DEPARTMENT OF THE INTERIOR
ALBERT B. FALL, Secretary

UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, Director

PROFESSIONAL PAPER 122

COPPER DEPOSITS

OF THE

TYRONE DISTRICT, NEW MEXICO

BY

SIDNEY PAIGE

WASHINGTON
GOVERNMENT PRINTING OFFICE
1922

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COPPER DEPOSITS OF THE TYRONE DISTRICT, NEW MEXICO.

By Sidney Paige.

Part I.—GEOGRAPHY AND GEOLOGY.

INTRODUCTION.

Field work.—The Tyrone district was mapped geologically by the writer first in 1910, while studying the much larger area included in the Silver City quadrangle. The results of this work have been published.[1] The field work on which the present report is based was done during the period August 9 to October 31, 1915.

Acknowledgments. — Many courtesies accorded to the writer by those engaged in mining are here acknowledged with sincere gratitude. Every facility was furnished for underground studies, and the mining companies gave free access to all their data. The writer is particularly indebted to Mr. E. M. Sawyer, resident manager, Mr. E. F. Pelton, superintendent, Mr. Norton Johnson, geologist, and Mr. Earle Fraser-Campbell, chief engineer, of the Burro Mountain Copper Co.

Previous work.—In 1905 a general reconnaissance of the ore deposits of New Mexico was undertaken by the United States Geological Survey. During this work the Tyrone district was examined by Graton.[2] He recognized the intrusive nature of the quartz monzonite porphyry, the "secondary" character of the chalcocite ores, and the general relations of the ores to the fracturing.

In 1910 the district was studied by the writer during the geologic mapping of the Silver City quadrangle. This work, which was somewhat more detailed, involved the mapping of the quartz monzonite contact and corroborated Graton's conclusions regarding the nature and position of the ore bodies. Physiographic studies[3] were also made at this time, and the turquoise deposits[4] were described. During the summer of 1913 R. E. Somers studied that portion of the district immediately adjacent to the mines of the Burro Mountain Copper Co.[5] Somers made detailed studies of many thin sections and polished surfaces and published many excellent microphotographs, throwing light on the nature of the enrichment. His general conclusions regarding the nature of the ore bodies are in accord with those of Graton and the writer.

Private reports have been written by a number of mining engineers, and several of them have been read by the writer. Among these that of E. M. Sawyer, resident manager of the Burro Mountain Copper Co., states for the first time the generalization that the larger ore bodies will probably be found near the porphyry-granite contact.

GEOGRAPHY.

POSITION OF THE AREA.

The Tyrone district is in Grant County, in southwestern New Mexico, about 40 miles east of the Arizona line and 60 miles north of the Mexican border. (See fig. 1.) The area shown on the topographic and geologic maps that accompany this report covers approximately 30 square miles in Tps. 19 and 20 S., R. 15 W. Parallel of latitude 32° 37′ 30″ passes through the approximate center of the area, and meridian of longitude 108° 22′ 30″ passes about a mile east of the center. (See Pls. I and II, in pocket.)

The district lies 10 miles southwest of Silver City, a town of 2,662 inhabitants (1920), the terminus of a branch of the Atchison, Topeka & Santa Fe Railway and long a supply point for neighboring mining districts. The princi-

[1] Paige, Sidney, Metalliferous ore deposits near the Burro Mountains, Grant County, N. Mex.: U. S. Geol. Survey Bull. 470, pp. 131–150, 1911; U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 199), 1916.

[2] Lindgren, Waldemar, Graton, L. C., and Gordon, C. H., The ore deposits of New Mexico: U. S. Geol. Survey Prof. Paper 68, 1910.

[3] Paige, Sidney, Rock-cut surfaces in the desert ranges: Jour. Geology vol. 20, pp. 442–450, 1912.

[4] Paige, Sidney, The origin of turquoise in the Burro Mountains, N. Mex.: Econ. Geology, vol. 7, pp. 382–392, 1912.

[5] Am. Inst. Min. Eng. Trans., vol. 52, pp. 604–644, 1915.

pal settlement in the district is the mining camp of Tyrone, formerly situated in St. Louis Canyon near its junction with the headwaters of Mangas River, now near by in Mangas Valley, where the Burro Mountain Copper Co. has built a model town. Leopold, a mile farther southwest, where once were established the offices and mill of the Burro Mountain Copper Co., has been abandoned.

A branch of the El Paso & Southwestern Railroad connects Tyrone with Deming.

TOPOGRAPHY AND DRAINAGE.

The southwestern United States has been divided into a number of physiographic provinces, which are delineated on maps by Ransome[6] and Hill.[7] These authors are in substantial agreement regarding the basis on which the subdivisions should be made but have drawn certain boundaries (which in their nature are indefinite) at somewhat different places. The physiographic provinces of interest here will be briefly described in order that the topographic setting of the Tyrone district may be more complete.

The Nevada-Sonoran region is described by Ransome as follows:

> The whole province is diversified by mountain ranges, which, while displaying considerable variety of trend, show a marked adherence to meridional lines in the Great Basin proper and to northwest-southeast lines in Arizona. As Dutton has said, their appearance on a map suggests an army of caterpillars crawling toward Mexico. These ranges are generally narrow and short, although some fairly continuous crests attain lengths up to 300 miles. They are separated by flat-floored valleys which, despite some statements to the contrary, based on the occurrence of planated rock surfaces in certain localities, are, as a rule, deeply filled with detrital deposits, derived from the neighboring ranges.

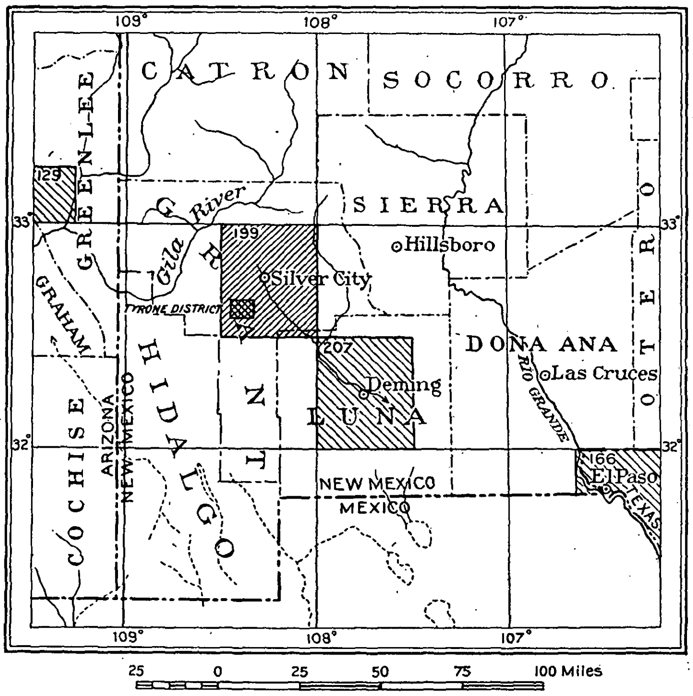


FIGURE 1.—Index map of southwestern New Mexico. Shading indicates areas covered by geologic folios as follows: 129, Clifton; 166, El Paso; 199, Silver City; 207, Deming.

It is on the borders of this region of parallel ranges and waste-filled valleys that the Tyrone district lies. It might equally well be said to lie at the north end of the Mexican Plateau province, a region of very similar topographic and geologic relations. In fact, Hill has drawn the western boundary of the Mexican Plateau province northwestward to meet the Colorado Plateaus in central Arizona, as shown by the dashed line on figure 2—that is, the Mexican Plateau region at its north end, at least its central portion, merges with the Nevada-Sonoran region, as interpreted by these two writers.

The short northwestward-trending ranges, with their intervening waste-filled valleys, form a characteristic feature of that part of the Silver City quadrangle in which the Tyrone district lies, and the dominant topographic features of this district are the results of processes directly controlled by erosion in a semiarid region of inclosed basins and block-fault ranges.

To the north great floods of lava, subsequently carved by streams into imposing mountain ranges, mask the structural relations of this desert fault-block country to the Colorado Plateaus, which represent perhaps a less disturbed portion of the earth's crust. In the words of Hill:

> The Mexican Cordilleran province [Mexican Plateau of Ransome] is * * * a folded and faulted extension of

[6] Ransome, F. L., The Tertiary orogeny of the North American Cordillera and its problems: Dana Commemorative Lectures, New Haven, Conn., 1915.

[7] Hill, R. T., The geographic and geologic features and their relation to the mineral products of Mexico: Am. Inst. Min. Eng. Trans., vol. 32, p. 164, 1902.

the feature known in the United States as the Colorado Plateau. * * * The faulting attending the southern and eastern portion of the plateau grows in intensity, together with folding, southward into Mexico.

A view from the summit of the Big Burro Mountains (8,009 feet high), in the extreme southwest corner of the Tyrone district (see Pl. I), toward the north, south, or east discloses what appears to be a great plain sloping gently outward from the foot of the rather precipitous mountain side, 800 or 900 feet below. To the northeast the plain is interrupted by a small, narrow range, the Little Burro Mountains, a fault-block mountain mass that trends northwest and is about 10 miles long. This treeless and semiarid plain, built up of waste from the

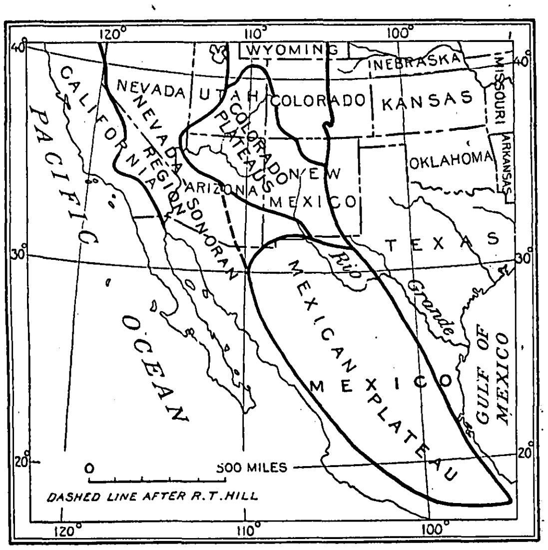


FIGURE 2.—Map of physiographic provinces of the southwestern United States. (After Ransome.)

neighboring mountains, sweeps far to the east and south and is the most impressive feature of the region. In the distance may be seen ranges rising island-like from its nearly level floor. The eye, in following the gentle rise of this plain in its ascent to the Big Burro Mountains, can not in many places detect an interruption where the gravel terminates and a plain cut in rock, which borders the mountains, begins. The two merge imperceptibly, and at once there arises the suggestion of their contemporaneous origin. As will be shown below, they are contemporaneous; the plain underlain by rock, now more or less scored by stream canyons, originated during and as a function of the deposition of the gravel.

A more careful scrutiny of the country from this commanding point of view reveals several features of significance. The position and limits of the gravel terrane within the district can be made out, sweeping northward from the southeast corner of the district and thence westward to the northwestern part. It will be noted, too, that the gravel fills the Mangas Valley, merging far to the northwest with the valley of the Gila, and while it terminates abruptly on the east against the somewhat precipitous Little Burro Mountains, it continues beyond the mountains far to the east. The gravel in this valley is intricately dissected by erosion, but what remains still graphically proves the presence of an ancient gently sloping valley floor.

Within the rock plain mentioned above, which nearly surrounds the Big Burro Mountains, may be observed a shallow panlike depression 3 to 4 miles in width, extending northeastward from the Big Burros and bordered by hills slightly higher than the average level of the country within the depression. It marks the position of the unaltered part of an intrusive mass of quartz monzonite porphyry which here invades the pre-Cambrian granite of the region.

The topography of the district in its broader aspects may be said to be controlled by a few salient features. Thus the Little Burro Mountains are, as a whole, a monoclinal fault block with precipitous western scarp and gently dipping, partly gravel-covered eastern slope; the Big Burro Mountains are erosion remnants standing well above the surrounding country; the great plain is for the most part an accumulation of rock waste in an extensive inclosed basin, having minor topographic features produced by erosion and aggradation; and associated with this gravel plain is a plainlike rock surface bordering the higher mountains, a dissected plain, above the general level of which no hills rise but upon which many minor irregularities have been imposed by erosion, controlled by the varying hardness of the rocks and structural features to be described later.

Streams flowing radially from the Big Burro Mountains as a center have cut canyons or valleys below the level of the hard rock plain. This area is therefore one of long, narrow even-topped ridges, sloping outward from the mountains, and a progressively more intricate drainage system as the mountains are left behind. The largest streamways are Whitewater Canyon, Big Murray Gulch, Deadman Gulch, and Cherry Creek, all of which head well up toward the foot of the Big Burros. The first three streams just before passing on to the gravel-covered area flow through well-developed, steep-sided canyons. This feature will be discussed below, under the heading "Physiography." During the summer a small amount of water may usually be found in all the streamways mentioned, particularly in their canyon portions. On reaching the gravel, however, this meager supply sinks beneath the surface.

The Continental Divide passes diagonally through the area from the southwest to the northeast corner. Mangas River (or Valley) receives all the westward-flowing drainage and carries it to Gila River, about 25 miles to the northwest. Eastward-flowing drainage sinks beneath the surface in the gravel-filled basin into which Mimbres River discharges its flood water, about Deming, N. Mex.

WATER SUPPLY.

Water for domestic purposes at the new town of Tyrone is obtained by pumping through prospect drill holes in the Quaternary gravel, in which there is an abundant supply. Water for the town of Leopold was obtained by pumping from Deadman Gulch.

Water for the concentrator, about 3 miles east of the mines, is pumped from the No. 2 Chemung shaft. This supply is augmented by recovery from the tailings. Ranches of the district obtain water from wells, and there is a little water in the upper courses of the streams radiating from the Big Burro Mountains.

GEOLOGY.

GEOLOGY OF THE SURROUNDING REGION.

GENERAL GEOLOGY.

A study of the Tyrone district alone, as a discrete unit, could not lead to a comprehensive account of the geologic history of the district, for the rocks within it are all igneous intrusives and fail to reveal many important facts which become evident on a study of the surrounding region. Therefore, before the geology of the district is described, a summary will be presented, setting forth the main stratigraphic and structural features of the Silver City quadrangle,[8] in which the Tyrone district lies.

The rocks of the Silver City quadrangle are in part of sedimentary origin and in part of igneous origin and range in age from pre-Cambrian to Recent. The sedimentary rocks fall into two general groups—one consisting of hard strata, of Paleozoic and Mesozoic age, and the other of unconsolidated or partly consolidated gravel and sand, of Cenozoic age, forming extensive bolsons, or desert plains. The hard strata consist of quartzite, sandstone, shale, and limestone and comprise formations representing all the Paleozoic systems, though each is represented sparingly. No Triassic or Jurassic strata are known, but the Cretaceous system is represented by two formations, one certainly and the other possibly of Upper Cretaceous age. The unconsolidated deposits that form the bolsons are chiefly of Quaternary age, but sand and gravel are interbedded with the Tertiary lava flows.

The general character, thickness, and order of succession of the stratified rocks are shown in figure 3.

The igneous rocks likewise fall into two general groups—one consisting of granite and associated rocks of pre-Cambrian age, and the other of a great series of intrusive and effusive rocks of Cretaceous (?), Tertiary, and Quaternary age. The intrusive rocks occur in stocks, dikes, and laccolith-like bodies and comprise granodiorite, quartz monzonite, quartz diorite porphyry, andesite porphyry, rhyolite, quartz latite, and similar rocks. The effusive rocks form an extensive series of flows and flow breccias and comprise rhyolite, latite, andesite, and basalt. Interbedded with them are tuff and detrital sand and gravel. These rocks, all younger than the Colorado shale, may be classified in order of age as follows:

1. A great complex of dikes of generally dark-colored porphyritic rock of dioritic and andesitic facies, with which are associated volcanic breccias and lavas of similar type.

2. Laccoliths and stocks of quartz diorite porphyry.

3. Masses of granitic, monzonitic, and dioritic rocks with associated porphyritic facies

[8] Paige, Sidney, U. S. Geol. Survey Geol. Atlas, Silver City folio (No. 199), 1916.

System.	Formation and group.	Section.	Thickness (feet).	Character of rocks.
Quaternary.	Gravel and sand with interbedded basalt lavas.		1,000+	Gravel and sand, in part consolidated, and basalt flows.
	Unconformity			
Tertiary.	Lava flows and interbedded sediments.		2,000+	Rhyolite, latite, andesite, and basalt, with interbedded partly consolidated gravel, sand, and tuff.
	Unconformity			
Cretaceous?	Andesitic breccia.		(?)	Andesitic breccia intruded by diorite and diorite porphyry.
	Unconformity			
Cretaceous.	Colorado shale.		2,000±	Chiefly shale, in places calcareous and sandy, with numerous thin sandstone lenses.
	Beartooth quartzite.		90-125	Quartzite with thin beds of shale locally.
	Unconformity			
Carboniferous.	Fierro limestone.		800±	Gray, blue, and black limestone with many cherty layers.
Devonian.	Percha shale.		300-500	Green to black shale.
	Unconformity			
Silurian and Ordovician.	Fusselman and Montoya limestones.		330±	Gray and pink limestone with prominent cherty layers near base.
	Unconformity?			
Ordovician.	El Paso limestone.		900±	Gray limestone with many cherty layers.
	Unconformity?			
Cambrian.	Bliss sandstone.		180±	Quartzose sandstone and glauconitic sandstone, calcareous near the top.
	Unconformity			
Pre-Cambrian.	Granite, syenite, and allied porphyries.			Granite, syenite, and allied porphyries.

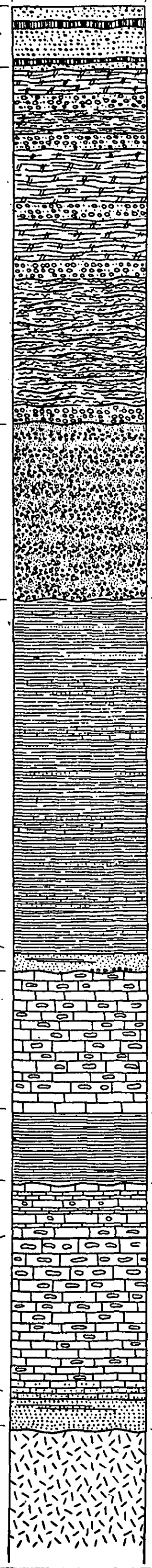


FIGURE 3.—Generalized columnar section of the sedimentary rocks exposed in the Silver City quadrangle. Scale, 1 inch=1,000 feet.

and accompanying dikes. Groups 1, 2, and 3 are of probably late Cretaceous age.

4. Great flows of basaltic, andesitic, rhyolitic, and latitic lavas, with which are interbedded tuffs, breccias, sand, and gravel, in all aggregating several thousand feet in thickness.

5. Stocklike masses of fine-grained rhyolite and quartz latite porphyry, breaking through all the older rocks and through the lava flows just mentioned. Groups 4 and 5 are of Tertiary age.

6. Intrusive basaltic masses and basaltic lava flows interbedded with the Quaternary gravel.

Folding, faulting, extrusion, and intrusion have played important parts in the development of the geologic structure of this region. The principal structural features in the area are shown in figure 4.

The folding is decidedly open and is probably due in part to the forces that produced the faulting and in part to earlier igneous intrusion.

