwest side of the circle.

Chrysocolla, $CuSiO_3.2H_2O$; light bluish green. Occurs in small quantities in the lower-grade ore from the carbonate stopes. Replaces the matrix of sandstones, Cotunnite, $PbCl_2$; white, waxy. Occurs as a replacement of chalcocite in a specimen collected on the dump. It is seen in minute branching veinlets cutting the chalcocite, from which it may be distinguished by a pinkish tone on polished surfaces; also has a nonmetallic luster. This mineral is not pure, as it in turn is being replaced by malachite. It may be phosgenite, $(PbCl)_2.CO_3$, though it is thought that the carbonate found in the tests came from the malachite.

Cuprodescloizite, yellowish. A specimen collected on the dump shows a thin greenish-yellow crystalline coating along joints of pinkish arenaceous limestone. W. T. Schaller has found lead, copper, and vanadium to be present in this coating, but it does not contain uranium.

Malachite, $(CuOH)_2.CO_3$; green. Occurs as a replacement of the matrix of calcareous limestone and arenaceous sandstone, as an alteration product from chalcocite and from the cotunnite. Is the most prevalent ore mineral in the mine.

Limonite, $(Fe_4O_3.(OH)_6$; dull brownish. Occurs below the 250-foot level in the ore zone, also more or less widely scattered throughout the ore bodies.

Mr. Callaway reports that he has seen chalcopyrite and bornite in minute grains in the chalcocite ore, but neither of these sulphides was observed by the writer.

ORIGIN OF THE ORES.

The apparent failure of the copper ores to extend much below a depth of 250 feet, though the pervious ledge matter extends below that depth, leads to the belief that they were deposited by downward-moving waters. That these waters were probably cold seems to be rather well demonstrated by the absence of any hydrothermal alteration of the wall rocks in the vicinity of the deposit.

The sulphide ores in the flat stopes may have originally been chalcopyrite and bornite. If this was the case, these iron-bearing copper sulphides have been almost completely replaced by or altered to chalcocite, which was the only sulphide seen by the writer in those stopes, though small quantities of chalcopyrite and bornite are said to have been found in them. The masses of carbonate are in the larger lenses around the filling are thought to be in part secondary after copper sulphides deposited in those localities, and in part formed by direct deposition of the carbonates from solutions that derived their copper content from higher portions of the ore body.

It is considered probable that the present ore bodies have been formed by the gradual downward movement of the ore materials along this cylindrical channel as the surface was eroded. The absence of ores in the filling is to be explained by the fact that this filling is only slightly if at all pervious to water. In the mine it is everywhere dry, while at the 300-foot level outside of the ore zone there is a suggestion of moisture along some of the bedding planes of the limestone.

The deposition of the ore probably did not begin until after the consolidation of the filling. If the waters that were present at the time the filling was deposited had carried copper in solution, it would seem that this copper should have been precipitated by the lime carbonate and kaolin which are so abundant in the mud. As a matter of fact, there is not the slightest suggestion of any copper mineralization in the filling.

The origin of the iron, present as limonite in minor amounts in the copper carbonate stopes and in somewhat larger quantities on the 300 and 400 foot levels, is not entirely clear. It may have been derived from chalcopyrite and bornite that may have been present in the sulphide ore bodies on their alteration to chalcocite. Iron-bearing copper sulphides are certainly not now abundant. If these sulphides were present and were altered to chalcocite, their iron content would account for the limonite in the mine. The iron may possibly have been derived from the ferruginous coloring matter of the strata which once covered the terrace and are now seen in the cliffs east of the mine.

CONCLUSIONS.

So far as developments have demonstrated, the ore at the Grand Gulch mine does not extend below a depth of about 250 feet. The ledge matter, apparently as porous as in the upper levels, continues below the known ore bodies. The question arises, May this portion of the ore zone be a barren leached zone, and is it possible that at greater depth other ore bodies will be found?

The ore zone at the Grand Gulch mine below the known ore bodies contains some limonite, but so far as seen there were no copper minerals of any kind on either the 300 or the 400 foot level. It would seem that if this were a leached zone, there should be traces of copper carbonates left, or the material should have a pitted texture indicative of the former presence of sulphides. No such indications were noted by the writer.

According to the explanation of the origin of this deposit advanced in the preceding pages, all the metals were brought to their present positions by generally downward-moving waters. If the amount of copper carried by these solutions was comparatively small, as it is thought to have been, it is possible that all of the copper may have been taken from them and deposited in the first 250 feet of their descent.

BRONZE L MINE.

DEVELOPMENT AND ECONOMIC FEATURES.