All the faults observed are of the normal type and express an extension or stretching of the strata. The strong northwesterly faults are probably parallel to and closely connected with broad axes of folding, for, broadly viewed, the fractures may be placed in two distinct systems, one trending northwestward and the other trending northeastward. The Silver City Range, for example, and its southeastern structural analogue, Lone Mountain, where not faulted along their eastern fronts, are sharply

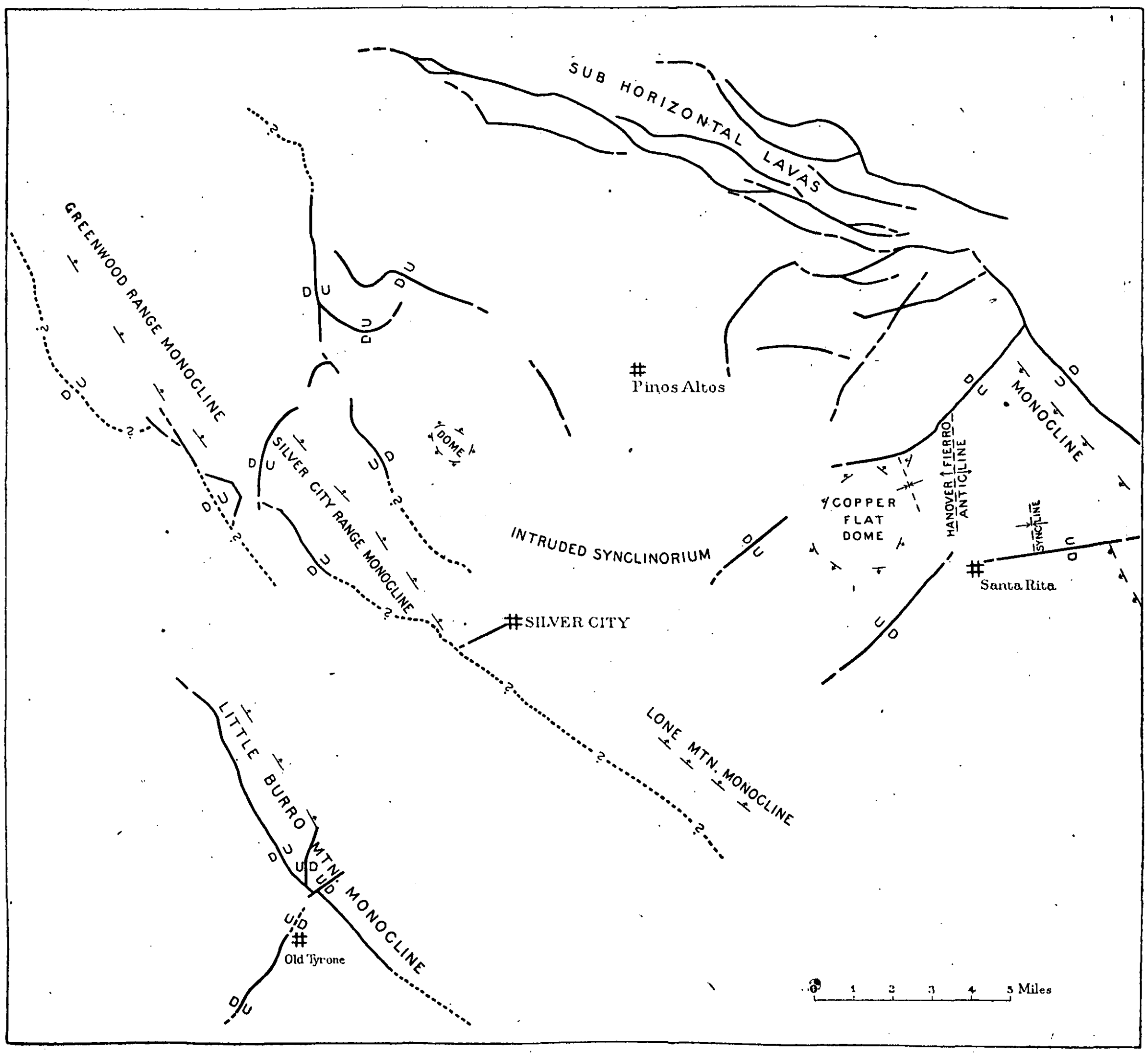


FIGURE 4.—Map of the principal faults and folds in the northern part of the Silver City quadrangle. D, downthrown side; U, upper side.

flexed, some beds standing at angles of 70° or more. West of these mountains, too, as is partly visible at Treasure Mountain and in the hills north of it, are strong faults nearly parallel to the fault on the eastern front.

The west flank of the Little Burro Mountains is also marked by a fault which is parallel to the monoclinal axis of the range. At Georgetown a strong northwesterly fault is parallel to the broad monocline that dips to the southwest.

In striking contrast to these widely separated dislocations are the closely spaced and on the whole much shorter transverse northeasterly fractures. These are well exposed in the Silver City Range. It is evident that almost every cross fault is downthrown on the north side (or uplifted on the south side). Such a system of faults involves a marked extension or lengthening of the entire block.

Several faults indicate rather certainly movements later than the period of Pleistocene deposition, though the recent movement on each of these faults was perhaps only a continuation of a much earlier disturbance. Such a fault is the one which separates the Pleistocene deposits from pre-Cambrian rocks at the western base of the Little Burro Mountains. Near the north end of this fault, a short distance south of Wind Canyon, the gravel beds abut against the rhyolite which with the overlying andesite forms much of these hills. (See Pl. III, *B*.) It does not seem possible that this attitude of the beds could be brought about by any other means than a fault. When this fault is traced southward to Redrock Canyon the abruptness of the contact of the gravel beds with granite is strikingly apparent. At the canyon, though the evidence that faulting has taken place is not perfectly clear, there are certain conditions which are rather opposed to a normal overlapping contact, the most significant of which is the fineness of the sediments that abut vertically against the granite. Although there is some granitic material in the gravel, the amount seems insufficient to establish a purely local origin for the pebbles. Furthermore, at a point about a mile north-northeast of Tyrone a cross fault offsets the straight fissure of the main fault. Both north and south from the cross fault the gravel contact for half a mile along the main fault is straight, but at the cross fault the contact is sharply offset for about 300 feet in a direction accordant with the dip of the fault planes and the throw of the cross fault. A short distance to the north of the point where the road crosses the main fault there is a vertical contact of fine gravel against broken rocks of the andesite complex, separated by about 3 feet of fault gouge. The gravel at the contact is not composed of material of the complex but of light-colored granite. Still another fact that may be cited is the difference in the character of the gravel contact on the two sides of the range. On the east it is much higher than on the west, and the gravel lies upon an irregular surface of rhyolite with a crooked contact and shows very coarse material at the base, the conditions presenting a marked contrast to those on the west side.

Similar evidence of post-Pleistocene faulting may be seen at several other localities north of Treasure Mountain and east of Georgetown.

The age of movement along a plane or surface of weakness is difficult to determine, for where a break has once been formed by movement a continuation of the movement is likely to take place, perhaps at intervals, through a long period of time. It is therefore impossible to determine definitely when faulting first began in this area. It is evident that faulting has taken place since the deposition of the Pleistocene gravel and that some faults break the Tertiary lava flows without apparently affecting the Pleistocene gravel; but though no fault was found that cuts Cretaceous rocks and does not cut Tertiary lavas, yet faulting might have begun before the lavas were deposited and continued along the same planes after their deposition. The absence of any direct evidence pointing to this conclusion, however, permits the tentative assumption that faulting began after the lavas had been poured out and continued at intervals along certain breaks after the deposition of Pleistocene gravel.

GEOLOGIC HISTORY.

PRE-CAMBRIAN ERA.

The ages that preceded Cambrian deposition doubtless comprised many periods of sedimentation, erosion, and disturbance, covering in all a longer time than that represented by all succeeding geologic history. Only the merest fragments of this history can be read in this area. The pre-Cambrian rocks are largely granites, in which are enmeshed the almost indistinguishable traces of sedimentary deposits. A few small areas of quartzite and schist point to the existence of ancient seas. The metamorphosed and fragmentary character of these sedimentary rocks shows that their history has been varied.

There is abundant reason to believe that old mountain ranges existed in this region and that the forces of erosion in the past, even as to-day, carried on their work of denudation. The character of the surface upon which the earliest Cambrian strata rest serves to corroborate what has been observed at many other localities, namely, that a prolonged period of erosion and planation preceded the subsidence of the pre-Cambrian land beneath the sea to form a floor of moderate relief on which the Cambrian sands were deposited.

PALEOZOIC ERA.

The nature of the basal Cambrian strata, which are composed of quartzose, calcareous, and glauconitic material, shows that at the time of their deposition the sea was gradually transgressing upon a land surface of moderate relief. It is probable that as the sea advanced wave action reduced still further a rather low relief, and that the remarkably flat contact between the Cambrian sediments and the pre-Cambrian basement is in part a result of this action.

The subsidence whose beginning is marked by these Cambrian beds endured for a long period. As the seas gradually grew deeper or as the shore line slowly transgressed landward, calcareous sediments gradually became more prevalent, and finally they formed the only record of deposition. Though these seas were not deep they were probably extensive. Whether the interval of time indicated by the differences between the fauna of the Bliss sandstone and that of the El Paso limestone includes a period when Cambrian beds were raised above sea level and subjected to erosion can not yet be determined. Apparently there was a rather abrupt transition from the sandy limestone layers of the older formation to the more calcareous beds of the younger formation, but if there is an unconformity between the two formations it has not been detected. The incursion of sandy material in the upper part of the El Paso limestone marks the unsettling of a delicate balance of depth rather than any great uplift. The quartz sands found in this part of the Cambrian system may have been carried there by currents that swept across wide areas of shallow seas or may in part have been blown from neighboring beaches by violent winds, for limestone deposits may be formed close to the seashore provided great quantities of débris are not being contributed to the sea.

The record of Silurian time, with its fossiliferous and chert-bearing beds, shows that the conditions then were similar to those of the preceding period, but the abrupt change from Silurian limestone to Devonian shale suggests a fundamental difference in conditions of sedimentation. Though the bedding of the Silurian limestone and the Devonian shale seems to be concordant, there is reason to believe that the beginning of Devonian deposition was preceded by marked erosion in this southwestern area. At Bisbee, for example, as stated by Ransome,[9] Devonian beds rest upon Cambrian limestone; at Clifton, as shown by Lindgren,[10] Devonian beds overlie Ordovician beds; and in the Silver City region Devonian beds rest upon Silurian beds. These facts and the sudden change in sedimentation marked by the deposition of Devonian shale on Silurian limestone point to decided irregularities in the Paleozoic sequence in this southwestern province, probably indicating a period of uplift and erosion.

The gradual change from shale to limestone observed at the top of the Devonian Percha shale indicates an uninterrupted period of deposition between Devonian and Carboniferous time and a decided clearing of the seas. The faunal changes are likewise noteworthy. The muddy waters in which the upper part of the Percha shale was laid down seemed especially adapted to Devonian forms, but when the waters became clearer they no longer afforded a suitable habitat for the Devonian fauna, which therefore disappeared and was succeeded by Carboniferous forms. No stratigraphic break has been detected between the Mississippian and Pennsylvanian beds, though differences in the fossils of these series suggest such a break.

[9] Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Bisbee folio (No. 112), p. 12, 1904.

[10] Lindgren, Waldemar, U. S. Geol. Survey Prof. Paper 43, p. 59, 1905.

MESOZOIC AND CENOZOIC ERAS.

After the quiet of the Paleozoic seas came the gradual emergence of a Mesozoic continent. No evidence is at hand to prove that the uplift was accompanied by notable structural disturbance. No certain pre-Cretaceous faults are recognized, nor has any folding been observed that might not be assigned to later periods. It must be inferred, therefore, that although the emergence was widespread, it took place in this area without other deformation than gentle warping and tilting. That the tilting may have been appreciable is shown by certain relations between the basal Cretaceous beds and the underlying Paleozoic rock. For example, the Beartooth quartzite shows a remarkably clean-cut flat surface at its base, especially on the summit of the Little Burro Mountains, suggesting a decided leveling of the underlying floor. Now, as the basal Cretaceous beds were deposited on Pennsylvanian, Mississippian, Devonian, Silurian, and pre-Cambrian rocks, it may be inferred that these old rock beds were tilted during their uplift and their edges eroded nearly to base-level.

The absence of Triassic or Jurassic strata beneath the Cretaceous sediments points either to the existence of a continent during Triassic and Jurassic time or to an even longer period of denudation than has just been inferred.

The accumulation of Cretaceous sandstone, shale, and calcareous shale to a thickness of probably several thousand feet followed the subsidence of this eroded land surface. The quiet sedimentation, however, may have been interrupted by subaqueous outbursts of andesitic and allied volcanic material. The breccias of the andesite-diorite complex have here and there the appearance of sills, being both underlain and overlain by shale; but as the pyroclastic nature of the breccia precludes an intrusive origin, it is suggested that near the end of Cretaceous sedimentation, or after it had ceased, volcanoes added their quota of material to the marine Cretaceous accumulations. The apparent sill-like relation observed may, however, be due to faulting.

There is abundant evidence of intense igneous activity from this time on. Thousands of dikes cut both the Cretaceous shale and the breccias, indicating that the outbursts which furnished the pyroclastic accumulations were followed by continued long-extended fracturing of the strata and concomitant filling of the fissures with igneous material. The great preponderance of this complex in the Cretaceous rocks suggests that a center of volcanic activity existed somewhere near or north of Pinos Altos, though there may have been subsidiary centers near the Little Burro Mountains.

The next period was notably different from the long period of sedimentation above described. No evidence that the land was ever again beneath the sea has been found, but there is conclusive evidence that no less than five stages of intrusion succeeded the one already described and that they were associated with notable structural dislocations.

The product of the first of these intrusions was rock of the quartz diorite porphyry type, which is well developed around Fort Bayard and extends southward and eastward from that point. This intrusive takes the form of a sheet at some places—for example, at Fort Bayard, where it lies above the Cretaceous sediments and dips westward with them. Farther west it dips beneath the Colorado shale. Moreover, it follows regularly the nose of the domelike uplift of which Copper Flat is the center. It is rather hazardous to correlate intrusive masses by lithologic features alone, but it is believed that the intrusives west of the Kneeling Nun, at Hermosa Peak, and near Lone Mountain are of the same date as the laccolith just described.

Next in order of intrusion are such masses as the granodiorite between Hanover and Fierro, the masses at Copper Flat, Santa Rita, Pinos Altos, Gomez Peak, and Silver City, and the quartz monzonite mass of the Big Burro Mountains. That the mass between Fierro and Hanover and the mass at Santa Rita are later than the Fort Bayard intrusive mass is suggested by the presence in the Fort Bayard laccolith of dikes very similar in composition and general aspect to the Fierro mass. The intrusion of these later crystalline porphyries is of structural importance in that their entrance through the overlying rocks domes up the otherwise undisturbed beds. The masses at Copper Flat, Hanover, and Gomez Peak, for example, clearly illustrate such action. When these bodies of igneous rock, whose great surface exposure probably only indicates a still greater subsurface extent, had cooled, there ensued a period of active erosion, which is clearly indicated by the fact that such masses as the granodiorite of Pinos Altos, which must have cooled under considerable cover, probably 1,000 feet or more, were exposed at the surface before the outpouring of the broad floods of lava that overlap them on the north. At Pinos Altos, for example, the granodiorite passes beneath the lava cover, and the surface outcrop at the veins which cut the granodiorite is abruptly terminated by the overlying glassy rhyolite.

Little imagination is required to picture the conditions that must have existed at the beginning of this epoch of volcanic activity, which closed the Cretaceous period. There is evidence that violent explosions preceded the welling out of the vast floods of lava and that torrential rains distributed the material of the breccias and tuffs over the uneven surface of the land. Here and there lakes were formed, into which fell the dust and the coarser ejectamenta from the active volcanic vents. Such coarse and fine accumulations are well exhibited in the region north of Lookout Peak, and the finer sediments and gravels at the base of the lava series may be seen at many places, notably east of Lone Mountain and north of it along the scarp that forms the edge of the lava floods in that region.

Then followed, in Tertiary time, the eruption of great sheets of rhyolite or latitic lava, covering hills and valleys alike and obliterating the older landscape, which the earlier explosive accumulations had modified.

After these outbursts of rhyolite-latite, which in places aggregated 800 feet in thickness, there were floods of andesitic or basaltic lava, which in time were followed by more siliceous lavas. Indeed, an alternation of the two kinds is a marked feature of these accumulations. Between the outbursts of lava there accumulated local deposits of fine sand and tuff, the detritus washed from the more elevated portion of the deposits to the basin-like areas which must have been formed in such a chaos of molten flowing material. These sediments attain considerable thickness in places but are generally thin at the edges and disappear, permitting the overlapping of successive lava floods. Such thinning out of interbedded clastic material is well shown in the range east of Lone Mountain and in the area farther north, adjacent to Black Peak.

As if in adjustment of the enormous disturbance of equilibrium that must have been caused by the flooding of this broad territory with lava and of the shifting of so large a mass of material from beneath the surface at one locality to the surface of the crust at another locality, faulting was renewed and has continued, probably with interruptions, up to the present time. This faulting was attended by the intrusion of many stocklike masses of latitic material that cut through all the underlying strata alike from the pre-Cambrian complex to the latest lavas. During this stage of faulting the present higher parts of the Silver City Range and Lone Mountain were probably outlined, and Bear Mountain was formed by the intrusion of the stocklike mass that constitutes its core. Then, too, the Little Burro Mountains assumed or began to assume their monoclinal attitude, and the region around Santa Rita was broken by faults. At this period also the lavas farther north were sliced into numerous narrow curving fault blocks, and the region north of Stewart Peak was faulted and intruded.

The remaining changes that have affected the area are due principally to erosion and concomitant deposition and to sporadic outbursts of basaltic lavas. Widespread deposits of Pleistocene gravel accumulated in the already maturely dissected valleys, and on this gravel thin basaltic lava flows were spread, to be later covered by still more gravel.

GEOLOGY OF THE TYRONE DISTRICT.

ROCKS.

All the hard rocks exposed in the Tyrone district are igneous intrusives. Semiconsolidated gravels cover several square miles, but drilling through these superficial deposits has revealed no ancient sedimentary terranes.

The igneous types recognized in mapping are granite, quartz monzonite and quartz monzonite porphyry, quartz latite porphyry, aplitic dikes, and rhyolite dikes. The distribution, petrography, and structural interrelations of these types will be described in turn, after which the structure, metamorphism, and physiography of the region will be discussed.

GRANITE.

Distribution.—Granite occurs in the southeast corner of the district over an area of about 5 square miles; in the southwest corner, forming the higher portion of the Big Burro Mountains; and along the northern border, in a strip about $1\frac{1}{4}$ miles wide. It also forms a number of isolated masses near the center of the area and near the eastern gravel contact in secs. 26 and 27, T. 19 S., R. 15 W., where it is surrounded by quartz monzonite porphyry.

Petrography.—The granite of the Tyrone district is not a single homogeneous mass but includes a number of varieties exhibiting differences in texture and slight differences in mineralogy.

For the most part the granites are medium to coarse grained holocrystalline rocks ranging in color through gray and pink. They are composed dominantly of quartz and orthoclase feldspar, with some oligoclase feldspar. Biotite mica, though not generally a conspicuous mineral, is present in many places. The common accessory minerals, iron oxide, apatite, and zircon, may be noted.

A coarse-grained variety near Sugarloaf Mountain is gray and contains prominent pink feldspars. Abundant biotite is plainly visible.

The Big Burro Mountains are composed of a medium-grained gray granite consisting of orthoclase, quartz, and a little oligoclase, with biotite. A semblance of porphyritic structure is caused by scattered orthoclase feldspars larger than the average crystals of the rock.

In Deadman Gulch below the road crossing, west of Leopold, there are a number of varieties of medium to coarse grained granite, among them one containing prominent pink orthoclase feldspars set in a matrix of gray feldspar and quartz. The scarcity of ferromagnesian minerals is striking.

In the southeast corner of the district there are wide areas underlain by pink medium-grained granite that is generally lacking in ferromagnesian minerals, but this lack is due partly to alteration.

As a whole the granites are characterized more by their variation from place to place than by uniformity of appearance. Undoubtedly a number of distinct invasions have taken place in pre-Cambrian time. No attempt was made to unravel the complexities of these intrusions.

QUARTZ MONZONITE AND QUARTZ MONZONITE PORPHYRY.

PRINCIPAL MASS.

Quartz monzonite and quartz monzonite porphyry form the largest single rock unit of the Tyrone district. This unit is a roughly circular intrusive stock cutting pre-Cambrian granite. A small portion of its contact lies beyond the area shown on the map. Quartz monzonite porphyry also occurs in dikes, many of which are too small to be mapped.

Distribution.—The main mass occupies a central position in the area, where it covers about 15 square miles, or about half the total area. Its contacts with the invaded pre-Cambrian granite are for the most part easy to locate and follow. There are places, however, where the distinction between the two rocks is not so plain. Several conditions account for this obscurity. First, within the pre-Cambrian granite complex are rocks of granitic types that closely resemble the quartz monzonite, particularly where the two rocks are weathered and have undergone partial disintegration. At such places, though the contact may not be precisely located, by studying the contact region it can be shown that unmistakable granite is close at hand, because the granitic terranes as a whole are not homogeneous, whereas quartz monzonite and its porphyritic phases on the whole are homogeneous to a high degree This is a good criterion on which to distinguish the two groups in the field.

Another source of difficulty is occasioned by the presence of small outliers of pre-Cambrian granite within the main monzonite mass—small slivers and blocks broken off at the contacts. This feature, however, is a minor one in the Tyrone district.

A third difficulty arises in the fact that irregular aplitic dikes are present in some places both in the granite and in the quartz monzonite porphyry, and where this condition exists along a contact precise boundaries are not readily established.

The main north contact runs eastward from the western border of the district to a point about a mile south of Tyrone. This contact, from the western edge of the district to St. Louis Canyon, passes along the southern slope of a number of hills—that is, the porphyry is eroded to a lower level than the invaded granite. From St. Louis Canyon eastward, however, there is no such difference in degree of erosion. In this area both rocks are silicified and mineralized. These features will be discussed under the heading "Physiography" (pp. 19–22).

The contact passes beyond the area mapped on the western border and enters it again to skirt the base of the Big Burro Mountains. It also passes from and reenters the area on the southern border. The boundary on the east side of the Big Burro Mountains is in places buried beneath granitic débris, swept over the contact.

It is possible that inclusions of granite smaller than those mapped may be present and have been overlooked, as the rock in much of this territory is highly metamorphosed. The occurrence of such blocks is, however, of no economic importance, as will be shown below.

Petrography.—The main mass of quartz monzonite porphyry contains a number of textural varieties. These are (1) rocks of granular texture and properly not porphyries, (2) porphyries characterized by large orthoclase phenocrysts (as much as 3 inches in length) and prominent quartz phenocrysts, in many places doubly terminated by pyramid faces; and (3) porphyries in which the orthoclase phenocrysts are intermediate in size or are no larger than the other feldspar phenocrysts of the rock.

Field studies indicate that the change from type 2 to type 3 takes place on the north rather abruptly along a roughly east-west line (see Pl. II, in pocket), but that on the south the two types are transitional into each other. Along the northern line no intrusive contact was seen, and it is concluded that the change is due to physical and chemical factors governing crystallization.

The granular type of quartz monzonite is a medium-grained rock of gray color containing abundant biotite. It is composed predominantly of oligoclase feldspar and quartz, with a minor amount of orthoclase feldspar. In places it contains considerable light-green hornblende. Titanite, apatite, and iron oxide may be present. The rock might equally well or perhaps better be named a granodiorite.

The porphyritic type, characterized by large orthoclase feldspars, resembles the granular types in that it contains abundant biotite and though of porphyritic texture has nevertheless, where medium to coarse grained, a somewhat granular appearance. It differs in carrying conspicuous large phenocrysts of pink feldspar and abundant smaller phenocrysts of quartz, and many of the latter are crystallized as double pyramids joined by short prism faces. The spacing of the feldspar phenocrysts and the abundance of the quartz phenocrysts vary considerably from place to place—they may be separated by only a few inches, or there may be several feet between individual phenocrysts, and locally they are entirely absent. The phenocrysts vary in size also and in places are hardly more prominent than the other minerals of the rock.

The phenocrysts may be either oligoclase feldspar, quartz, or biotite, set in a granular groundmass of varying degrees of fineness, consisting of quartz or orthoclase. Many of the quartz phenocrysts show resorption phenomena.

DIKES AND SMALL MASSES OF QUARTZ MONZONITE PORPHYRY.

Dikes and small masses of quartz monzonite porphyry occur both as offshoots from the main mass and as later dikes cutting through the main mass.

Several of these later dikes have been mapped. Two near the northern border of the district have been traced for more than 3 miles. For a considerable distance they are approximately parallel, but they diverge noticeably at their east ends and are not everywhere continuous at the surface. The southern dike at its east end is very thin and can not be located with certainty, but float and small outcrops indicate its presence.

Dikes of similar character are found to the south, in secs. 26 and 27, and similar rock, intensely altered, occurs in secs. 10 and 15. These dikes are characterized by abundant large idiomorphic phenocrysts of feldspar and quartz. Many of the quartz crystals retain their crystal faces, and in places as many as six intergrown so as to constitute a single quartz phenocryst were noted. The number and size of these prominent minerals vary from place to place. Biotite is present, though not conspicuous.

The main body of the rock consists of smaller phenocrysts of oligoclase in a very fine grained groundmass of quartz and orthoclase. There are many quartz phenocrysts within these rocks, besides those displaying well-developed crystal faces, which show marked absorption phenomena. Their surfaces are corroded and rounded and in places deeply embayed, and reaction rims of the quartz and feldspar of the groundmass surround them. It is possible that some of the corrosion took place during the injection of the dikes. On examination with the microscope it becomes evident that much sericite has formed, both as disseminated flakes in the feldspar and completely replacing the biotite.

A small mass of porphyry cutting the granite in sec. 35 is different from the common porphyry of the district. It is finer grained, and fresh specimens have a brownish color. Small biotite and feldspar phenocrysts may be made out with the naked eye, set in a sugar-grained groundmass somewhat resembling a fine-grained sandstone. The microscope shows phenocrysts of oligoclase and biotite with some light-green hornblende, in a fine-grained groundmass of quartz, oligoclase (in rods), and some orthoclase. The rock is without question closely related in chemical composition and probably in date of intrusion to the main mass of porphyry.

APLITIC DIKES.

Some of the aplitic dikes are allied with the pre-Cambrian granites, and others with the quartz monzonite porphyries. Such rocks are characteristically developed with acidic intrusives and represent the more siliceous portions and latest injection of the magma. Within the pre-Cambrian granites notably, and in the quartz monzonite porphyry to a lesser degree, they are associated with pegmatitic facies of the main masses.

These dikes have nowhere been mapped on the surface and are considered simply as an abnormal development of the main masses.

The aplitic dikes and masses are characteristically irregular in form and both on the surface and in the mines have very irregular boundaries. Along the main contact between Leopold and the gravel sheet these dikes and masses occur and in places made it difficult, especially where surface débris is plentiful, to locate the porphyry contact. North of the main contact, too, in this general area, the granite is broken by narrow dikes and masses of this rock, a confusing condition in an area where the rocks are so intensely metamorphosed. It was not practicable to map them.

The aplites are fine-grained rocks of pinkish-white color, composed of orthoclase and quartz in about equal amounts, with a little biotite and in places evenly dispersed iron oxide. Locally the quartz and orthoclase assume a rude micrographic texture. Very small phenocrysts of quartz appear here and there.

RHYOLITE DIKES.

Rhyolite dikes are not abundant within this area. A few, the more prominent, have been traced and mapped in the northwest corner of the area, and one is shown in sec. 35. These dikes are very numerous to the south, beyond the confines of the area under consideration.

The rhyolites are fine-grained white rocks of somewhat porphyritic character. Under a hand lens small phenocrysts of orthoclase and quartz and small biotite crystals are plainly visible, set in an aphanitic groundmass, which proves on examination with a microscope to consist of orthoclase and quartz, at least locally showing micrographic intergrowth.

These rocks are of later age than other intrusives of the district, but it is not possible to assign to them a precise date of intrusion, as it is known that several periods of volcanic activity occurred in post-Cretaceous time.

QUARTZ LATITE PORPHYRY.

Quartz latite porphyry occupies a small area in the extreme northeast corner of the district. It is part of a larger area of such rock that forms the south end of the Little Burro Mountains.

The metamorphism, however, is here so thorough that it is not possible to affirm positively whether the rock is of the same age or younger than the quartz monzonite porphyry at Tyrone. The latter conclusion seems the more probable; and the rock is therefore correlated with the later Tertiary intrusions of other parts of the Silver City area.

SEMICONSOLIDATED GRAVEL AND SAND.

The Tyrone district borders a region made up of large areas of semiconsolidated sand and gravel. Portions of these deposits occur within the district, principally in the northeastern part and along the northern border.

Character.—The material of these deposits is derived from the neighboring mountains and consists of fragments of lava or of pre-Cambrian igneous rocks or younger sediments, its character depending upon the kind of rock that is exposed in the adjacent uplands. The fragments range in size from fine dust to blocks several feet in diameter. In some places large boulders form a part of the deposits. Most of the fragments are subangular, as would be expected in view of the proximity of their source and the mechanical nature of the rock disintegration by which erosion was aided in Pleistocene time, as it is at present.

Calcite, silica, and iron oxide, alone or combined in differing proportions, are the cementing materials which in places bind together the otherwise loosely collected fragments and make of them a resistant conglomerate.

Relation to underlying surface.—The contact of the gravel about the Big Burro Mountains is apparently a normal depositional contact. That the gravel formerly covered parts of the foothill region which are now bare and that it has been carried outward to its present position during a period of recent dissection seem certain. How much of the Big Burro Mountains was covered is indeterminable, but a well-defined rock bench that occupies at least much of the north and east sides of these mountains is plainly visible from any high point on the Little Burro Mountains. Probably gravel once covered this bench, but presumably the main mountain core was never covered and in fact was the source during Pleistocene time of much of the gravel that now surrounds the mountains.

In the Little Burro Mountains the conditions are somewhat different. The gravel contact along their east side is normal and follows the crest of the eastern ridge of the mountains, but for much of its length the contact on the west side is along a fault and lies at the base of a more or less precipitous mountain scarp.

Age and correlation.—Gilbert [11] in 1873, while studying the region drained by the upper Gila and its tributaries, gave the name Gila conglomerate to certain valley deposits which he described as follows:

The boulders of the conglomerate are of local origin, and their derivation from particular mountain flanks is often indicated by the slopes of the beds. Its cement is calcareous. Interbedded with it are layers of slightly coherent sand and of trass and sheets of basalt, the latter, in some cliffs, predominating over the conglomerate. One thousand feet of the beds are frequently exposed, and the maximum exposure on the Prieto is probably 1,500 feet. They have been seen at so many points, by Mr. Howell and myself, that their distribution can be given in general terms. Beginning at the mouth of the Bonito, below which point their distinctive characters are lost, they follow the Gila for more than 100 miles toward its source, being last seen a little above the mouth of the Gilita. On the San Francisco they extend 80 miles, on the Prieto 10, and on the Bonito 15. Where the Gila intersects the troughs of the Basin Range system, as it does north of Ralston, the conglomerate is continuous with the gravels which occupy the troughs and floor the desert plains. Below the Bonito it merges insensibly with the detritus of Pueblo Viejo Desert. It is, indeed, one of the "Quaternary gravels" of the desert interior and is distinguished from its family only by the fact that the watercourses which cross it are sinking themselves into it and destroying it, instead of adding to its depth.

The Pleistocene deposits in the Silver City quadrangle correspond to the Gila conglomerate in all important features. Gilbert, followed by Ransome, assigned an early Quaternary age to the Gila conglomerate. Fossil bones are reported from the gravels south of Santa Rita, but none were seen by the writer. There is no reason, therefore, to assign to the beds an age other than that already suggested.

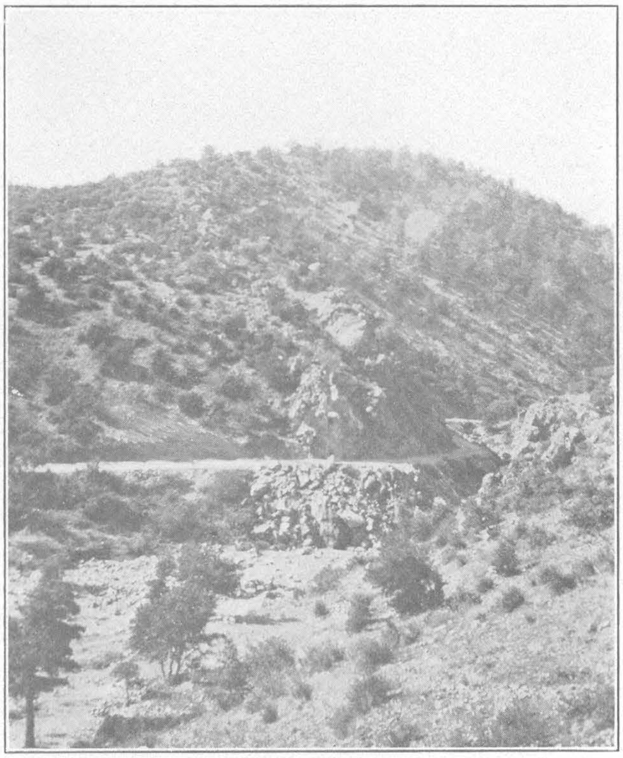
STRUCTURE.

As all the rocks of the Tyrone district, except the gravels, are massive intrusives, their structural relations have to do wholly with intrusion, faulting, and fracturing. Folding plays no evident part in their interrelations.

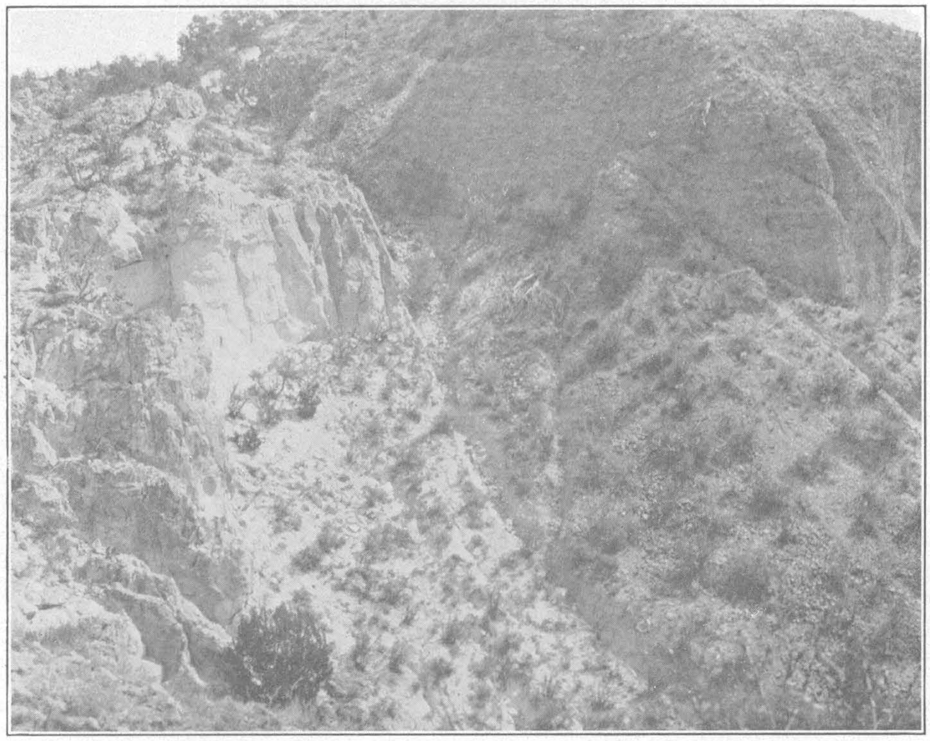
INTRUSION.

The main stock of quartz monzonite porphyry intrudes a granite complex and is subcircular in its outcrop. There is some evidence that on its northern border it dips to the south. At other places no clue has been gathered as to the attitude of its walls—whether converging or diverging downward. Offshooting dikes from the main mass indicate that fracturing of the invaded rock played a part in permitting the entrance of the magma. Whether or not stoping of the wall rock has taken place on a large scale is undetermined. On the southern contact in secs. 3 and 34 a

[11] Gilbert, G. K., U. S. Geog. and Geol. Surveys W. 100th Mer. Rept., vol. 3 p. 540, 1875.



A. FAULT CONTACT BETWEEN GRANITE AND GRAVEL IN ST. LOUIS CANYON.



B. QUATERNARY GRAVEL FAULTED AGAINST RHYOLITE ALONG THE EAST SIDE OF MANGAS VALLEY.

long tongue of porphyry projects at a low angle, nearly parallel with the contact, into the granite, nearly isolating a slice of that rock. Should such a block of granite have been entirely severed from its parent mass, it might possibly have sunk into the magma. The detached island-like masses of granite in secs. 22, 27, and 26 may represent remnants of a roof, in place, or may connect downward with the main granite mass. The writer found no certain evidence on which to base an opinion regarding these points.

A number of dikes cut the granite and the quartz monzonite porphyry. Structurally they suggest that the region was still under the influence of tensional stresses after the larger intrusions had solidified. This suggestion is accordant with the evidence afforded by the faulting and fracturing.

FAULTING.

REGIONAL FAULTING.

Faulting has played a very important part in the dynamic history of the region about Tyrone. Reference to figure 4 (p. 6) will show that there are two principal fault systems, one having a northwest to west-northwest trend, the other a northeast trend. The close spacing of the northeast breaks indicates the completeness with which the ground was fractured, and when it is borne in mind that there are many fractures not shown a fair impression is gained of the thoroughness of the process of dislocation. These two dominant fault systems are, it is believed, connected in origin with movements of folding. The evidence supporting this belief has been given in the Silver City folio, on the maps of which the relation of faults to folds is made clear. It is reasonable to suppose that a broad syncline whose axis passes northwestward between Silver City and Santa Rita is but one of several similar broad folds. (See fig. 4.) So conceived the region about Tyrone would fall somewhere on the eastern limb of a broad anticline, upon the details of which, for lack of data, it is futile to speculate.

It is believed that the formation of such a system of folds accompanied widespread uplift and intrusion and that gravitative adjustment, accompanying or succeeding such distentional movements, accounts for the faulting that ensued. That the movement of uplift was such as would produce distention is suggested both by the normal character of the faults and by the vast amount of igneous material that has entered the rocks, particularly during Cretaceous time. There are wide areas filled with narrow dikes. Only the distention of the crust could have made possible this great influx of magma; and it is not surprising that such a process should result in the instability of individual blocks. Both during and after such an uplift faulting would take place on a great scale. The cause of such widespread uplift may well be connected with igneous injection even if not controlled by it. The primary cause must be sought in the realm of the theory of earth physics. It is a fact that in the Silver City region igneous invasion accompanied uplift, and beyond this important fact it is here not necessary to go.

FAULTING IN THE TYRONE DISTRICT.

Of the larger northwestward-trending breaks one that forms the western scarp of the Little Burro Mountains crosses the Tyrone district. This fault tilts the pre-Cambrian rocks of the Little Burro Mountains and the overlying Cretaceous sediments toward the east, and it may be presumed that the rocks west of the fault, which are relatively downthrown, are also tilted eastward. There are certain facts which support this presumption. Two of the faults of the northeast system (see fig. 4) if continuous southwestward across the Mangas Valley must enter the Tyrone district a short distance west of Tyrone. There is field evidence to support the view that they are thus continuous. The contact between gravel and pre-Cambrian granite from St. Louis Canyon northward for half a mile is a fault contact. Both at the road crossing where the relation is evident (see Pl. III, *A*) and in a tunnel driven through the contact at the old turquoise workings north of the road the fault may be seen. At the turquoise workings the vertical plane between gravel and bedrock is particularly well displayed. Drill records obtained farther north along the trend of the fault support the same view. The downthrown side of the fault is on the south, as it is at both of the faults across the Mangas Valley.

It is difficult to trace this fault farther southwestward, for the rocks supposedly cut by it are all igneous, and there is little or nothing whereby to distinguish a fault from ordinary fracturing, much less to determine the direction or extent of movement. Nevertheless, there are certain features connected with the fracturing and metamorphism along this zone that support the idea that the effect of the fault persists for at least 2 miles farther to the southwest. These features consist, first, in a strong vein filled with fluorite a short distance north of shaft No. 2, showing brecciated material and slickensided walls; second, in an unusually abrupt boundary between rock which is thoroughly metamorphosed and fractured and rock in which there is decidedly less metamorphism; and third, in a line of benches flanking the northeastward-trending ridge in the southeast corner of sec. 21. These flanking benches may be clearly seen from any elevated point on the west side of Deadman Gulch opposite Copper Mountain. From an altitude of 6,300 feet on the east side of the creek the even tops of the ridges, transected by westward-flowing streams, become at once visible.

The topographic relations in this vicinity suggest a fault with the downthrow on the north, whereas the fault of which it has been presumed this is a continuation has its downthrow on the south. One of two explanations may be offered for this apparent anomaly. Either there has been rotation on the fault plane, about an axis located somewhere between the two points under consideration, so that at opposite ends of the block the fault is opposite in throw, or the present westward-facing scarp is due to superior hardness of the rocks on the south side of the fault (by reason of metamorphism), erosion thus being able to bring the north side to a lower elevation.

Whatever conclusion may be reached regarding this point, the physiographic evidence bearing on which is set forth at another place, it seems highly probable that this line represents the extension of the fault. Further support to this belief is afforded by the fact that to the southwest, in direct line with this supposed fault, there are a number of alined topographic saddles in which prospect holes show well-developed fault gouges. On the map, therefore, this fault is indicated by a dashed line passing through these saddles.

Other evidence of faulting within the district consists in brecciated veins within the mines and at the surface. A number of these veins are described in the section on the ore bodies.

As no evidence of overthrusting has been found in this region, all the breaks mentioned above are considered normal faults.

AGE OF FAULTING.

Movement along fault planes in this region has persisted down to a late date, as is proved by the intricate fault system cutting the lava ranges in the northern part of the Silver City quadrangle and in the Little Burro Mountains and by the fault planes along which Pleistocene gravel abuts against older formations.

To establish the precise date at which faulting began is more difficult. Beginning during Cretaceous time, it was probably connected with the folding that has affected the Cretaceous rocks and quite probably was brought about by igneous invasion.