The Bronze L mine, 3 miles south-southwest of the Grand Gulch mine, is developed by a shaft said to be 200 feet deep, which has caved a short distance below the 100-foot level. The shaft is an incline to the southeast at an angle of 60°, and there are drifts about 100 feet long on the 60 and 100 foot levels. Hoisting is done by a bucket and whim.

The collar of the shaft is 500 feet below the top of the mesa, in a steep-walled ravine which opens northward into Pigeon Canyon near its mouth. (See fig. 6.) A road half a mile long from the mine to the mesa is rather steep, so that in the fall of 1913 burros were used to carry the ore that distance. It is said, however, that with little additional expenditure a wagon road, already partly built, could be completed to the Grand Wash. This would shorten the haul about 13 miles and would reduce the climb about 1,700 feet.

THE ORES.

OCCURRENCE.

The mine lies near the middle of the more arenaceous member (No. 4 of the section on p. 45) of the beds forming this terrace. The sandstones are somewhat calcareous throughout, and some beds are decidedly limy.

The ore bodies are closely related to a rather tight fissure zone which strikes N. 45° E. and dips 60° SE. In some places along this zone the ore occurs as small lenses connected by stringers. There are also stringers and small flat kidneys of ore parallel to the horizontally bedded sediments. One bed of very dense reddish sandstone with some calcareous cement exposed at the 60-foot level, 100 feet southwest of the shaft, has been fractured and is seamed with veinlets of sulphide for at least 18 feet from the fissure zone.

On the 100-foot level, about 75 feet northeast of the shaft, a 10-foot crosscut extends southward into a 4-foot zone of fracturing which strikes N. 20° W. and stands vertical. There is some carbonate ore on the small angular fragments in this zone.

ORE MINERALS.

The ore minerals are largely sulphides, with smaller amounts of azurite and malachite derived from their alteration. A specimen of ore obtained from the southwest drift at the 60-foot level shows the series of alteration from chalcopyrite and bornite, through chalcocite, to the carbonates. The chalcopyrite apparently first alters to bornite, which usually surrounds the remaining kernels of the yellow iron-bearing sulphide. In places, however, remnants of chalcopyrite are inclosed in chalcocite without the intervening band of bornite. The bornite is replaced by or alters to chalcocite, which in turn is seamed by veinlets of a mixture of copper-pitch ore and copper carbonates. (See fig. 10.) In his use of the term "copper-pitch ore" the writer follows Lindgren,[1] who applies it to "a dark-brown to black substance, sometimes dull, but generally with glassy to

[1] Lindgren, Waldemar, Copper deposits of the Clifton-Morenci district, Arizona: U. S. Geol. Survey Prof. Paper 43, pp. 114-115, 1905.

resinous luster, hardness about 4, streak dark brown." The name as used probably covers a series of obscure minerals containing oxides of copper, manganese, and iron, with silica and locally other constituents.

Microscopic examination of polished sections indicates that most of the bornite has been formed secondarily at the expense of the chalcopyrite, but some of it may be primary. All the secondary chalcocite appears to be crystalline, as shown by etching a polished surface with nitric acid. The etched surfaces are similar in appearance to those of chalcocite ore from the Grand Gulch mine, which, while thought to be primary as regards other minerals in that deposit, is probably of supergene origin. This is contrary to the opinion expressed by Graton and Murdoch,[1] that "secondary" chalcocite is not crystalline, though they say that in some places it shows a system of cleavage lines inherited from bornite, and usually an irregular system of cracks which are "the outlines of individual grains."

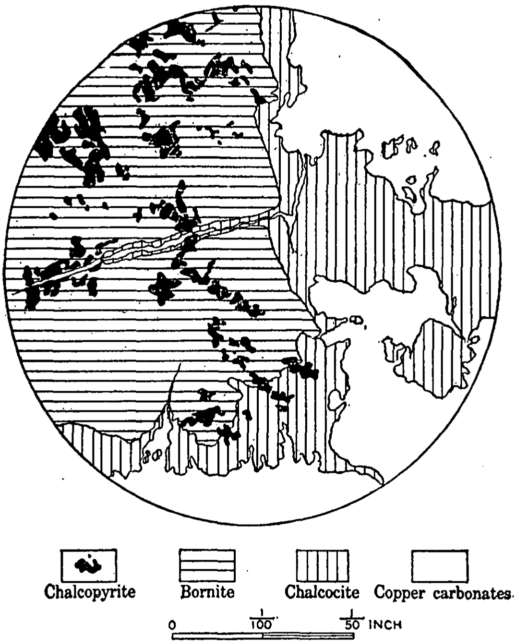

FIGURE 10.—Camera lucida drawing of a polished section of ore from the Bronze L mine, Bentley district, Mohave County, Ariz., showing the steps of alteration of chalcopyrite and bornite through chalcocite to the copper carbonates.

ORIGIN OF THE ORES.

These ores are believed to have been deposited by atmospheric waters along the more or less open fissure zone. Whether the waters moved in a downward or a lateral direction was not determined, though it is thought that the original deposition was effected under reducing influences, and that the carbonates now present were all derived later from the original sulphides. The opinion has been advanced that the Bronze L is a deposit similar in character to that of the Grand Gulch. The fissure, it is true, is slightly curved, but the rocks on each side are the same, and there is no indication of the former existence of a sink hole.

[1] Graton, L. C., and Murdoch, Joseph, The sulphide ores of copper; some results of microscopic study: Am. Inst. Min. Eng. Bull. 77, pp. 760-765, 767, May, 1913.

PROSPECTS.

Three-quarters of a mile south of the Bronze L mine there are a few shallow shafts and pits on a northeasterly fissure containing some chalcocite and copper carbonate ore. The mode of occurrence is similar to that at the Bronze L mine.

COPPER KING MINE.

The Copper King mine is situated about 40 miles east of the Grand Gulch mine, at Copper Mountain, on the Kanab Plateau. The mine is 3 miles north of Colorado River, on the rim of the Grand Canyon, and there is said to be an abundance of water in springs 8 miles distant. A small spring a quarter of a mile from the camp supplies 20 gallons a day. This mine is the property of John A. Swapp, of Overton, but is being worked by Bishop Whitehead, who ships every two months a carload of ore said to carry 23 to 26 per cent of copper and from $3 to $4 a ton in silver.

This property was not visited by the writer. He was informed that the ores occur in northwest fissures, which dip steeply to the southwest and cut approximately horizontal sedimentary rocks. The ore bodies are in a white sandstone that is covered by a light-colored limestone. They are said to be lenslike bodies connected by stringers of good ore. The ore minerals seen at Bishop Whitehead's store at Overton are chalcopyrite, chalcocite, copper-pitch ore, cuprite, malachite, and azurite. Mr. Whitehead reports, however, that cerusite and calamine are sometimes found in open watercourses through the other ore.

A specimen given to the writer by Bishop Whitehead shows remnants of chalcopyrite altering directly to copper-pitch ore, which in turn is altering to cuprite and carbonates. This material is covered with botryoidal layers of limonite and malachite, with a final coating of beautiful green feltlike masses of malachite.

BIBLIOGRAPHY OF COPPER ORES OF THE "RED BEDS."

A review of the literature shows that the preponderance of evidence leads to the conclusion that the copper ores occurring in the "Red Beds" of the Western States are epigenetic and have been deposited by atmospheric waters moving generally downward. The original source of the copper is not definitely known. The metal is thought to have been deposited in Triassic and Jurassic (?) sediments, in part as detrital material from older copper-bearing deposits and in part by solutions which had derived the copper from such older deposits. It is fairly well established that the copper of the present deposits was widely desseminated in the sediments and that it was gathered and brought to its present position by cold waters charged with chlorides and sulphates.[1]

The copper was probably carried as a sulphate and was deposited as a sulphide by natural reducing agents such as carbonaceous matter and also by calcareous or kaolinic cementing materials. Ransome[2] has lately proposed the term "supergene" to designate "minerals deposited by generally downward moving initially cold solutions."

The following list includes the more important publications on the deposits of copper in the "Red Beds" of the Western States:

BLANDY, JOHN F., An Arizona copper deposit: Eng. and Min. Jour., vol. 64, p. 97, 1897. Describes a deposit of copper and iron sulphide 50 miles north of Williams, near the rim of the Grand Canyon.

CAZIN, F. M. F., New Mexico v. Lake Superior as a copper producer: Eng. and Min. Jour., vol. 30, p. 87, 1880. Describes copper deposits of the Nacimiento Mountains, N. Mex., as carbonates and silicates of copper largely replacing plant remains and impregnating marls and as pebbles in conglomerate.

EMMONS, S. F., Copper in the Red Beds of the Colorado Plateau region: U. S. Geol. Survey Bull. 260, pp. 221–232, 1905. Summarizes existing reports on "Red Beds" deposits and describes a deposit on the Grand View trail, 12 miles east of the Bright Angel trail, in the Redwall limestone. The ores are copper carbonate and chrysocolla, with chalcocite in the center of the larger masses. Pyrite and chalcopyrite are occasionally found. Ores occur along a shear zone. Also mentions occurrence in Unaweep Valley, 15 miles south of Grand Junction, Colo.

EMMONS, W. H., The Cashin mine, Montrose County, Colo.: U. S. Geol. Survey Bull. 285, pp. 125, 129, 1906. States that the ores occur along a fissure in La Plata (Jurassic) sandstone, where covellite, chalcocite, bornite, native copper, malachite, azurite, cuprite, and iron sulphate are found disseminated in the crushed zone. Thinks that the ores were leached down from above.