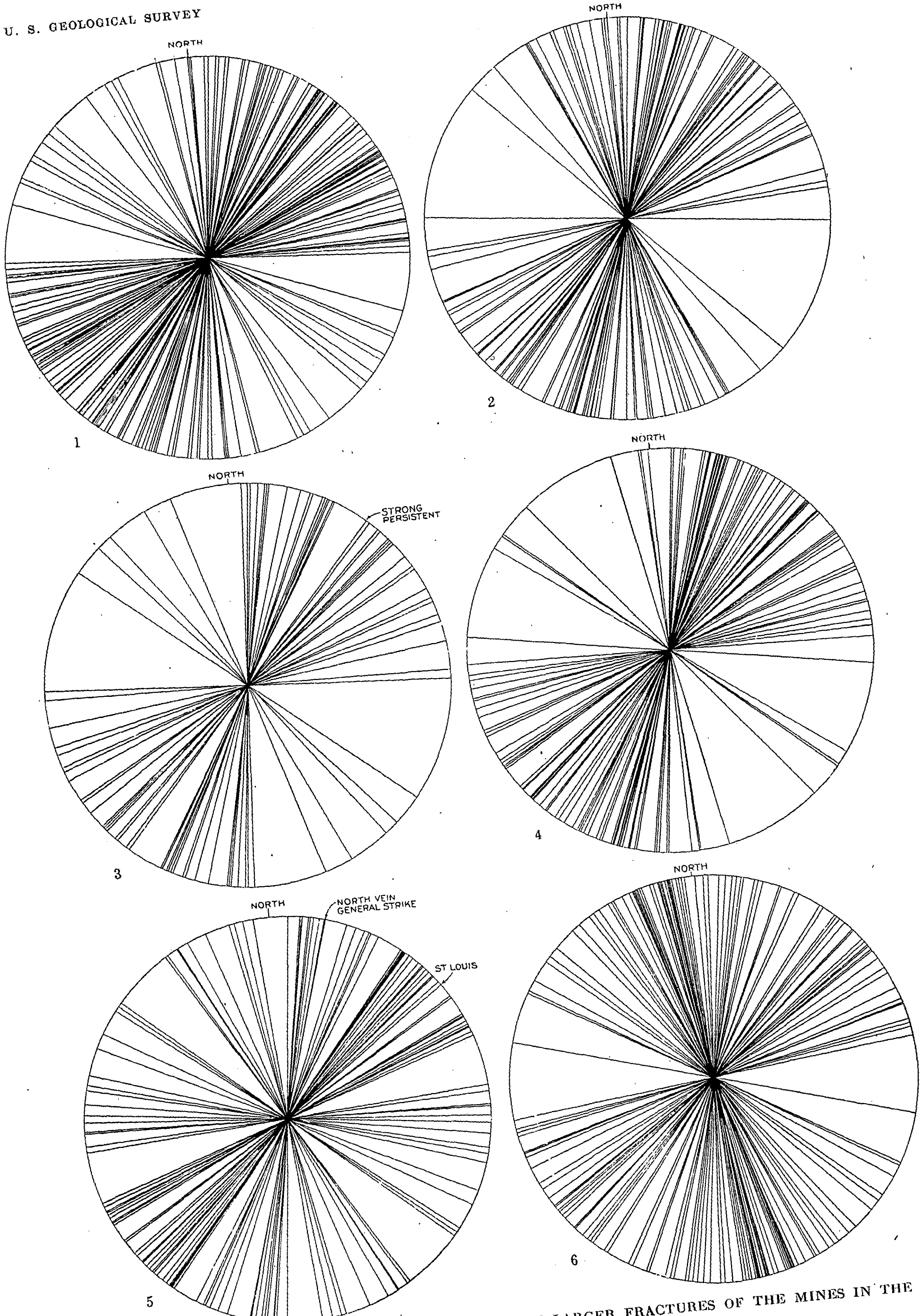
The strongest argument supporting the belief that the faulting began at an early date lies in the fact that the intense mineralization and alteration of the quartz monzonite porphyries is dependent upon intricate fracture systems connected with the faulting; and the mineralization surely took place soon after intrusion and probably during the cooling of the deeper portions of the magma. For this reason it becomes logical to assume the sequence of intrusion, folding, faulting (with fracturing), and mineralization in the Cretaceous history of the region.

FRACTURING.

DISTRIBUTION.

Fracturing of the rocks in the Tyrone district has been carried to great lengths. Associated with this fracturing has been intense metamorphism. The following statements concerning the distribution of fracturing therefore apply equally well to the distribution of metamorphism.

The principal fracture zone of the district is included within a roughly triangular area whose base may be considered the gravel and hard rock boundary between Tyrone and Oak Grove and whose apex is at a point about 2 miles southwest of Leopold. (See Pl. II, in pocket.)



DIAGRAMS ILLUSTRATING THE DIRECTION OF THE LARGER FRACTURES OF THE MINES IN THE TYRONE DISTRICT.

1, 400 level; 2, 200 level; 3, B sublevel; 4, 300 level; 5, A level; 6, Bison ore block.

The degree of fracturing throughout this area is not the same. It is more intense along the northwest side of the triangle and most intense between the towns of Leopold and Tyrone. Southeast of this zone of maximum intensity and extending nearly to the granite contact on the southeast the fracturing, though not so intense, is nevertheless very evident.

The change from very thoroughly fractured rock to rock that is much less broken is remarkably abrupt along the northwest side of this area, occurring in places within a quarter of a mile. This feature is particularly noticeable in the vicinity of Copper Mountain on Deadman Gulch and along the boundary to the southwest and northeast of that place. (See Pl. II.)

This zone is believed to mark a line of notable movement. Southwestward from Leopold, however, an appreciable diminution in the degree of fracture may be noted until at the point indicated on the map as the apex of the triangle intense fracturing is no longer present, though nowhere within the district are the rocks free from fractures.

On the southeast side of the fracture zone under discussion the change from fractured to relatively unfractured rock is more gradual and is marked by no pronounced structural feature. The curved line delineating the southern boundary of the zone in a measure expresses this condition.

The position of the major zone of fracturing is independent of rock type. Both granite and quartz monzonite porphyry have been fractured. The main contact of these rocks east of Leopold directly crosses the trend of the fracture zone.

Beyond the limits of the principal zone intense fracturing is confined to individual veins and shear zones. A shear zone extends southwestward for about a mile in secs. 10 and 15 and is coincident with the position of a small porphyry dike. The old workings of the rich turquoise deposits of the Azure Mining Co. are on this zone.

NATURE OF THE FRACTURING.

The fracturing of the rocks is directly connected with faulting. It may indeed be regarded as a distributive type of faulting, wherein the movement of relief instead of being limited to a few large breaks is taken up by a great number of minor breaks. It is believed that in the main where there existed a tendency to form large open fractures either the intrusion of a dike or the collapse of the rock closed such openings.

A striking feature of the individual fracture is its discontinuity. Extending for a few feet or for several hundred feet, it then grows weaker and dies out, its place being taken by another of similar character but having a more or less different strike, dip, and degree of prominence. The fractures are thus compound breaks, and even the strongest, those carrying evidence of considerable movement, partake of this character. Such, for example, is the North vein, the hanging wall and footwall of which for

FIGURE 5.—Diagram illustrating the nature of the systems of anastomosing fractures of which the mineralized fracture zones are made up.

several feet are essentially fracture or crushed zones. The St. Louis vein is another typical example of such fractured ground. (See mine descriptions below.)

The fracture planes are rarely plane surfaces, being characteristically uneven and warped and of irregular shape and extent. Although the direction of a particular zone of movement may be well defined, the individual fractures that together make up this zone follow this direction only approximately. Such an anastomosing system is illustrated in figure 5. This irregularity is shown vertically, as well as horizontally, on the vein and is characteristic of all the veins, from those that carry brecciated zones 8 or 10 feet in width to minute, hairlike breaks.

An analysis of the dominant trend of the fracture systems within the mines shows that these trends are not everywhere the same.

In Plate IV the azimuths of many fractures have been plotted about the center of a circle. On level A there is concentration in a N. 45°–60° E. direction, with a noticeable number trending N. 70°–80° E. and fewer N. 10°–15° E. In the northwest quadrant the directions are varied and the fractures are present in only minor amount.

On the tunnel level (not shown in Pl. IV) there is heavy concentration along lines N. 70° E. and N. 80°–85° E., with some concentration in a N. 10° W. direction, also N. 70° W.—in fact, the fractures trend in all quarters of the circle.

In the Bison ore block there is marked concentration in the northwest quadrant, particularly N. 5°–10° W. and N. 15° W. There is, however, an even distribution throughout from N. 60° W. to N. 80° E.

On the 200-foot level fractures are well disposed through the northeast quadrant but are concentrated around N. 20° E.

On the 300-foot level there is heavy concentration near N. 20° E. and N. 10° E., with some concentration at N. 60° E. Fractures are well distributed throughout the northeast quadrant, in fact, but are generally lacking in the northwest quadrant.

On the 400-foot level there is heavy concentration between N. 40° and 45° E. and between N. 60° and 65° E., with generally dispersed fracturing throughout the northeast quadrant. Scattering fractures are found in the northwest quadrant, and there is some concentration north and south.

On sublevel B there are concentrations at N. 4°–12° E., N. 25°–31° E., and N. 40°–50° E., with other fractures scattered in the northeast quadrant and also in the northwest quadrant.

By far the greater number of these fractures dip to the east, generally at rather high angles, though there are many exceptions to this generalization, both as to direction and angle of dip.

BRECCIA.

At two places within the Tyrone district there are brecciated zones of rather unusual character, in that the broken block of ground was not apparently dependent upon a simple fracture or set of fractures. One breccia occurs within the Burro Mountain Copper Co.'s mines and is known as the Breccia ore body; the other is on the summit of a small hill in the northeastern part of sec. 26.

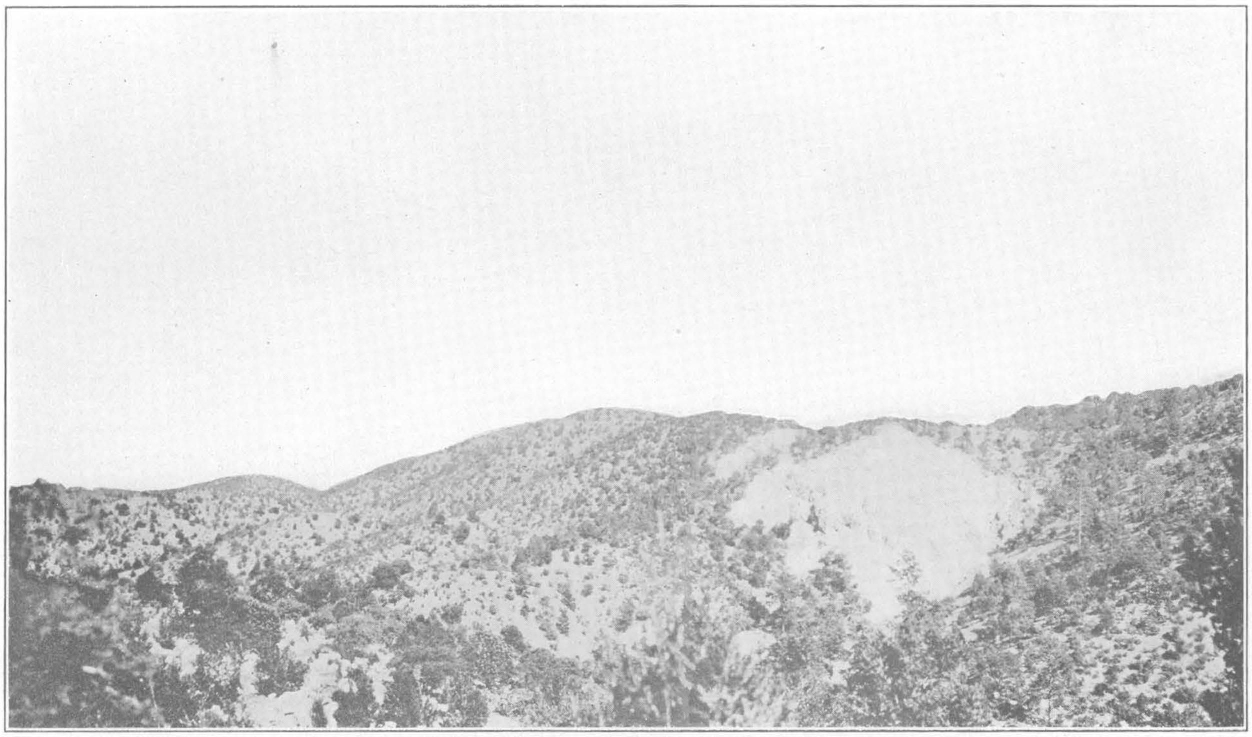
The irregular and ill-defined outline of the Breccia ore body is roughly indicated on the plans and cross sections. (See fig. 23, p. 44.) It is not the same on the various levels. On the 300 and 400 foot levels its dimensions (narrow and long) suggest association with ordinary fractures. How deep this breccia descends is not known to the writer. The mines were not unwatered below the 400-foot level at the time his investigation was being carried on.

The breccia is composed in large part of angular fragments of granite, and the matrix is generally of the same material, only more finely crushed. In places intrusive aplite dikes form a large portion of the breccia. As the pre-Cambrian granite is composed of granite of various types, it is not surprising that the breccia presents an appearance of great heterogeneity. In places crushed aplite makes up most of the breccia, and, as shown on the maps, porphyry intrusives partly border the breccia, particularly on sublevel B. The fragments vary in size, and the largest are several feet in diameter. Later fractures cut the breccia and pass from fragment to matrix.

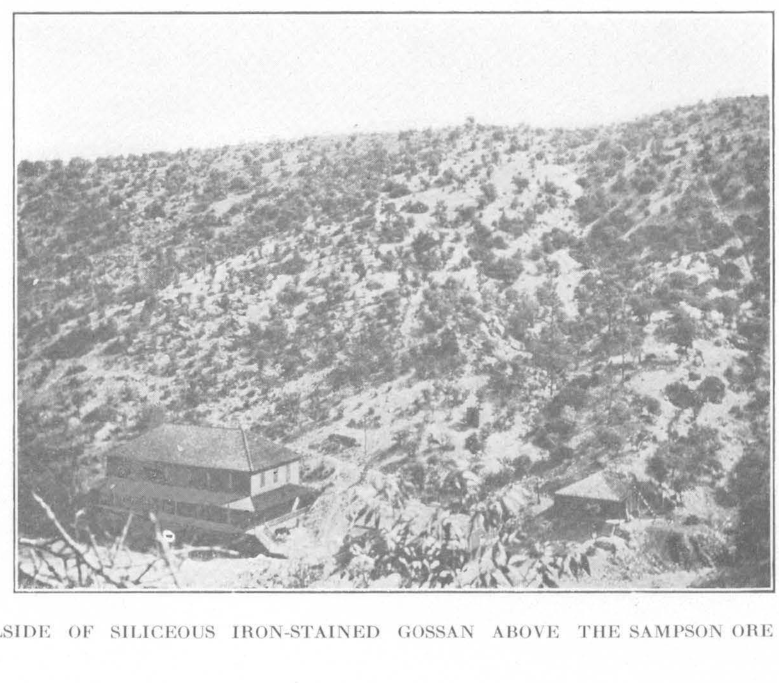
It is not easy to determine positively the nature of the movement that caused this breccia. Certain of its features, however, suggest a reasonable explanation. First, the breccia is in the main composed of angular fragments of material not noticeably different from the matrix in which they are set. Some of the fragments are rounded. Second, the breccia is associated with intrusions of fine-grained porphyry—in fact, the fine-grained porphyry is in places brecciated. Third, the breccia has been fractured by movements since its formation. Fourth, there are no strong breaks parallel to the breccia which would make of it a fault breccia associated with a particular vein or set of veins.

The dynamic history of the region suggests only two processes which might have played a part in the formation of the breccia—faulting and intrusion. It is reasonable to suppose that both processes acted somewhat as follows:

The pre-Cambrian granite was subjected to tensional stresses accompanied or soon followed by both fracturing and intrusion. Rugged gaps were torn in such rocks as granite, and magma flowed in to fill these gaps. Movement did not cease then, however, but followed repeatedly, and the newly intrusive rocks were likewise torn apart. Some of this movement of distention (the result of uplift) was compensated by the formation of normal faults. In other places the magma filled the gaps formed by the movement. In yet other places,



A. COPPER MOUNTAIN, LOOKING NORTHEAST.



B. HILLSIDE OF SILICEOUS IRON-STAINED GOSSAN ABOVE THE SAMPSON ORE BODY.

of which the breccia block is considered one, the net result of the application of forces and the possibilities of relief was the collapse of extensive blocks of ground. Such a conception is reasonable when it is borne in mind that a wide area was being literally torn apart. If by circumstance a detached block of ground was not supported by the immediate introduction of magma, or by movement along appropriate shearing planes, further pressure might well accomplish its complete demolition, as in the case of the Breccia ore body. That such a place might be the site of subsequent movement is also reasonable, for such is the history of all fault movements in this and other districts. The actual entrance of the magma may have taken part in the brecciation by tearing blocks of rock asunder, for brecciation along dikes is not an unusual feature in the district.

The brecciation may be considered, then, a phenomenon directly connected with the violent dislocation that attended the distention of the country rock and its invasion by magma.

METAMORPHISM.

DISTRIBUTION AND GENERAL RELATIONS.

The rocks throughout the several fractured terranes described above have to varying degrees lost their normal igneous characteristics. Their original constituents—the feldspars, the quartz, and the ferromagnesian minerals (biotite and hornblende)—have been partly or wholly replaced by sericite, quartz, and pyrite, with lesser amounts of chlorite, biotite, and chalcopyrite; and superimposed upon this primary alteration have been changes caused by the downward circulation of oxidizing surface waters, wherein valuable concentrations of copper minerals have been brought about.

In consequence outcrops within the more intensely fractured areas are iron stained and siliceous and of various hues of yellow, brown, and red, and in places the courses of strong veins are marked by a typical "iron hat." (See Pl. V, *B*.)

The fracturing was the necessary forerunner of this alteration or metamorphism, for the rocks that are not fractured show no appreciable alteration, and the intensity of alteration is a direct function of the intensity of fracturing. This generalization applies equally well beyond the principal zone of alteration—for example, along individual shear zones. In this district the two conditions are interdependent; a zone of notable fracture is generally a zone of alteration. This view is supported by the fact that the degree of alteration is practically independent of the rock type affected. Granite, granodiorite porphyry, and allied dikes are altered to degrees depending not on their chemical constitution but on their degree of fracture. Thus, for example, the principal zone of alteration crosses the main contact between pre-Cambrian granite and granodiorite porphyry; and the rocks across the Mangas Valley, beyond the prominent northwest-southeast fault, though probably of later age than the porphyry west of Tyrone, show in part intense alteration—an alteration connected with a fracture system which, it seems to the writer, is independent of the main fracture zone of the district.

NATURE OF THE METAMORPHISM.

The metamorphism of the rocks of the Tyrone district was brought about by two very different and altogether unrelated sorts of chemical activity. One involved changes produced by ascending hot alkaline solutions arising, so far as can be determined, from deep-seated igneous rocks, supposedly the lower portions of the quartz monzonite porphyry, now exposed at the surface; the other includes only changes produced by descending cold, slightly acidified rain waters, principally active above the zone of permanent ground water. The ore deposits of the district are in a measure due to the activity of both of these processes, but they are particularly related to the second process, without which there would have been no enrichment of copper minerals.

These processes are discussed in detail under the heading "Mineralization" (pp. 24–40).

PHYSIOGRAPHY.

The geologic history of the Silver City region has been outlined on pages 7–10. The last chapter in this history, namely, the development of the present land forms, has special application to the ore deposits of the Tyrone district and therefore deserves more extended discussion.

The dominant topographic features comprise the Little Burro Mountains, a monoclinal fault block; the Big Burro Mountains, an erosion remnant standing well above the surrounding country; the great gravel plain, for the most part an accumulation of rock waste in an extensive inclosed basin and having minor topographic features depending on erosion and aggradation; and a planated rock surface, now scored by erosion, bordering the Big Burro Mountains and merging on its outer border with the gravel plain. A minor feature is the panlike depression within the planated area, formed by the erosion of the unaltered quartz monzonite porphyry. All these features are primarily the result of the erosion of rocks of varying hardness under special topographic conditions in a semiarid climate, modified by faulting.

Inasmuch as the copper deposits of the district occur beneath the planated rock surface above referred to, it is obvious that the processes involved in its formation and those effecting the enrichment or other modification of the ore bodies are related. A somewhat extended analysis of the history and origin of this planated surface is therefore warranted. A consideration of land forms will also throw light on the faulting of the region and thus aid in deciphering the history of the ore deposits.

Many observers have commented on the fact that numerous mountain ranges in the southwestern part of the United States rise abruptly from sandy desert plains, like islands from the sea. The streams that flow down their canyoned sides pour out débris in a series of great fans, whose edges coalesce to form sloping plains. The process of aggradation is in full play. An inspection of the Pleistocene deposits in most of the Silver City area, however, indicates clearly that a decided change has taken place along their edges.

Although the deserts farther south are still areas of active aggradation, or building up, much of the corresponding part of this area is being actively eroded. Yet there is abundant evidence that these gravels once formed an unbroken sheet that lapped up on the mountains they surround. The observer who stands upon the Big Burro Mountains and looks northward over the valley of Mangas River can not fail to be impressed, even astonished, at the intricacy of the carving by which the eventopped sheet of sand and gravel is cut into innumerable gullies and canyons, nor can he fail to conclude that the gravel must once have extended farther toward the steep mountain scarps.

An interesting question immediately arises in connection with this intricate carving of the Pleistocene deposits: When and why did erosion become so manifestly active? The answer may be read in certain prominent physiographic features of the neighboring hard rocks. These features may be best observed from an elevated viewpoint. To the northwest from the summit of Four A Mountain may be seen a remarkably fine example of a rock bench, which slopes gradually from the foot of the lava range on the northeast to the edge of the gravel sheet on the southwest. This bench is about 2½ miles wide. It has three prominent characteristics—its inner border terminates abruptly against a steep mountain flank, it slopes evenly away from the mountains and is continued in the gravel without a break, and it is sharply incised by canyons that pass into the gravel.

Across the gravel toward the southwest there is a narrower but similar bench, which, when viewed from the top of the Little Burro Mountains, appears strikingly accentuated, forming the broad slope at the foot of the Big Burro Mountains. These benches may be explained by tracing to its end a cycle of erosion proceeding under the special conditions imposed by subaerial filling of inclosed basins of wide extent in an arid or semiarid climate.[12]

It is assumed, first, that inclosed basins were formed by a disturbance of level, such, for example, as that which produced the Basin Range system, with its partly buried mountains and detritus-filled inclosed valleys, continental warping probably being the underlying cause. Next is assumed a climate so arid that evaporation would prevent the rise of water in these basins and thus augment subaerial accumulation. These two conditions being assumed, it is apparent that a basin would be progressively filled from its center outward, and that this process of progressive burial would permit erosion to act with accumulating effect upon each succeeding unburied portion of the basin—that is, the last part to be covered would have undergone the greatest erosion. Although it is true that there would be appreciable deposition of coarse gravel near the borders of the basin where streams debouched from the mountain

[12] Paige, Sidney, Rock-cut surfaces in the desert ranges: Jour. Geology, vol. 20, pp. 442–450, 1912.

canyons, it should be borne in mind that such deposition must be confined largely to the stream ways. The interstream areas would remain without a mantle of gravel and thus continue to be subjected to erosion long after the center of the basin was effectively masked with fine débris. If the basin were of great extent the last part to suffer burial would probably have become a nearly planated surface. This end seems inevitable for the following reasons: First, the edge of the accumulating gravel sheet—below which (vertically) erosion could not extend—determines a local base-level, and, second, the territory above the gravel would constantly tend to become reduced to the level of the gravel. But this level is slowly rising; therefore the end product of such a cycle would be a sloping, evenly cut rock plain abutting against a mountain scarp.[13] The maintenance of this scarp is due partly to the cutting action of the mountain stream as it successively occupies the opposite borders of the convex alluvial fan formed at the canyon mouth. Such a plain formerly bordered the Big Burro Mountains, and the copper deposits of the district lie beneath its surface.