FLECK, HERMAN, and HALDANE, W. G., A study of the uranium and vanadium belts of southern Colorado: Colorado Bur. Mines Rept. for 1905–6, pp. 80–81, 1907. Discusses green cupriferous sandstone in southwestern Colorado.

GALE, H. S., Geology of the copper deposits near Montpelier, Bear Lake County, Idaho: U. S. Geol. Survey Bull. 430, pp. 112–122, 1910. Describes some copper deposits in the "Red Beds" (Triassic). Malachite and azurite occur in joints and bedding planes of a somewhat calcareous sandstone and in shales. Chalcocite and covellite at depth replace wood fiber.

HERRICK, C. L., The occurrence of copper and lead in the San Andreas and Caballo Mountains: Am. Geologist, vol. 22, pp. 286–291, 1898. Describes copper deposits of the San Andreas Mountains, N. Mex., as occurring in a bed of red sandstone which lies at the contact of granite and overlying Carboniferous sediments and which carries hematite, chalcocite, malachite, and cuprite.

HILL, J. M., Copper deposits of the White Mesa district, Arizona: U. S. Geol. Survey Bull. 540, pp. 159–163, 1914. Describes some copper deposits on the White Mesa, 145 miles north of Flagstaff, Coconino County, Ariz., in rocks which are probably to be correlated with the La Plata sandstone of southwestern Colorado.

[1] Lindgren, Waldemar, The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, p. 79, 1910; Mineral deposits, pp. 375–376, New York, 1913.

[2] Ransome, F. L., Copper deposits near Superior, Ariz.: U. S. Geol. Survey Bull. 540, p. 153, 1914.

JENNINGS, E. P., The copper deposits of the Kaibab Plateau, Ariz.: Am. Inst. Min. Eng. Trans., vol. 34, p. 839, 1904. Describes the replacement deposits on the Kaibab Plateau in the vicinity of Jacobs Lake, which occur in the "Aubrey" (Carboniferous) limestone, now known as Kaibab limestone.

JONES, F. A., Mines and minerals of New Mexico, 1904. Describes the copper ores in the "Red Beds" of New Mexico.

LINDGREN, WALDEMAR, Notes on copper deposits in Chaffee, Fremont, and Jefferson counties, Colo.: U. S. Geol. Survey Bull. 340, pp. 170–174, 1908. Describes the occurrence of copper carbonate and chalcocite in "Red Beds" at Red Gulch, Fremont County, Colo.

——— Mineral deposits, New York, 1913. On pages 368–382 discusses the foreign and American deposits of copper, lead, vanadium, and uranium in sandstone and shale and states that the epigenetic character of such deposits is proved beyond reasonable doubt.

LINDGREN, WALDEMAR, and GRATON, L. C., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, pp. 76–79, 1910. Conclude from a study of the copper deposits in sandstones in New Mexico that they are of epigenetic origin, formed by the replacement of carbonaceous, kaolinitic, and calcareous material of the sandstone by chalcocite, through the action of atmospheric waters charged with chlorides and sulphates.

LUNT, H. F., The copper deposits of the Kaibab Plateau, Ariz.: Am. Inst. Min. Eng. Trans., vol. 34, p. 989, 1904. In discussing paper by E. P. Jennings, mentions the somewhat similar deposits on the White Mesa north of Flagstaff.

NEWBERRY, J. S., Geological report: Exploring expedition from Santa Fe, N. Mex., to the junction of the Grand and Green rivers * * * in 1859, p. 117, 1876. Describes copper ores in the Nacimiento Mountains, N. Mex., as copper carbonates in light-colored sandstones containing plentiful plant remains.

PETERS, E. D., Notes on the Oscura copper fields and other mines in New Mexico: Eng. and Min. Jour., vol. 34, p. 270, 1882. Describes copper deposits in the Sierra Oscura, N. Mex., which occur in deformed Permian sediments.

SCHMITZ, E. J., Copper ores in the Permian of Texas: Am. Inst. Min. Eng. Trans., vol. 26, pp. 97–108 (see also pp. 1051–1052), 1896. Describes copper deposits in flat-lying red beds along the valleys of Red and Brazos rivers, northern Texas.

TARR, W. A., Copper in the "Red Beds" of Oklahoma: Econ. Geology, vol. 5, pp. 221–226, 1910.

TURNER, H. W., The copper deposits of the Sierra Oscura, N. Mex.: Am. Inst. Min. Eng. Trans., vol. 33, pp. 678–681, 1903. Describes copper deposits which occur in deformed shales and sandstones of Permian (?) age. Ores are copper glance and carbonate in minute grains disseminated through the rock and in nodular masses with a kernel of chalcopyrite, bornite, and chalcocite replacing plant remains.