At present, however, this Big Burro Mountain bench is undergoing strong dissection, which, though probably a result of various causes, is believed to be due mainly to faulting and accompanying tilting of the faulted blocks. The gravel, in consequence, has been swept outward and removed from the surface of the bench, and relatively deep canyons have been cut in the underlying hard rock.

Evidence to prove that the mineralized area is a tilted, faulted, fractured block may be found, first, in the master fault along the west border of the Little Burro Mountains (with downthrow on the west), which limits the Tyrone block on the east; and second, in the fault entering the Tyrone district from the northeast and crossing St. Louis Canyon a short distance above the old town of Tyrone (a fault downthrown on the south at Tyrone, but probably upthrown on the south farther west, as indicated by certain benches to be mentioned later). Moreover, there is both direct and indirect evidence that the gravel sheet formerly extended much farther westward.

The last two points need elaboration. In the section on faulting the evidence is set forth to support the statement that the fault which enters the Tyrone district from the northeast is downthrown on the south at Tyrone. Farther west, however, it has not been possible to locate this fault except by indirect evidence. Thus, it is known that the hypothetical extension of the fault would correspond to the northern boundary of the main fracture zone; but this boundary occurs wholly within igneous rock, and the needed direct criteria for proving its presence are lacking. At this point the aid of physiography (the interpretation of land forms) becomes valuable. Just west of Copper Mountain and east of Deadman Gulch there are certain benches cut in rock and located precisely where the hypothetical boundary of the fault passes and at the border of the main fracture zone. These benches, however, indicate a fault upthrown on the south, for their surface is presumed to correspond with the higher planated surface to the southeast, across the supposed fault. This throw is therefore opposite to that of the fault at Tyrone. The question is naturally raised, Is there not a hinge point somewhere between these benches and Tyrone? Such a hinge point would in part account for the failure to trace the fault, for movement would be slight in the region of the hinge.

The conclusions that these benches indicate a fault, and that this fault is upthrown on the south are further supported by the following facts: This line of disturbance may be traced a mile still farther southwestward, as shown on the geologic map, and coincides with the position of several alined topographic divides in which prospect drifts show well-defined fault gouges. Faulting is thus clearly indicated.

Again, the maximum elevation of these benches, 6,280 feet, corresponds with the top of the planated surface to the north, across the intervening valley; whereas immediately to the southeast, across the assumed fault, the top

[13] Lawson, A. C., The epigene profiles of the desert: California Univ. Dept. Geology Bull., vol. 9, pp. 23-48, 1915.

of the surface is at 6,400 feet, indicating a throw of 120 feet, with the uplift on the south.

Returning to the evidence presented by the position of the edge of the gravel sheet, in support of the idea that tilting has occurred, we may refer first to the fact that on the southern border of the Big Burro Mountains the gravel extends within a short distance of the steep slopes of the mountains. This is conceived to be the normal position of the gravel at the end of the cycle of erosion discussed above. Further, in some places in the Silver City region isolated outliers of gravel indicate that the main boundary has been eroded basinward; and finally, there are deposits of iron-cemented gravel in the vicinity of Tyrone whose mode of origin indicates that their present position at the edge of the gravel sheet has been established recently (in geologic time); formerly such deposits were deeply buried, and the border of the gravel sheet was farther mountainward.

Thus, in the light of all the evidence available, it would seem reasonable to postulate that the planated rock surface beneath which the copper deposits occur was first a smooth gravel-covered, sloping plain; that it was subsequently faulted and tilted eastward; that the gravel was stripped from its surface and canyons cut within it; and finally, that during all these changes the copper deposits were being more or less modified.

Part II.—THE COPPER DEPOSITS.

HISTORICAL NOTES.

Until the late seventies and early eighties the Burro Mountains were the stronghold of the savage Apaches, and it was a common belief that no prospector ever returned who chanced to wander into the region. The beautiful Mangas Valley, to the northeast, received its name from the notorious Apache chieftain Mangas Coloradas (Spanish for red sleeves), whose deeds are written in blood on the pages of frontier history. It is probable that the Indians mined for turquoise before the district was known to white men.[14]

The "old timer" John E. Coleman, better known in the early days as "Turquoise John," is generally credited as being the discoverer of the district, as no prospecting of any consequence was ever done before his time. He was in the district in 1879 and made a number of locations of both copper and turquoise, having discovered turquoise in some ancient workings during that year. Nevertheless it seems that Robert and John Metcalf were the first to make locations in the region, about 1871. They found both turquoise and copper.

The St. Louis deposit was discovered in 1879 by James Bullard, John Swisshelm, and J. W. Fleming, and shipments of surface ore were made to Denver.[15] The discoverers negotiated a sale with Paschal R. Smith and Frank Marshall, who organized the Val Verde Copper Co. and erected a 50-ton reverberatory furnace in Deadman Gulch. The town around the works was called Paschal. The company owned the St. Louis, Burro Chief, Boston, Marshall, Copper Mountain, and several other claims. The nearest railroad point was Deming, N. Mex., over 50 miles distant, and the wagon haul cost $50 a ton. The ore was obtained mostly from the St. Louis mine and smelted in the reverberatory furnace. The supply of high-grade material was small, and the operating costs were so high that the company soon failed. Later a 500-foot shaft was sunk on the St. Louis claim, and a large body of sulphide ore was found.

Two years later another company, under the management of Colonel Smith, built a smelting plant at Oak Grove, but this ran only a short time.

Soon afterward Judge Deming organized the Alessandro Copper Co. to work a group of claims about 3 miles east of the St. Louis mine. The treatment plant installed here involved a leaching process, using sulphuric acid made on the ground from pyrite. The low grade of the ore, the lack of a railroad, and the attempt to leach 30 years ago resulted in failure.

The Val Verde Copper Co. merged with the Southwestern Copper Co., and all operations were suspended on account of marauding Indians. During this time other discoveries were made in the district, among which was the Sampson deposit, found by George Sublett and Robert Thompson.

In 1904 Theodore Carter interested the Leopold Brothers, of Chicago, in the St. Louis mine and other properties and organized the Burro Mountain Copper Co.[16] This company took over the St. Louis, Sampson, Boston, and other claims belonging to the Southwestern Copper Co. A 150 to 300 ton mill was built at Leopold and treated 4 per cent ore from the Sampson and St. Louis claims.

In 1904 Phelps, Dodge & Co. bought a third interest in the company and acquired at the same time an option on the remaining two-thirds of the property.

About 1905 the Comanche Mining & Smelting Co. and the Copper Gulf Development Co. started developing property in the camp. They merged later as the Savannah Copper Co.

In May, 1906, the Briggs Oliver Development Co. took under option the Burro Chief group, belonging to Thomas S. Parker, and started Nos. 1, 2, and 3 shafts at Tyrone. This company later became the Tyrone Development Co., and then the Chemung Copper Co. It carried on extensive development work,

[14] Jones, F. A., New Mexico mines and minerals, pp. 55–56, 1904.
[15] Bush, F. V., Min. Press, February 6, 1915, p. 222.
[16] Wade, R. W., Eng. and Min. Jour., Aug. 15, 1914, p. 287.

sinking shafts, driving drifts, crosscutting, and blocking out ore bodies.

The Phelps Dodge Co. bought out the Leopold interests in the Burro Mountain Copper Co. and in 1913 purchased the Chemung Copper Co. and the property of a number of individual claim holders.

NATURE OF THE DEPOSITS.

The principal copper deposits of the Tyrone district are chalcocite ore bodies in porphyry and granite. They owe their value to the enrichment of pyrite and chalcopyrite by descending rain water. No primary ore is mined in the district. The deposits exhibit all the characteristics of the now well-recognized chalcocite "porphyry" ore. The chalcocite is either disseminated regularly throughout large masses of fractured country rock or concentrated along exceptionally strong veins or shear zones. The valuable ore bodies are characterized by both these features. The chalcocite ores are everywhere overlain by ground of variable thickness either barren of copper minerals or containing carbonates and other oxidized copper minerals, and at varying depths beneath the workable chalcocite ores the primary pyrite is everywhere encountered. The deposits are clearly related to zones of intense fracturing and do not appear where such fracturing is lacking. As they exist to-day, they are not the result alone of a long period of enrichment but clearly reveal the effects of perhaps equally extensive impoverishment.

The principal ore bodies lie within a northeastward-trending zone of fracture between Leopold and Tyrone. They may be considered the end result of, first, primary mineralization of a fracture zone in porphyry and granite; second, enrichment by downward percolating rain water at various stages in their development; third, impoverishment of previously existing ore at various stages by leaching.

In harmony with the nature of their origin, the ore bodies are very irregular in size and shape. They range from roughly blanket-like masses, grading upward into oxidized ground and downward into primary pyrite, to strong veins or shear zones, which are likewise barren near the surface and too lean to be of value below, where chalcocite gives way to primary pyrite.

The East ore body, about 700 feet long and 600 feet in greatest width and related to two strong fractures, is typical of the blanket type. At the top and bottom the body has little horizontal extent, but it swells notably at the middle, its form being regulated somewhat sharply on the west and northwest by the St. Louis and North veins, respectively. To the east and south the ore merges with country rock carrying too little copper to be regarded as ore.

The so-called "flat veins" of the Chemung group are typical of the shear-zone type. Here strong central anastomosing veins constitute, with the adjoining wall rock, profitable ore bodies.

The roughly cigar-shaped form of the richer bodies near Leopold may be discerned from the mine maps, where the narrowing and widening of the worked-out stopes on various levels may be clearly seen.

It is highly probable that the localization of all these ore bodies was determined by the presence of an appreciably greater amount of chalcopyrite than is found on the average throughout the rock mass.

PRIMARY MINERALIZATION.

GENERAL FEATURES.

The primary mineralization of the granodiorite porphyry and the granite was effected by the passage through these rocks in numberless channels, some large but most very small, of great quantities of aqueous solutions, the mineral content of which not only filled the countless open fractures in the rock but metasomatically replaced the wall rock of fissures great and small, searched out the innermost parts of the rock mass, and, to various degrees of perfection, performed its work of alteration. Although the changes thus accomplished, measured by the quantity of material introduced, indicate a chemical interchange on a vast scale, the minerals formed are few in number and characteristic throughout the area.

Of the nonmetallic minerals, sericite and quartz far exceed in amount any others. Indeed, except for a little chlorite, a little secondary biotite, a little calcite and epidote, and an amount of fluorite not easily estimated (as described below), they may be said to be the characteristic nonmetallic accompaniment of the alteration.

Of the metallic minerals, pyrite is preeminently the most abundant, and considering the fact that copper is the valuable metal sought in these deposits, there is an astonishing scarcity of chalcopyrite and a lack, so far as was observed, of any other primary copper mineral. A little zinc sulphide occurs, also a little molybdenite, but besides these there is a dearth of introduced metals. Sericite and secondary quartz are present in the metamorphic rocks in amounts ranging from a few scattered flakes of sericite within the feldspars to aggregates almost completely replacing the rock. Of these two minerals, however, sericite is by far the more abundant.

FORMATION OF SERICITE.

The formation of sericite has apparently proceeded under two sets of physical conditions—it has filled open cracks in the rocks as veinlets, either with or without quartz, or it has metasomatically replaced the constituents of the rock. The second mode of occurrence is the predominant one. The nature,

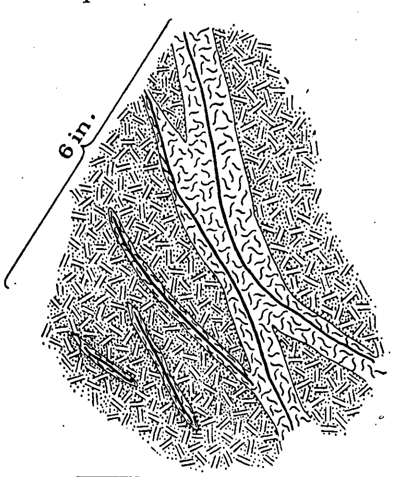


FIGURE 6.—Metasomatic replacement of porphyry by pyrite veinlets, sericite, and quartz.

texture, and composition of the rock replaced, the nature of the solution that accomplished the alteration, and the time during which it acted each affected the end results. Slightly altered granites may show a few flakes of sericite scattered through the feldspars. In another place the chemical composition of parts of zoned feldspar may have offered the necessary chemical environment, and the sericite is seen in an orderly arrangement within the

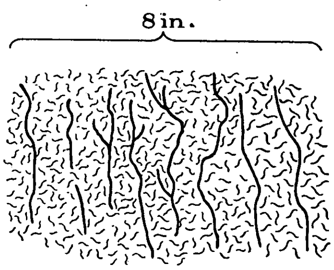


FIGURE 7.—Pyrite, sericite, and quartz replacing porphyry in a sheeted zone. In places this process affects large blocks of ground.

feldspar, following crystallographic directions or cleavage planes. In rocks more strongly affected the feldspars may all be filled to various degrees with sericite blades, while the quartz remains entirely unaltered. In a yet more advanced stage sericite replaces the edges of quartz grains, and from this stage on a progressively more nearly complete replacement may be observed to those rocks in which quartz and feldspar alike are filled with sericite blades.

How quartz is formed or introduced in these various stages is not clearly understood. The fact that it fills cracks in the other mineral grains as countless veinlets and larger veins is clearly observed, but quartz has also replaced the walls of veins and veinlets, and in such positions it is not everywhere clear what portion has been introduced and what portion is a residuum from reactions involving the formation of sericite. (See fig. 6.) From a study of thin sections, however, and from observation in the field, it is believed that the bulk of the secondary quartz occurs either in open fillings or in the replaced walls of the veins not far from the feeding channel of circulation. It may thus replace a large body of rock in a sheeted zone where ready access was afforded to the circulating solutions. (See fig. 7.)

It may be shown that the deposition of quartz and that of sericite are under certain assumed conditions intimately related—that the formation of the sericite demands the setting free of a certain amount of silica. Whether this silica is immediately redeposited or not would depend upon conditions, the arbitrary assumption of which leads to no particularly valuable conclusion. For example, the replacement of a molecule of albite by a molecule of sericite, if the silica of the albite molecule remains constant—that is, furnishes all the silica needed—results in a volume change, which demands more space for the resulting sericite than was taken up by the albite molecule. Of necessity, then, silica of the albite molecule was set free to be deposited immediately near by as quartz or to be carried off in solution. Observation of many thin sections shows that in some places the quartz was clearly not deposited near by and therefore was carried off in solution. Where the rock certainly contains more quartz than originally the question may well arise, How much of this quartz is residual and how much introduced? But the original rock was so variable in its content of quartz as to make an answer to this question of little value.

On the other hand, if the anorthite molecule is replaced by sericite, stable silica being assumed, there is insufficient quartz in the anorthite to fill out the entire space with sericite, and therefore silica must be supplied by the solution.

If all the material of the albite molecule were replaced by the sericite molecule—that is, if all its silica took part in the reaction—a larger space would be needed, and thus it is evident that this reaction can not take place if such space is lacking. Probably, therefore, a portion of the albite molecule goes into solution before replacement properly begins, and it is this general rule that must operate wherever it can be shown that replacement does not proceed by interchange of equivalent weights.

As a matter of fact the igneous rocks involved in these reactions contain feldspars which are mixtures of the albite and anorthite molecules.

If the porosity of the altered rock may be used as a criterion of the resultant, it would seem that ample space was at hand for these reactions, for the pore space of the altered rock exceeds that of the unaltered rock.

The transformation of feldspar to sericite, theoretically at least, may be brought about by highly heated water alone, thus: Orthoclase reacting with water alters to sericite, potassium silicate, and silica.

$$3KAlSi_3O_8 + H_2O = KH_2Al_3Si_3O_{12} + K_2SiO_3 + 5SiO_2$$

The potassium silicate is carried off, while the liberated silica may be partly removed in solution or it may recrystallize as quartz.[17] Or the reaction may be chemically expressed as follows,[18] water containing carbon dioxide being the only reagent necessary:

$$3KAlSi_3O_8 + H_2O + CO_2 = KH_2Al_3(SiO_4)_3 + K_2CO_3 + 6SiO_2$$

Sericite forms with as much ease from oligoclase, andesine, and labradorite as from orthoclase,[19] as is supported by field evidence at Tyrone, where all these varieties of feldspar are more or less transformed to sericite.

The occurrence of notable amounts of fluorite as a vein filling at several places in the Tyrone district and observations in the mines, below the zone of chalcocite enrichment, which suggested that quartz phenocrysts in the porphyry had been dissolved raised the question whether fluorine had not been active in secondary alteration and whether its source was to be sought not only in fluorite but also in sericite. It is well known from analyses that muscovite carries fluorine, but its presence in sericite has not been supported by so much evidence. Spurr[20] has argued that fluorine is necessary for the formation of sericite, but his tests were not convincing as to the fluorine content of sericite, though its presence to the amount of 0.12 per cent in a specimen (which contained no sericite) indicated that the waters which altered the rock contained it.

Believing that the influence of fluorine may be very potent in both the primary and the secondary alteration of the rocks, the writer selected a typical sericite vein for analysis, and the presence of fluorine in the sericite was definitely established.

The specimen chosen for analysis was part of a replacement vein about 1 inch thick, typical

[17] Clarke, F. W., The data of geochemistry, 4th ed.: U. S. Geol. Survey Bull. 695, pp. 596–597, 1920.

[18] Lindgren, Waldemar, Metasomatic processes in fissure veins: Am. Inst. Min. Eng. Trans., vol. 30, p. 608, 1901.

[19] Bischof, G., Lehrbuch der chemischen und physikalischen Geologie, 2d ed., vol. 1, pp. 31 et seq., p. 44, 1863.

[20] Spurr, J. E., Geology of the Tonopah mining district, Nev.: U. S. Geol. Survey Prof. Paper 42, pp. 232–233, 1905.

of countless similar veins that traverse the fractured altered rocks. Its mineralogy was simple, as it consisted of quartz, sericite, and pyrite. After the specimen was freed from as much pyrite as possible the following results were obtained on analysis:

Analysis of specimen from replacement vein.

[George Steiger, analyst.]

Silica (SiO_2)	68.11
Alumina (Al_2O_3)	16.84
Ferric oxide (Fe_2O_3)	.80
Ferrous oxide (FeO)	3.53
Lime (CaO)	.44
Magnesia (MgO)	.50
Soda (Na_2O)	.44
Potash (K_2O)	4.08
Sulphur (S_2)	3.15
Fluorine (F)	.09
	97.98

The mineral composition computed from this analysis is quartz 45.30 per cent, sericite 46.09 per cent, pyrite 6.68 per cent, and by allotting all the fluorine to the sericite it may be shown that this mineral carries practically 0.20 per cent of fluorine, a notable amount.

Thus as the sericite generally contains an appreciable amount of fluorine, the explanation of the breaking down of feldspar by hot waters alone or by carbonated waters may be considered simply as a supporting argument for a far more potent cause—that is, the presence of fluorine in the primary solutions.[21]

PYRITIZATION AND THE INTRODUCTION OF COPPER.

The silicification and sericitization of the rocks was accompanied in many places by pyritization and the introduction of copper, probably in the form of finely disseminated chalcopyrite. The pyrite accompanies quartz in numberless veinlets and veins (see fig. 8) and also impregnates the wall rock. In fact, there is every reason to believe that the sulphur needed to form the pyrite was an element in the solutions which carried the potash necessary for the formation of sericite. The outline of pyrite grains within the wall rock of veins is usually sharp, transecting quartz, feldspar, and sericite alike, suggesting that the mineral was formed during a late stage of the metamorphism. It is true that in some places sericite blades may be observed penetrating grains of pyrite, but this is unusual and indeed would seem to point to no more than contemporaneity of origin at that place. There is no evidence to be gathered from the thin sections to support the view that the pyritization was decidedly earlier than the sericitization and that the sericitization was a late phenomenon, as is held by Rogers,[22] who concludes that "Sericite is a rather low-temperature mineral formed at or toward the close of the hydrothermal period."

The pyrite varies greatly in amount. It is most abundant in strong veins where circulation has been very active. At certain places within the Breccia ore body pyrite is exceptionally abundant, solidly filling spaces several feet in diameter, between fragments of the breccia.

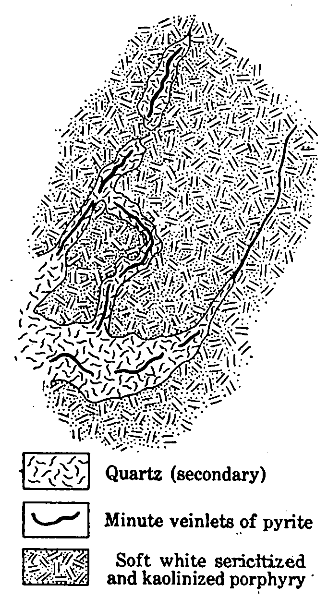


FIGURE 8.—Minute veinlets of pyrite accompanied by quartz cutting sericitized porphyry.

COMPOSITION OF THE SOLUTIONS.

If, as shown above, the primary alteration of the rocks consisted in the formation of sericite, quartz, and pyrite, accompanied by fluorite, epidote, calcite, and chlorite, it may pertinently be asked, What was the nature of the solutions that performed the work? No analyses of the rocks in this district have been made. This course was decided upon after careful consideration of results in other places where

[21] Paige, Sidney, and Steiger, George, Fluorine in sericitization: Washington Acad. Sci. Jour., vol. 8, pp. 234-239, 1918.

[22] Rogers, A. F., Econ. Geology, vol. 11, p. 145, 1916.

almost precisely similar associations or rocks and metamorphic processes prevail. It has been shown that in such districts potash has been introduced while soda, lime, magnesia, and alumina were removed; also that sulphur has been introduced while the proportion of quartz apparently remained about stationary.

It is believed that in the Tyrone district fracturing was the forerunner of metamorphism and that the degree of the one influenced the degree of the other; and as the intensely fractured zones contain great quantities of visible vein quartz and afford evidence that the walls of numberless veins were replaced by quartz it does not seem possible to believe that the silica present in the original rock at any particular level was sufficient to account for the quartz which may be observed. The same conclusion is believed to be warranted as regards the iron in combination with sulphur to form pyrite. Although the iron of the ferromagnesian minerals, biotite and hornblende, did combine with sulphur to form pyrite, as is clearly indicated where these minerals are altering to chlorite, sericite, pyrite, and quartz, yet the large quantities of iron necessary to form the pyrite of the heavy veins must, in part at least, have come from below.

If for a moment the more obvious nature of the reactions involved is considered, some idea of the elements in solution may be obtained. If, for example, potash was being exchanged for soda, lime, and magnesia, then all these elements must have been present in the solution, for at no particular point could it be determined that any of them was depleted. That some of the iron or alumina or soda may have been picked up below and that some potash may have been lost below can not be denied. In fact, that the solution was constantly varying in character as the reaction went on seems a necessary conclusion. Thus conceived, it would seem that sodium, potassium, magnesium, iron, sulphur, copper, zinc, silica, and fluorine were all present. That under the conditions that prevailed the solution was nearer concentration by potash than by any other of these elements would seem axiomatic from the sericitization of the rocks. It is also apparent that progressive enrichment of sodium and lime would take place in the solution.

ORIGIN OF THE SOLUTIONS.

The type of alteration just described implies the movement through the rocks of great quantities of aqueous solutions. It is futile to attempt an absolute proof of the origin of these solutions from deep-seated igneous rocks, but that they did so originate is for many reasons the most probable hypothesis. Alteration of this type is characteristic of fractured zones near and within intrusive bodies chemically allied to the one at Tyrone throughout a wide territory in the western United States and other parts of the continent. It has been shown that fracturing probably soon followed intrusion. Igneous dikes cutting the main mass indicate waning igneous activity. That aqueous solutions should continue to be given off from lower portions of a fractured consolidated magma is reasonable, and there is nothing in the nature of the elements which these solutions have been shown to contain that opposes this view. Indeed, the presence of fluorite and less conspicuously of apatite in veins indicates a magmatic source of the solutions. The intensity of the alteration indicates hot or at least warm waters. It is true that surface water might sink and later become heated, but there is nothing to show that this occurred here. Any hypothesis which assigns such alteration and mineralization to meteoric circulation must explain when and how the various substances needed were taken up and should cite evidence that such water at great depths exists and facts to prove that it could circulate through appropriate channels.

The association of springs with volcanic activity, the admitted and proved content of water in igneous magmas, and the connection between igneous magmas and volcanic activity all point to the conclusion that such solutions as are here considered were probably the last expression of a period of magmatic injection.

ALTERATION.

GENERAL CONDITIONS.

For a long time, perhaps during more than one period of erosion, rain water has been falling upon the surface of the altered rocks of the Tyrone district. These rocks when first exposed to erosion were composed essentially of feldspar, quartz, sericite, and pyrite, with a small percentage of chalcopyrite. They are now very different. That part of the rain water which sank beneath the surface has produced important changes.

At the surface in the place of pyrite there are at the present time limonite and hematite in great abundance, kaolin, and in sparing amounts the oxidized copper minerals, malachite, azurite, chrysocolla, cuprite, etc. Native copper occurs in a few places. Lower down there is pyrite coated with chalcocite or wholly replaced by it; in places this is the predominant mineral. Still deeper it becomes less conspicuous, and the unaltered pyrite is the only sulphide visibly present.

The factors that control the speed and thoroughness with which such a change takes place are physical. The depth to which oxidation can be effective is governed, first, by the fractures in the rock; second, by the position of the ground-water table, below which oxidation does not occur to an important degree. The thoroughness of the process is dependent upon the ease of circulation and the quantity of water supplied. Under stable conditions, which are seldom if ever realized, all the copper would ultimately be deposited as chalcocite near the water table. Thus viewed, the block of ground between the surface and the water table has acted in a measure as a great selective filter through which rain water leaching out the copper from higher levels has precipitated it again within narrower limits below. The process, however, is a chemical one.

Several factors have served to complicate the orderly oxidation of the mineralized rocks. First, the topography and underground drainage in this region have not always been as they are to-day. In consequence, the position of ground water has shifted from time to time. Second, the degree of fracturing varies greatly in different parts of the rock body, and circulation has therefore been irregularly distributed.

GROUND WATER.

The records of a number of drill holes prove that at the present time ground water thoroughly saturates the rocks below a rather definite level. This nearly plane surface slopes gently from the country west of Tyrone to the Mangas Valley, beneath which it is nearly horizontal. It slopes gently northward down the Mangas Valley and southward toward the desert and Deming. The cross sections in figures 9 and 10 clearly bring out these facts. Sections approximately north and south along the Mangas Valley show that the water level beneath the gravel does not vary more than 60 feet in elevation, whereas the elevation of the surface may vary several hundred feet. This is to be expected. The gravel that fills the Mangas Valley is porous, and water falling there easily finds its level. The gentle upward slope of the water table toward the west corresponds almost exactly with the slope of the rock surface that borders the gravel deposits and reaches the Big Burro Mountains. Such an accordance of slope and the fact that at other points the level of water corresponds proves that the rock here also is saturated below a rather definite level. Its porosity, however, is due to fracturing.

The position of this water table does not apparently bear any significant relation to the position of maximum enrichment of the chalcocite ores. (See cross sections, figs. 9 and 10.) At some places enrichment ceases above the water table; at others the position of maximum enrichment corresponds with the water table; at still others it descends well below the water table. This variation suggests that when the ores were formed the position of the water table was quite different from that of to-day. Moreover, there are places in the mines where barren sheeted zones carrying limonite and quartz cut through and below bodies of chalcocite ore. Such evidence supports the idea that the conditions that govern enrichment to-day are radically different from those that prevailed when the chalcocite ores were being formed at the levels where they are now found. This discordant relation of ore to ground water is further emphasized by a consideration of the chalcocite in relation to primary pyrite. The depth to which chalcocitization has been effective varies greatly, and the bottoms of the ore bodies are very irregular surfaces.

PERIODS OF ENRICHMENT AND CHANGES IN THE LEVEL OF GROUND WATER.

An explanation for the conditions described above must be sought in the geologic history of the region. Fortunately the broad studies of the Silver City quadrangle afford some basis for such an explanation.

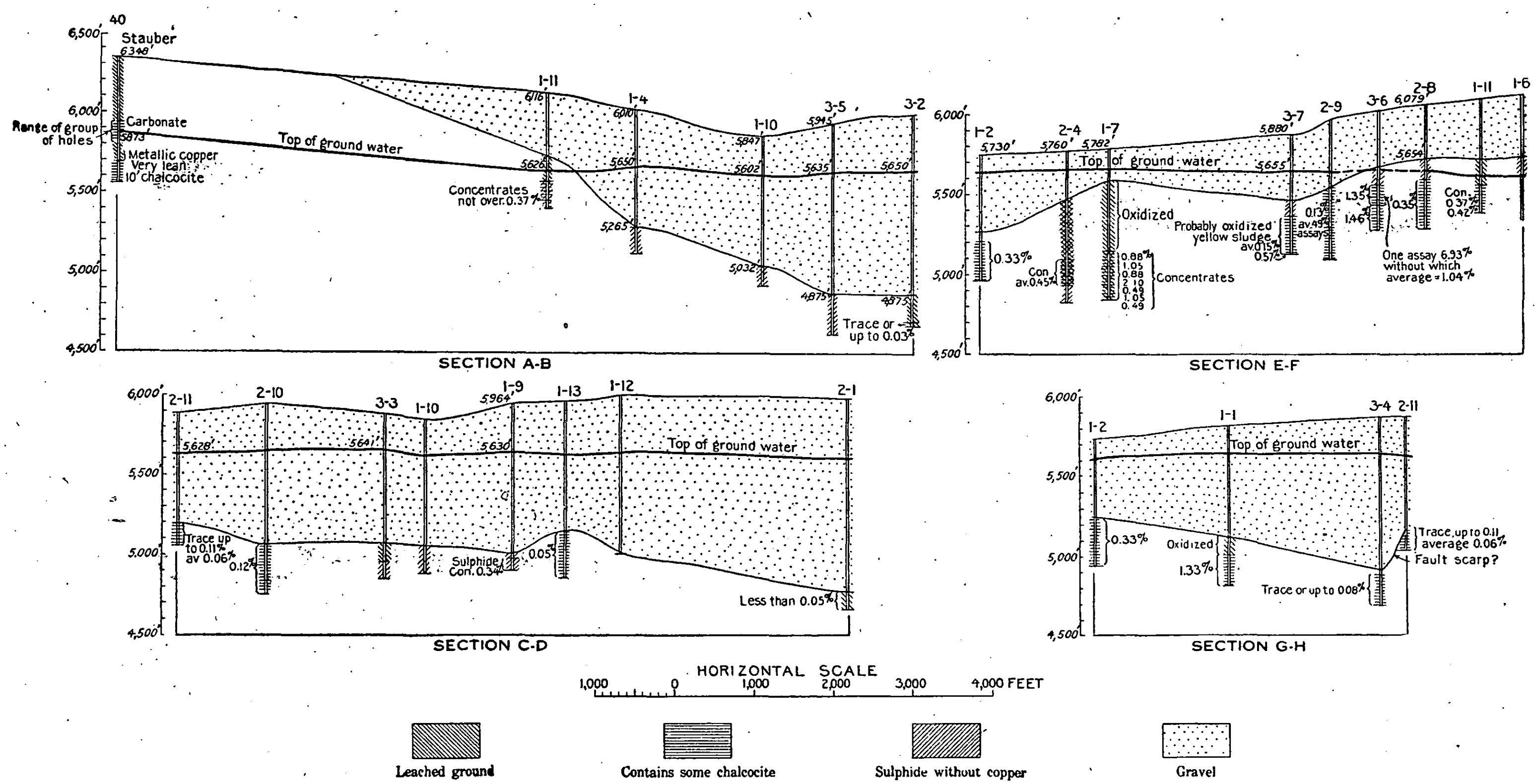


FIGURE 9.—Cross section showing relation of ground water to chalcocite enrichment.

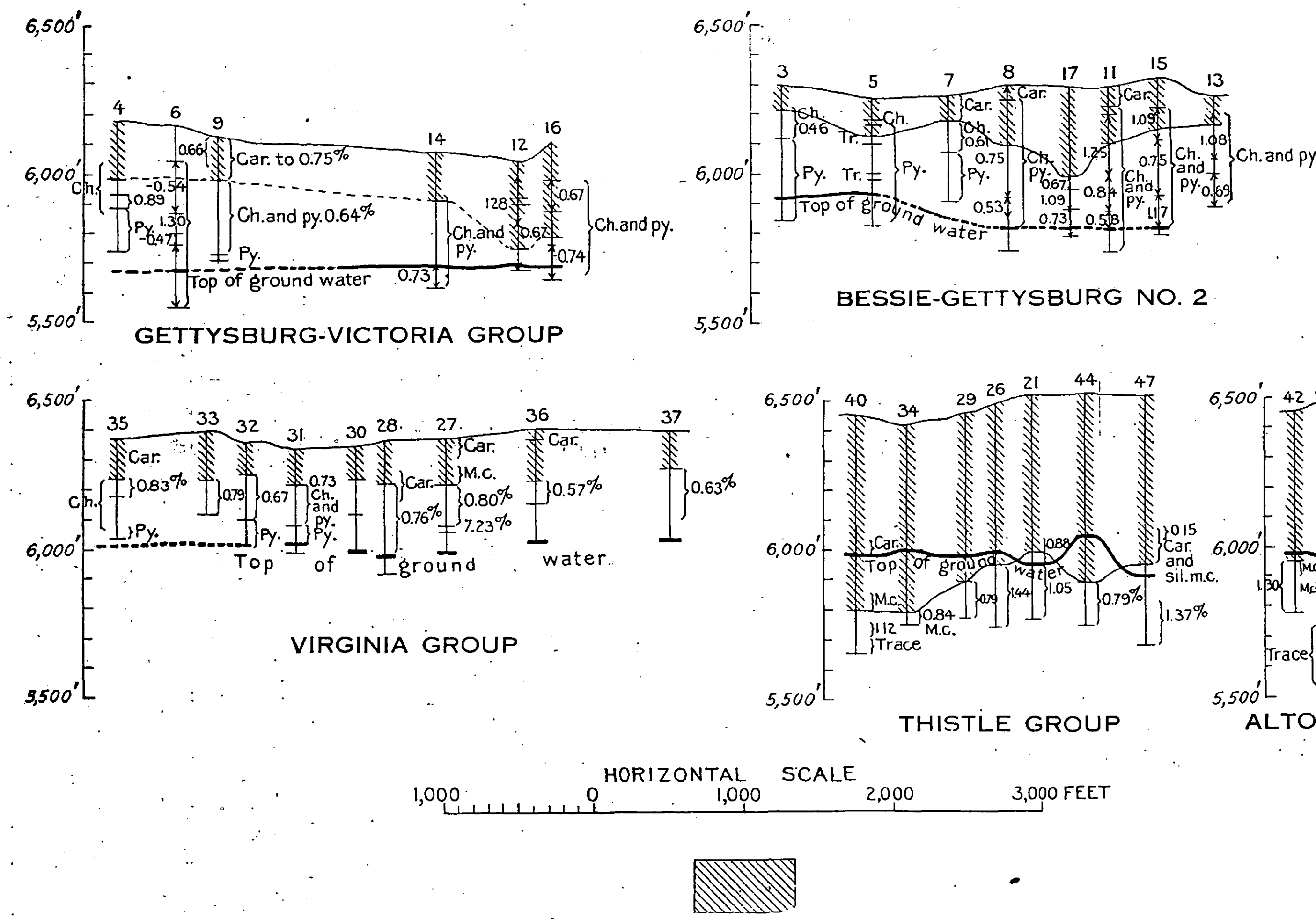


Figure 10.—Cross section showing relation of ground water to chalcocite enrichment

Evidence is clear that Tertiary lavas flooded a country of irregular relief, already eroded to sufficient depth to expose the mineralized quartz monzonite at Tyrone. At that time, however, the outcrops of the monzonite stood higher than at present and formed no such even plain as is indicated by the topography of to-day. Enrichment began, therefore, well before the lavas appeared.

The position of the ground water at that time can only be conjectured, but it is reasonable to suppose that the water table was more irregular than at present, for the topography was more rugged. This supposition is also supported by evidence furnished by drill records in the Tyrone district, for the bottom of the enriched ore is extremely irregular and clearly was not determined by any particular level of ground water—that is, the chemical activity of the descending solution that formed the ore was not halted by the presence of any regular sheet of underground water. Evidently the chalcocite never came into contact with such water. The maximum depth at which it was deposited was determined by other factors than the presence of a water table.

How far enrichment proceeded before lava flooded the country is not known, but such flooding must have very effectually retarded the processes of enrichment. This pre-lava enrichment may be considered the first stage in the development of the ore bodies. Then followed a long period during which the rocks were again being stripped from above the mineralized area. During this second period of erosion conditions of the underground water were surely different from those that prevailed during the first period, and probably during this stage of the formation of the ores the leaching so evident in the mines occurred. It is conceived that the new conditions of erosion and underground drainage set up by this lava flooding and the crustal adjustments that probably took place incidentally thereto may account for this leaching, which is so difficult to explain otherwise than by referring it to some period wherein the physiographic control of drainage was radically different from that of the present. These leached zones, within which steeply dipping sheets of ground containing essentially only limonite and quartz descend far below present water levels, pass through the ore bodies and well into regions of unoxidized pyrite. This period of post-lava leaching may be considered the second stage; it probably passed by insensible gradation into the third stage.

An essential initial condition of this third stage must have been the outlining of great structural undrained basins as a result of warping and faulting. There is evidence that this condition was reached slowly. For example, the drainage of the Little Burro Mountains points clearly to a gradual rise of these mountains. The streams cut directly across the mountains. As the block rose the streams were able to cut their channels down equally fast. It may well be that the raising of this block impounded the ground water and caused it to rise in the Tyrone area.

Then began the great accumulations of gravel now so widely distributed, occupying these great inclosed basins. The underground drainage, formerly so free, now underwent a gradual change. Extensive planated surfaces sloping gently to the edge of the gravel deposits from the mountains were formed. These surfaces were cut in rock. Their formation, as has been pointed out in the chapter on physiography (pp. 19–22), was directly brought about by the accumulating gravel deposits. These surfaces are in the nature of peneplains, with the difference that during their formation the level toward which erosion tended to lower them was gradually rising. The portion of these plains farthest removed from the gravel deposit was the portion more perfectly planated.

It is evident that while such plains were being cut along the borders of the gravel deposits the ground water beneath the gravel rose gradually as the gravel filling proceeded and extended beneath hard rocks where these were fractured, up the slopes of the planated rock surface, as it does to-day. It is equally evident that as soon as ground water reached a particular level in the mineralized pyrite zone enrichment ceased below that level. The areas covered first by the gravel, therefore, were the first in which enrichment became inactive. The area farthest away from the gravel sheet remained subject to enrichment the longest. With this relation in mind, it is a striking fact that the richest ores of the Tyrone district are to the west, at the maximum distance from the gravel sheet, also that they are the shallowest. Their richness may well be due to their relatively prolonged period of enrichment; their shallowness may well be due to the higher stand of the ground water, for the ground water slopes upward toward the mountains on the borders of inclosed desert basins, and probably here it always stood higher than toward the valley.

Physiographic evidence elsewhere within the Silver City quadrangle shows that deposits of gravel extended well up the slopes of such planated rock surfaces as are being considered here, and it is reasonable to suppose that ground water at such times stood higher than it does to-day—that is, the chalcocite zone at Tyrone was probably once flooded even more than it is at present. Direct evidence on this point consists in iron-cemented gravels lying upon the porphyries. These indurated deposits are precise markers of horizons where the top of ground water passed from solid rock into gravel. (See fig. 11.) They occur where water, passing into porous gravels from the more solid rock, deposits a portion of its iron content as limonite. Such deposits in the Tyrone district therefore prove not only that the gravel extended farther west than at present (these deposits are now at the edge of the gravel), but that the ground water once stood much higher, for it is now far below these deposits. This high stand of ground water may be considered the culmination of the third stage of enrichment.

The fourth stage in the development of the ores was initiated by the movements that upset conditions producing aggradation and brought about the dissection both of the gravels and of the planated rock surfaces, the marked effects of which are so prominent in the topography to-day. During this stage faulting was probably very active, and the particular block of ground here considered is believed to have been tilted to the east, having been broken along the fault that borders the west side of the Little Burro Mountains. Such tilting would have the effect of raising the chalcocite zone on the west side of the block with reference to ground water, while relatively lowering it on the east side. Here again, therefore, enrichment was more favored to the west than to the east.

This period of erosion, however, while in all probability it served to enrich portions of the ore bodies—for example, those under hills—resulted in a second period of impoverishment of other portions, such as the leached ground in valleys, consequent on the erosion which they have suffered. Thus the fourth stage in the development of the ore bodies is brought up to the present time, when leaching and enrichment are both going on above the ground-water table. Should conditions remain stable for a long period, a concentration of chalcocite will be brought about near water level.

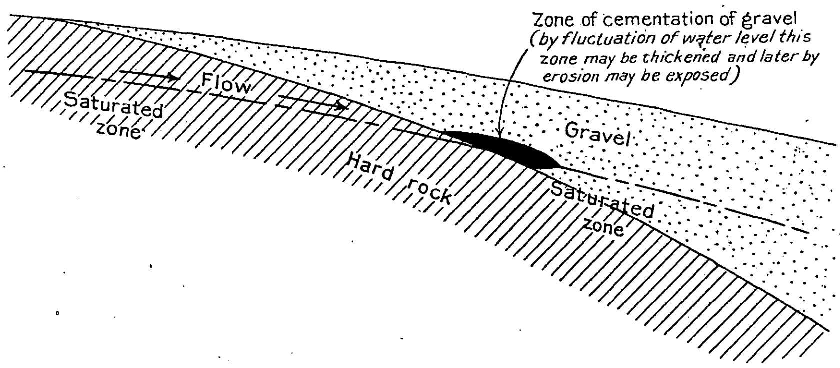


FIGURE 11.—Relation of iron-cemented gravel to ground-water level. Fluctuations in the level of ground water may thicken the cemented portions, and erosion with accompanying lowering of ground water may expose such accumulations at the surface, as found in the Tyrone district to-day.

FORMATION OF CHALCOCITE.

The study of the chalcocite ore bodies at Tyrone leaves little room for doubt that they were produced by enrichment. Although the lower portions of many ore bodies could not be examined, being under water, it is believed that no facts of particular importance would have been discovered had these portions been accessible, for there was an opportunity to observe both the top and the bottom of several chalcocite ore bodies, and there is no reason to believe that others were essentially different.

The primary sulphides are pyrite and a very small amount of chalcopyrite. The chalcocite replaces to various degrees both of these minerals. (See fig. 12.) Usually above an ore body there is a zone of leached ground in which sulphides are lacking. Still higher there may be carbonates and oxides, near or at the surface. In other places the chalcocite zone is surmounted immediately by oxides and carbonates, no barren zones being present.

At various depths the chalcocite zone merges with the zone of unaltered pyrite, and here there are in places prominent veins of kaolin-like products metasomatically replacing the pyritized porphyry.

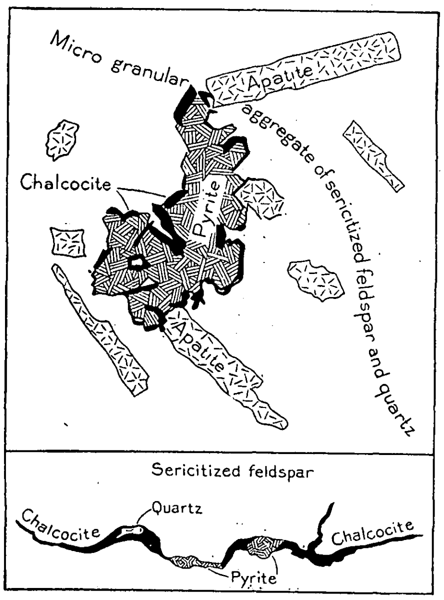


FIGURE 12.—Pyrite coated with chalcocite embedded on and in veins in sericitized porphyry.

The explanation of enrichment is found in the chemical interaction of rain water and the primary sulphides contained in the porphyry. According to Spencer,[23]

Rain water carries in solution the various gases of the air, including oxygen and carbon dioxide. In arid and semiarid regions it contains also noteworthy amounts of common salt, which may be regarded as of wind-blown origin. As these waters pass into the soil and into the porous weathered capping that lies above the ore mass they come into contact with orthoclase and mica and with oxidic compounds of iron and copper and basic carbonates of copper. (Note here that the process being described is that in progress at the present time and does not begin with the unoxidized pyrite. The result is, however, essentially the same, as will be pointed out below.—A. C. S.)

Metallic copper and the red oxide cuprite are also fairly common in the overburden. The silicate minerals in the capping tend to make the water alkaline,[24] but as they are only slightly attacked, this tendency is likewise slight. Of the metallic minerals in the capping, those containing sulphate decompose, being somewhat soluble, the final result being to produce and to leave in place insoluble limonite and copper carbonates and to furnish small amounts of iron and potash sulphates to the solution. Thus far the dissolved oxygen does not enter largely into reaction, because most of the minerals of the capping are already fully oxidized. The only exceptions to be noted are cuprite and native copper. Also, the carbonic dioxide has been by no means exhausted. Beneath the capping the solution encounters material rich in sulphide minerals that are subject to ready oxidation. Here, then, chemical action between the oxygenated water and the sulphide minerals ensues, a series of reactions being initiated, of which series the culminating reactions involve the deposition of chalcocite. At first the water contains free sulphuric acid furnished by the decomposition of pyrite, but gradually the acid becomes neutralized by bases furnished by the gangue minerals, and at sufficient depths the solutions become alkaline.

In the Tyrone mines, however, prominent veins of kaolin below the zone of chalcocite enrichment indicate the presence of free sulphuric acid. As the formation of chalcocite is accompanied by the formation of sulphuric acid, this condition would seem normal. Spencer continues:

If considered with respect to the minerals decomposed the reactions that occur beneath the capping present a succession of oxidations, whereas if considered with respect to the active solution the changes are of course as consistently in the direction of reduction. The reactions may be considered in three groups, assignable in a general way to higher, intermediate, and lower positions in the body of sulphide-containing material. In the upper part of a sulphide ore body atmospheric oxygen is the oxidizing agent; somewhat lower down, where free oxygen has been exhausted, ferric sulphate becomes active; and after the oxygen made available by this carrier has been utilized cupric sulphate furnishes oxygen. The *action of cupric sulphate* [25] on pyrite and chalcopyrite results in the deposition of chalcocite and the consequent enrichment of the material carrying the primary sulphides.

No attempt will be made here to review numerous experiments in chalcocite deposition undertaken during the last decade or earlier. This has already been done by W. H. Emmons.[26]

[23] Spencer, A. C., Chalcotite enrichment: Econ. Geology, vol. 8, pp. 622-624, 1913.

[24] Cameron, F. K., and Bell, J. M., U. S. Dept. Agr. Bur. Soils Bull. 30, pp. 12 et seq., 1905. Clarke, F. W., The data of geochemistry, 4th ed.: U. S. Geol. Survey Bull. 695, pp. 473-478, 1920.

[25] Italics by the writer.—S. P.

[26] The enrichment of sulphide ores: U. S. Geol. Survey Bull. 529, 1913; The enrichment of ore deposits: U. S. Geol. Survey Bull. 625, 1917.

The results of investigation have progressively tended toward harmonious conclusions. The progress of the theory of chemistry has been rapid during this same period. Electrochemistry, knowledge of the nature of colloids, and the application of physical chemistry to problems of ore deposits have all advanced rapidly. The summary which follows will present only those formulas which seem to offer an explanation of the changes involved. Stated for the first time in an orderly arrangement by A. C. Spencer in 1913 (though in part naturally based on the work of his predecessors), these formulas have been supported in part recently by the fundamental work of the Geophysical Laboratory at Washington.[27] Spencer inquires "whether the oxygen dissolved in rain water could alone have effected the oxidation of the mass of material which has contributed the secondary copper now contained in any given ore body." He answers this query in the negative, presents data to support his contention,[28] and concludes that "a large part of the oxygen must have been derived from air that circulated through the oxidized capping" and that "the greater part of the oxidation must take place during such times as the sulphides are merely moist rather than when they are flooded, because then the water could receive oxygen from the air in contact with it, at the same rate at which oxygen is being taken out of solution by the reaction of oxidation."

That part of Spencer's analysis of the process that has direct application at Tyrone is quoted below.[29] His analysis falls into three parts—first, the changes wrought by free oxygen; second, those produced by ferric sulphate, where free oxygen is no longer available; third, the oxidation by cupric sulphate, the last oxidizing agent. To this sequence of chemical reactions may be added the final stage of secondary rock alteration, the kaolinization of the primary ore material by sulphuric acid, active below the chalcocite zone.

OXIDATION BY FREE OXYGEN.

Beneath the capping the sulphides first encountered by waters that carry dissolved oxygen are pyrite and chalcopyrite. Just at the top of any porphyry ore body grains of these minerals persist after the removal of chalcocite coatings which they carried at a time when the bottom of the capping was slightly higher than at present. Here, too, is to be found some pyrite which never carried more than the slightest coating of chalcocite.

The sulphides named are of course readily decomposed by the oxygen-bearing solution. * * * The complete oxidation of pyrite may be considered as taking place in some such manner as represented in the derived equation (1).[30]

$$FeS_2+15O+H_2O=Fe_2(SO_4)_3+H_2SO_4 \ldots\ldots (1)$$

For chalcopyrite, (2) is an equation essentially analogous to (1):

$$2CuFeS_2+16O+H_2SO_4=Fe(SO_4)_3+CuSO_4+H_2O \ldots (2)$$

Part of the ferric sulphate formed at the upper surface of the body where free oxygen is present decomposes to form basic iron sulphates and hydrated iron oxide; another part may be supposed to pass downward in solution and to attack pyrite, chalcopyrite, and chalcocite. The formation of iron hydroxide may be represented in various ways—for example, as follows:

$$6FeSO_4+3O+3H_2O=2Fe_2(SO_4)_3+2Fe(OH)_3$$

The equations which have been given indicate that the decomposition of pyrite yields sulphuric acid and ferric sulphate. Under natural conditions solutions carrying these substances come into contact with chalcocite only a short distance below the point where pyrite and chalcopyrite were first encountered. Here, if any free oxygen remains, chalcocite is decomposed, with the formation of cupric sulphate:

$$Cu_2S+H_2SO_4+5O=2CuSO_4+H_2O \ldots\ldots (3)$$

The reaction indicated by this equation may be considered as using up the last of the free oxygen which can reach a body of enriched porphyry ore under ordinary conditions. At points immediately below those where the free oxygen has been entirely consumed, ferric sulphate and cupric sulphate are present. Both these compounds are capable of oxidizing the sulphides, but the former is more readily reduced than the latter, and it may be supposed to undergo almost complete reduction to ferrous sulphate before the latter can come into play as an oxidizing agent.

OXIDATION BY FERRIC SULPHATE.

* * * According to Vogt [31] the action of ferric sulphate on chalcocite, which would come into play below the shell of nearly complete oxidation, is as follows:

$$Cu_2S+2Fe_2(SO_4)_3=4FeSO_4+2CuSO_4+S \ldots\ldots (4)$$

[27] Zies, E. G., Allen, E. T., and Merwin, H. E., Some reactions involved in secondary copper sulphide enrichment: Econ. Geology, vol. 11, pp. 407-503, 1916.

[28] Spencer, A. C., op. cit., p. 631.

[29] Spencer, A. C., op. cit., pp. 632 et seq.

[30] Compare Stokes, H. N., On pyrite and marcasite: U. S. Geol. Survey Bull. 186, pp. 15, 19, 1901; Lindgren, Waldemar, Copper deposits of the Clifton-Morenci district, Ariz.: U. S. Geol. Survey Prof. Paper 43, p. 79, 1905 (this author gives an extended bibliography relating to pyrite oxidation); Allen, E. T., Sulphides of iron and their genesis: Min. and Sci. Press, vol. 103, pp. 413-414, 1911; Gottschalk, V. H., and Buehler, H. A., Oxidation of sulphides: Econ. Geology, vol. 7, p. 16, 1912; Tolman, C. F., Secondary sulphide enrichment of ores: Min. and Sci. Press, vol. 42, p. 40, 1913.

[31] Vogt, J. H. L., Problems in the geology of ore deposits: Am. Inst. Min. Eng. Trans., vol. 31, p. 166, 1902.

But if the sulphur set free reacts with more ferric sulphate SO_2 might be formed, and with still more ferric sulphate sulphuric acid will result, and eventually we may arrive at the equation suggested by Weed:[32]

$$Cu_2S+4H_2O+5Fe_2(SO_4)_3=10\,FeSO_4+4H_2SO_4+2CuSO_4 \quad (5)$$

* * * * *

The same reagent, ferric sulphate, may be considered as acting on pyrite in a manner represented more or less adequately by equation (6):

$$FeS_2+7Fe_2(SO_4)_3+8H_2O=15FeSO_4+8H_2SO_4 \quad (6)$$

It is to be noted that equation (6) is comparable with equation (1). For chalcopyrite an expression similar to (6) is:

$$CuFeS_2+8Fe_2(SO_4)_3+8H_2O=17FeSO_4+8H_2SO_4+CuSO_4 \quad (6a)$$

* * * * *

The foregoing discussion should make clear the following points:

First, that waters from the surface penetrating a body of porphyry ore will continue to decompose strongly the metallic sulphides present so long as they contain or can acquire free oxygen, or so long as they contain ferric sulphate. Second, that where chalcocite, pyrite, and chalcopyrite are all present the chalcocite will be largely and perhaps fully decomposed before the other minerals were attacked. Third, that the decomposition of chalcocite, pyrite, and chalcopyrite effects the reduction of ferric salts contained in the solution. Fourth, that the decomposition of pyrite, chalcopyrite, and chalcocite each tends to produce sulphuric acid. Fifth, that the decomposition of chalcocite and of chalcopyrite furnishes cupric sulphate to the solution. Briefly, then, when oxygen-bearing waters reach the upper part of the mass of sulphide-bearing rock the consumption of the dissolved oxygen begins at once, and before the waters can progress downward for any considerable distance all of this free oxygen is used up in decomposing the sulphides. Also within a short distance ferric sulphate is largely reduced to ferrous sulphate. So long as free oxygen is present the decomposition of chalcocite will progress until no sulphuric acid remains uncombined. It should be added that cuprous and ferric ions are always present in small concentration[33] in any solution containing cupric and ferrous sulphates.

OXIDATION BY CUPRIC SULPHATE.

The progress of the surface-derived waters has been followed to the point where they contain no free oxygen and only a minor amount of ferric sulphate but where they carry ferrous sulphate, cupric sulphate, and sulphuric acid. Thus far on its downward journey it may be assumed that the cupric sulphate has been protected from reduction because at ordinary temperatures and in acid solution it is less readily reduced than ferric sulphate.[34]

Beyond the place where the ferric sulphate concentration in the solution has been reduced to a certain minimum, cupric sulphate comes into play as an oxidizing agent. * * * Cupric sulphate attacks chalcopyrite and pyrite at ordinary temperatures, so that iron passes into solution as ferrous sulphate, sulphuric acid is formed, and a copper sulphide is deposited. The last part of this statement is supported by the fact that covellite and chalcocite are common products in nature where copper sulphate solutions from the upper zone of oxidation have encountered pyrite and chalcopyrite. * * *

The Stokes equation for chalcocite formed by replacement of pyrite through the action of cupric sulphate may be built up empirically. * * * Thus:

$$2FeS_2+2CuSO_4=Cu_2S+2FeSO_4+3S$$ [35]

$$3S+2CuSO_4=Cu_2S+4SO_2$$ [36]

$$6H_2O+5SO_2+2CuSO_4=Cu_2S+6H_2SO_4$$

$$12H_2O+5FeS_2+14CuSO_4+8Cu_2S+5FeSO_4+12H_2SO_4$$ [37]

In a similar manner the following equation indicating the replacement of pyrite by covellite may be deduced:

$$4H_2O+4FeS_2+7CuSO_4=7CuS+4FeSO_4+4H_2SO_4.$$

As thus derived each of the Stokes equations appears to summarize a succession of oxidation effects.

The replacement of pyrite by chalcocite has been recently made the subject of painstaking quantitative chemical analysis by Zies, Allen, and Merwin.[38] Their results agree perfectly with the formulas given above representing the changes pyrite to chalcocite and covellite to chalcocite.

Spencer notes that "the supposed change covellite to chalcocite under the action of cupric sulphate has not been established by experiment in which essentially pure natural covellite was used." Nevertheless, by an analysis of critical formulas[39] he evolves the equation

$$5CuS+3CuSO_4+4H_2O=4Cu_2S+4H_2SO_4$$

remarking that the establishment of this equation would be of noteworthy importance in the theory of chalcocite deposition. Since that time Zies, Allen, and Merwin[40] have estab-

[32] Weed, W. H., Enrichment of gold and silver veins: Am. Inst. Min. Eng. Trans., vol. 30, p. 429, 1901.

[33] Stokes, H. N., Experiments on the solution, transportation, and deposition of copper, silver, and gold: Econ. Geology, vol. 1, pp. 644–650, 1906. Wells, R. C., Discussion of secondary enrichment: Econ. Geology vol. 5, pp. 481–482, 1910.

[34] Stokes, H. N., Econ. Geology, vol. 1, p. 646, 1906.

[35] Vogt, J. H. L., Problems in the geology of ore deposits: Am. Inst. Min. Eng. Trans., vol. 31, p. 166, 1902.

[36] As intermediate between this equation and the one foregoing, the following reaction should be considered: $4H_2O+6CuSO_4+S=3CU_2SO_4+4H_2SO_4$. (See Stokes, H. N., op. cit., p. 44.)

[37] Stokes, H. N., op. cit., p. 22.

[38] Zies, E. G., Allen, E. T., and Merwin, H. E., Some reactions involved in secondary copper sulphide enrichment; Econ. Geology, vol. II, pp. 407–503, 1916.

[39] Spencer, A. C., op. cit., pp. 640–641.

[40] Zies, E. G., Allen, E. T., and Merwin, H. E., op. cit., p. 425.

lished this equation by refined chemical synthesis and analysis.

KAOLINIZATION.

Kaolin or halloysite is common in the mines at Tyrone. This alteration product occurs along strong fractures and fault fissures, in brecciated zones, and in anastomosing fractures in the porphyry and granite. It is found near the surface and in the deepest parts of the mines, beneath the zone of chalcocite enrichment. (See fig. 13.)

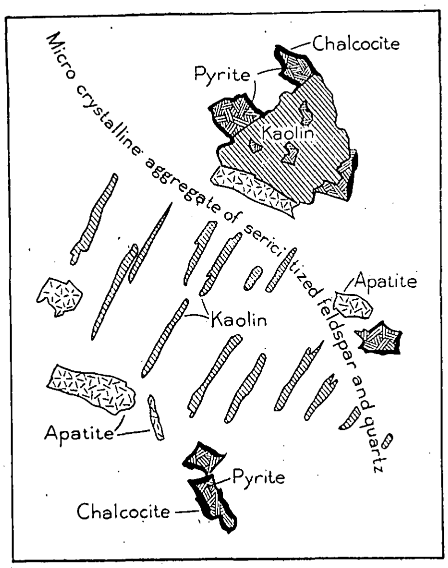


FIGURE 13.—Association of kaolin with chalcocitization of pyrite.

The form of the veins in which the kaolin is found at once suggests that this mineral is produced by the decomposition or metasomatic replacement of the porphyry and granite by descending acidified waters, and a further consideration of the nature of this chemical change suggests very strongly that fluorine, derived from the decomposition of sericite and fluorite, played a part in the transformation.

In places in the Breccia ore body vein systems of kaolin are without doubt formed by metasomatic replacement along what originally were minute fractures. The relations of the veinlets to the fragments of the breccia preclude the idea that movement has occurred along the walls of the veins. The fragments are not disturbed by the fractures. Moreover, the downward pointing of the smaller veins clearly indicates the direction of the movement of the waters that decomposed the porphyry. (See fig. 14.)

One feature connected with the formation of these kaolin veins deserves special consideration. It is the observed fact that quartz, even where present as noteworthy phenocrysts in porphyry or granite, yields ultimately, as well as the feldspar, to complete decomposition. At one place this change was observed with unusual clearness. Here a vein of kaolin between two small fractures merges at one end into porphyry, while in the opposite direction the kaolin-like product of decomposition is increasingly pure. Although the quartz was the last mineral to yield to decomposition, there was a considerable portion of the vein in which quartz was no longer present. (See fig. 15.)

In seeking to explain what was here clearly shown and what all the pure kaolin veins indicated, namely, that quartz suffered complete decomposition in the formation of kaolin, the possible agency of fluorine was invoked. As stated on page 26, the presence of fluorine in the sericite of the altered rock was proved;

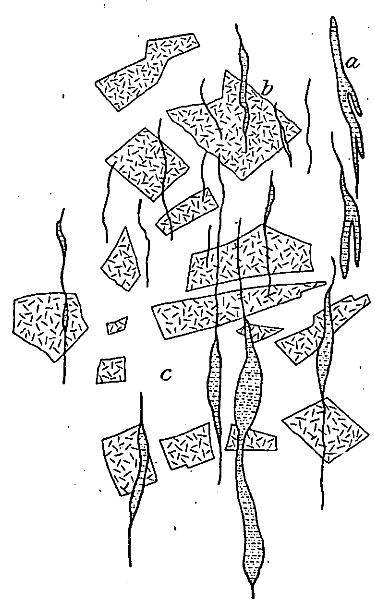


FIGURE 14.—Replacement of brecciated granite and porphyry (*b*) by kaolin veins (*a*). The relations indicate simple replacement without open fissure filling. *c*, Matrix of breccia.

and the mineral fluorite occurs in veins in the district and probably was generally present in minute veinlets in the altered porphyry.

Thus a vein known as the "fluorite vein" occurs about 160 feet north of the old No. 1 shaft of the Chemung Copper Co. The fluorite is several feet in thickness and may be traced 100 feet or more. Just above the Thompson shaft in Big Murry Gulch there is a vein carrying 6 or 8 inches of fluorite. These two occurrences indicate that fluorite may well have been abundantly deposited as a primary vein mineral, for though it was not noted in other places, this apparent scarcity is due to the reactions which theoretically should occur between fluorite and the descending acid waters of the zone of oxidation: fluorite would be removed. Fluorite is decomposed by sulphuric acid, with the formation of calcium sulphate ($CaSO_4$) and hydrogen fluoride (HF), and hydrogen fluoride unites readily with silica to form water and silicon tetrafluoride (SiF_4), a gas soluble in water. Silica would thus be attacked and carried off. It is known that

$$
\begin{array}{l}
SiF_4 + 4H_2O = Si(OH)_4 + (4HF) \\
(4HF) + 2SiF_4 = 2H_2SiF_6 \\
\hline
3SiF_4 + 4H_2O = Si(OH)_4 + 2H_2SiF_6
\end{array}
$$

Thus silicon hydroxide and hydrofluosilicic acid are formed. The latter compound is stable only in water and is inert so far as attacking quartz is concerned. In the rocks under discussion here it would probably form alkaline salts. On evaporation of the water, however, silicon tetrafluoride (SiF_4) would again be formed and the more or less insoluble alkaline salts would be deposited. Whether the silicon tetrafluoride (SiF_4) set free would on recombining with water again produce the active agent hydrogen fluoride (HF) is not known. More probably the process outlined above would be repeated, a certain portion of silicon hydroxide ($Si(OH)_4$) being deposited and the inert hydrofluosilicic acid (H_2SiF_6) going again into solution, to combine again with alkaline bases.

Now, the alteration of sericite to kaolin has been observed and recorded by many investigators. Nevertheless, sericite is a very stable mineral, probably quite as stable as the alkaline salts formed by the evaporation of hydrofluosilicic acid. But it is to be expected that these salts will yield to decomposition by acidified waters, like sericite, and there is reason to believe that fluorine will be again and again set free, so long as sulphuric acid waters are operating.

Thus the mass of sericitized porphyry, originally perhaps containing veinlets of fluorite, yields fluorine from two sources—from sericite and from fluorite—and this potent agent no doubt was active in the formation of kaolin. Considered from this angle, the heavy "gouges" of kaolin-like material developed along large fractures are probably due in part to this process, for they were main channels of circulation, where the accumulated effects of fluorine concentration would be accentuated.

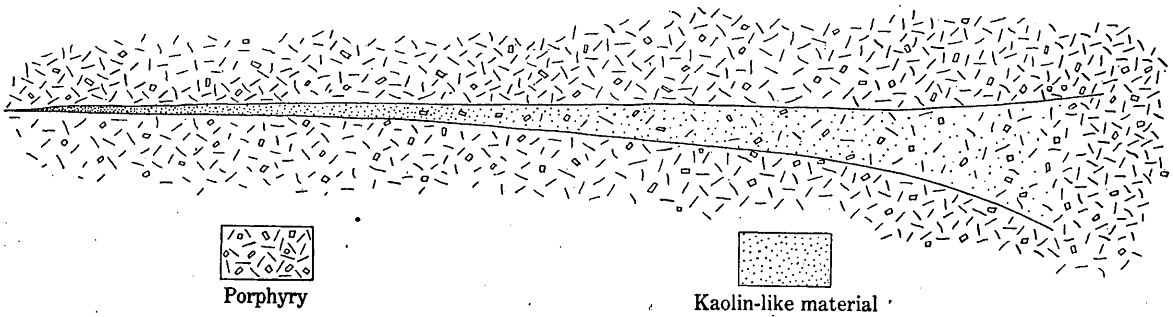


FIGURE 15.—Transition from porphyry to kaolin-like material in replacement vein of kaolin. Quartz phenocrysts survive the process of replacement the longest.

That sulphate waters played a part in this formation of kaolin is rather clearly indicated in a specimen of halloysite from the main tunnel (Burro Mountain Copper Co.), about 700 feet from the portal. Under the microscope this smooth, waxy green material reveals an isotropic mineral with an index of refraction of 1.527 (that of halloysite), and within this material in certain areas are myriads of tiny hexagonal crystals, each containing at its center a minute yellow grain. The crystals as a whole have positive elongation and are optically negative. Their index is about 1.59. These facts suggest that they are one of the jarosite series (sulphates of potassium and iron).

LEACHING.

The process of enrichment where ground-water level was stationary would theoretically result in the accumulation of all copper in a relatively thin chalcocite zone adjacent to ground-water level, extending from a position above this level to a certain distance below it.

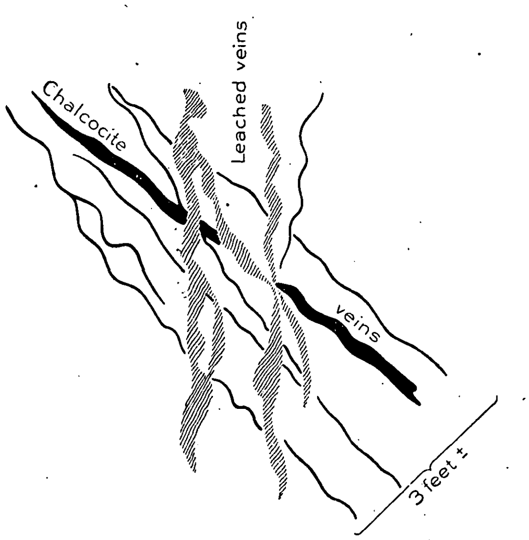


FIGURE 16.—Leaching of eastward-dipping chalcocite veins along later vertical veins carrying limonite.

Theoretical conditions, however, seem to be seldom if ever realized, and changes of water level upset the orderly deposition of chalcocite. Such has been the case at Tyrone, and as a consequence, in certain places, where formerly enriched sulphides were present there exist to-day only thoroughly oxidized bodies of rock impregnated and veined with iron oxide. (See fig. 16.)

The copper leached from these zones might under favorable conditions be recoverable below, but the facts at Tyrone do not justify hopes of such a recovery. As has been pointed out, there probably existed in the past a stage when ground-water level stood far below its present position, and it was presumably during this stage that considerable amounts of copper were removed from bodies of rock in which it had previously accumulated as chalcocite. The level of ground water was so deep during this stage of leaching that instead of concentration at definite levels there is reason to believe that copper may have been dispersed.

At the present time, when the water table is occupying a very definite level, it is difficult to escape the conviction that all copper that is being leached above the ground-water level is being redeposited somewhere above or just below this level; but there is no evidence in the mines that sufficient time has elapsed to permit any notable concentration at this present level of ground water.

In developing the mines, therefore, in search of new ore bodies, it becomes of first importance to discover criteria whereby the presence of bodies of chalcocite may be predicted, or at least whereby zones in which chalcocite is likely to occur may be distinguished from zones which are almost certainly barren.

Is there a difference to be noted in the leaching of chalcocite as contrasted with that of pyrite? Though it is not certain that such a distinction may always be made, the writer observed at several places in the Tyrone mines that, at least in the early stages, leached ground in which, there was every reason to believe, chalcocite had once been present was red, as contrasted with brown where only pyrite had been present.

In figure 17 the conditions in drift 48 on the fourth level (Burro Mountain Copper Co.) are illustrated. The drift is opened in pyritized porphyry, everywhere somewhat enriched by the deposition of chalcocite. Where leaching has taken place it has left a red stain. The encroachment of the leached zones upon the chalcocite zone is guided, as nearly everywhere, by prominent fractures. The area of strong red color at this particular place is preceded by an area colored to a lesser degree. Assays of the red material indicated that it still contained some copper, and it seems highly probable that disseminated cuprite in minute quantities accounts for both the red color and the copper content. Theoretically, further leaching would produce the common brown coloring of iron oxide. Although there is some justification, therefore, in using this

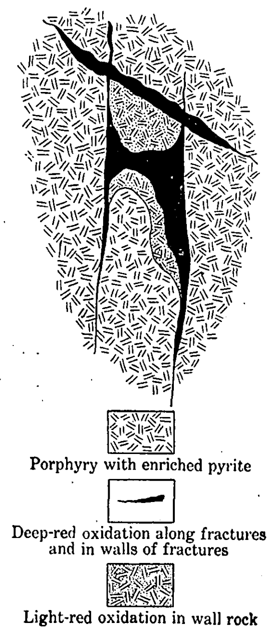


FIGURE 17.—Occurrence of red oxidation products (carrying cuprite) after chalcocite along fissures and impregnating wall rock.

red color as an indicator of the proximity of chalcocite, it must be considered only together with other known factors, such as the position of primary pyrite, zones of fracturing, leached zones, developed ore bodies, and all other data ascertainable from the developed portions of the mine, that might be used in intelligent exploration. It would serve no useful purpose to describe in detail the distribution of bodies of leached rock. Those exploring the mines are in possession of all such information. In general the positions of such leached zones are unpredictable. It is a characteristic of the ore bodies in this district that the value of the ore in a particular block is in many places impaired or strictly outlined by such leached zones.

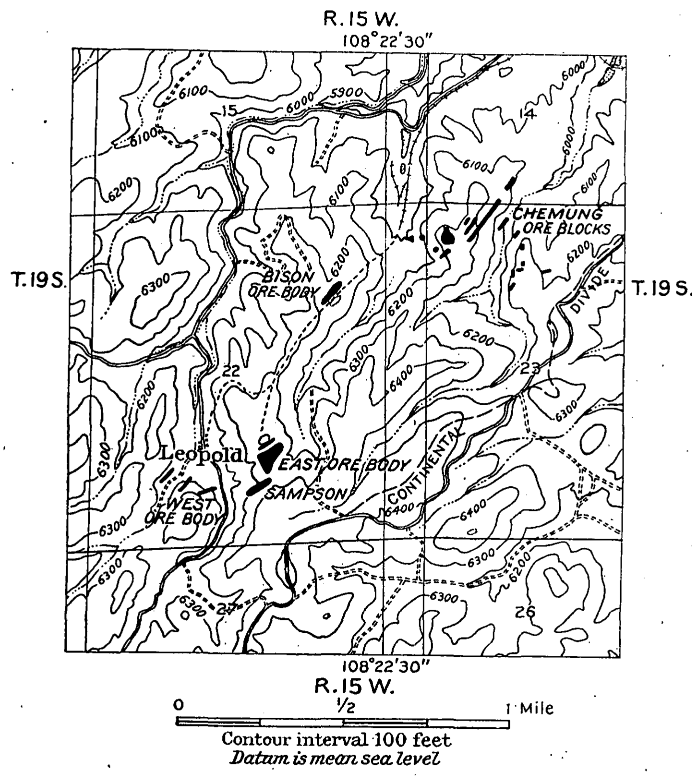


FIGURE 18.—Map showing the approximate position and form of the principal ore bodies of the Burro Mountain Copper Co.

THE ORE BODIES.

A description of the copper ore bodies of the Tyrone district is essentially a description of the properties of the Burro Mountain Copper Co. Since the field examinations were made this company has acquired the properties of the Savannah Copper Co. and thus practically all the developed ore bodies within the main fracture zone.

Of the developed ore bodies, or those which have been worked to some extent within the main fracture zone, two major groups may be recognized, and a number of less importance. One of the two major groups comprises the deposits of the old Burro Mountain Copper Co. adjacent to Leopold, among which are the East ore body, the Sampson ore body, and a number of minor deposits. The second group includes the deposits of the old Chemung Copper Co. adjacent to Tyrone, among which are a number of more or less distinct veins and blocks of ore. The positions of these several deposits projected to the surface are shown in figure 18, and the system of mine workings by which they are connected and are being developed is shown on the successive composite level maps in Plates VII–IX (in pocket).

Of the deposits which have been more or less developed but which up to the present time have proved less valuable are the several veins on the property formerly belonging to the Savannah Copper Co. but now acquired by the Burro Mountain Copper Co. These deposits are in five groups —the Oquawka and Boone mines, on the south; the Klondike mine, nearer Leopold; the workings on the Old Virginia claim; the Copper Gulf mine; and the workings about the Gettysburg and Parrot claims, about 1½ miles east of Leopold. (See Pl. VI.)

In addition to the properties mentioned, there are numerous prospects both within and outside the main fracture zone and some deposits developed by drilling which may prove in the future of economic importance.

The engineers and geologists of the Burro Mountain and Savannah companies had made before 1915 a very thorough examination of their properties by underground exploration and by drilling. Their examinations included systematic sampling of the deposits. As the shape of a chalcocite ore body is regulated by the tenor of the ore, and as its form may vary with the shifting price of copper, the descriptions in the present report are based on data supplied by the companies, particularly the Burro Mountain Copper Co., supplemented by studies by the writer.

With the exception of the East ore body, the mines adjacent to Leopold were practically inaccessible, and the lower levels of the mines adjacent to Tyrone were flooded at the time of this study. Descriptions of these workings must therefore be quoted.

MINES NEAR TYRONE.

The mines near Tyrone are developed by two shafts, Nos. 2 and 3, in Niagara Gulch. (See Pl. II, in pocket.) They open an extensive network of drives and crosscuts, illustrated in Plates VII–IX.

A third shaft, 1,500 feet to the west, does not connect with these workings or develop any considerable body of ore.

There are five levels in No. 2 shaft and six in No. 3. These levels are not evenly spaced, nor, with the exception of level No. 4, do they correspond in the two shafts. Level No. 4, however, is continuous throughout the workings adjacent to both shafts.

The relative positions of the ore bodies near Tyrone are shown in figure 19. The coordinates used in figures 19–21, 23–29 and Plate X are the same as those used on the company's maps.

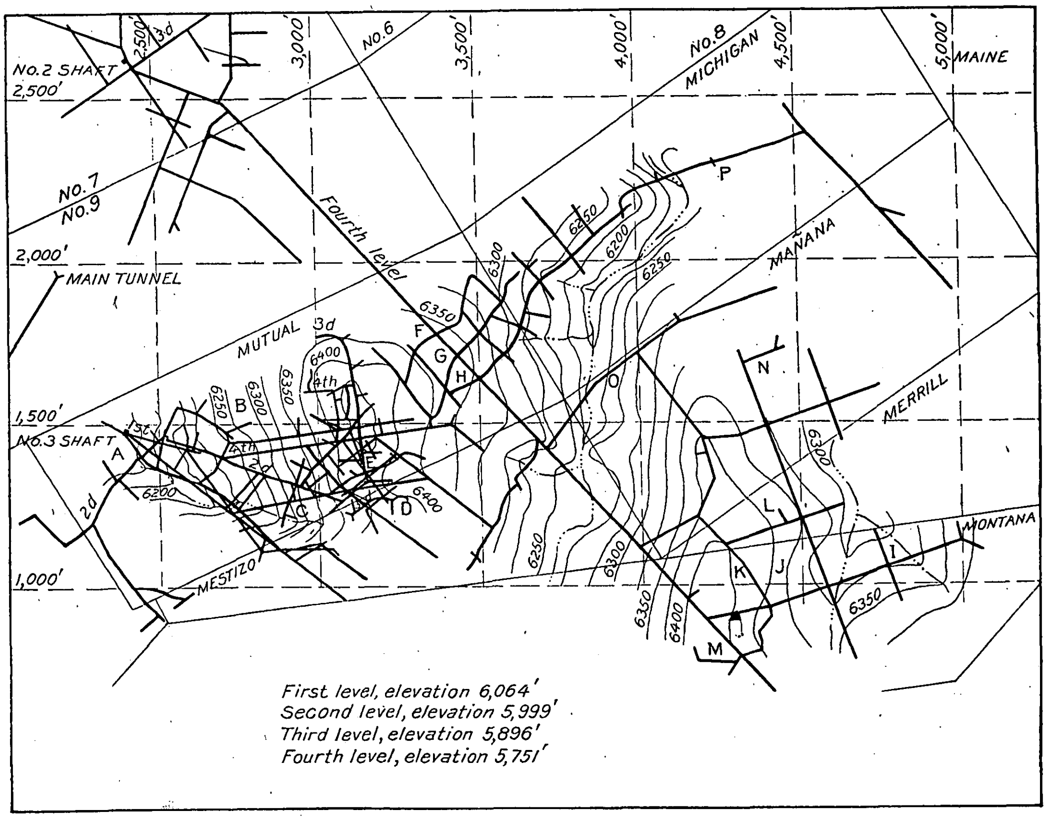


FIGURE 19.—Key map of the ore bodies near Tyrone.

Block A.—The block of ore designated block A (fig. 20) extends from a few feet above the 100 level of No. 3 shaft to a sublevel below the 200 level. The mass pitches eastward from the shaft, which it surrounds, at an angle of about 20°. It widens between the 100 and 200 levels and pinches below the 200 level. If the cross sections, as determined on the several levels by assays, are used as a basis for constructing a solid figure, the resulting mass is somewhat sphenoidal in form, being bounded by surfaces of either roughly rhombic or triangular outline, its upper western and lower eastern limits being determined by the intersection of such planes. The mass is therefore thickest at the center and narrows both upward and downward. The under side of this figure is roughly determined by a major fracture trending northwest and dipping at a rather low angle to the southeast. (See fig. 20.) In seeking to explain the particular form of this ore body it must be borne in mind, first, that its boundaries are determined by a definite percentage of copper. If a different percentage were used as a basis, a somewhat different shape would result. It should also be borne in mind that the percentage of copper in the rock may vary for several reasons—differences in primary mineralization, differences in enrichment, and differences in leaching or impoverishment.

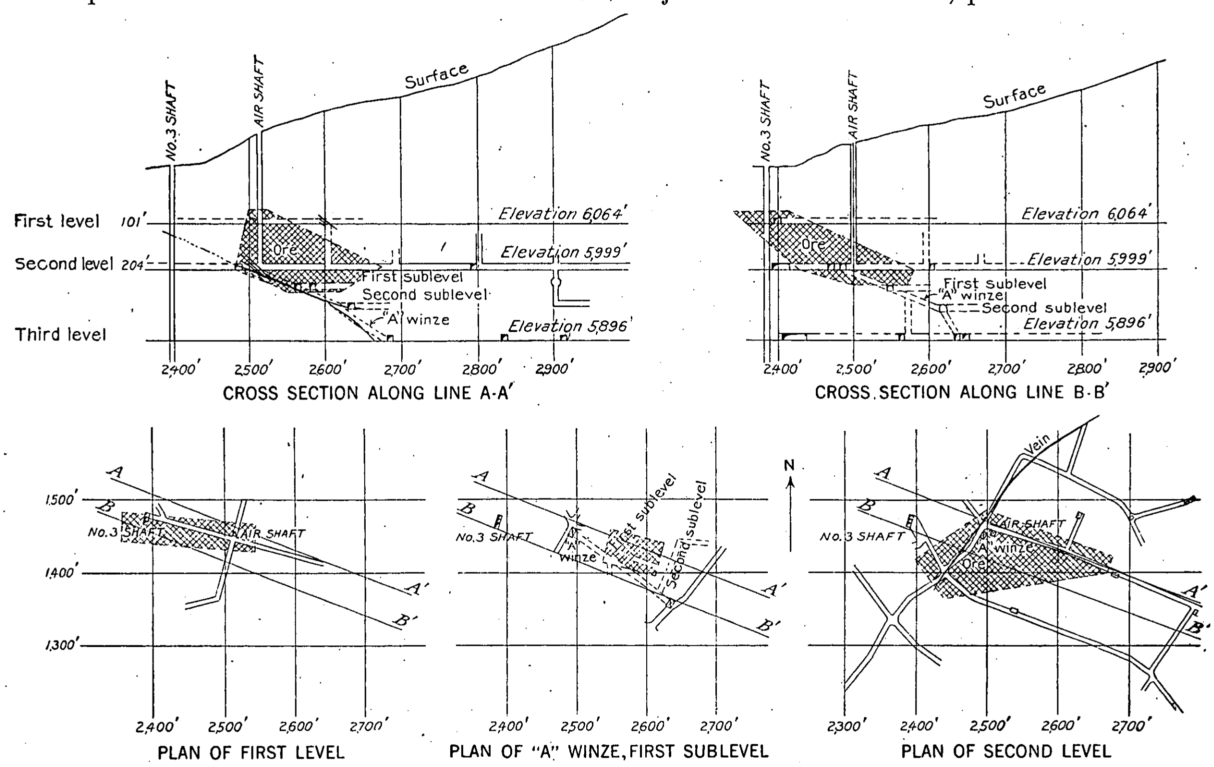


FIGURE 20.—Plans and cross sections of block A.

With these facts in mind, it is possible to point out some features that probably controlled the position of this ore body. Its base apparently conforms closely with an extensive fracture plane. Descending waters, on reaching this plane, were deflected down the dip, forming a channel along which enrichment took place. The lower limit of enrichment determines to-day the lower limit of ore. Essentially primary pyrite has been reached. To the southwest and northeast on the 200 level along this main fracture the ore terminates against leached ground. This condition also affects part of the footwall rock. In seeking a reason for the limitation of ore on the south side of this block on the 200 level, two facts are significant. First, the ore terminates in both drift 29 and drift 4 against a porphyry dike; second, the pyrite at these points is not sufficiently enriched to produce ore. This dike, therefore, may have acted as a bar to active circulation and enrichment. On the north side of the ore body leaching seems to be responsible for the lack of copper.

Therefore, although the ore in this block is dependent in a measure on the position of a major fracture and a dike, portions of the ore body along the major fracture, in the hanging-wall country rock, and along the north side of the body have been impoverished by leaching. The lower limits of the ore are determined by primary pyrite.

A small body of ore developed between 2-raise 3 and 2-raise 10 is apparently a part of this ore body, but leaching has reduced its volume and cut it off from the main body.

Block B.—Block B is a thin blanket of ore, about 20 feet thick, lying above and below the second level about 500 feet southeast of No. 3 shaft. This ore body is connected with a rather prominent flat vein. Beneath the ore body, on the third level, there is considerable primary pyrite, and it is doubtful if the ore ever extended to this depth. (See fig. 21.)

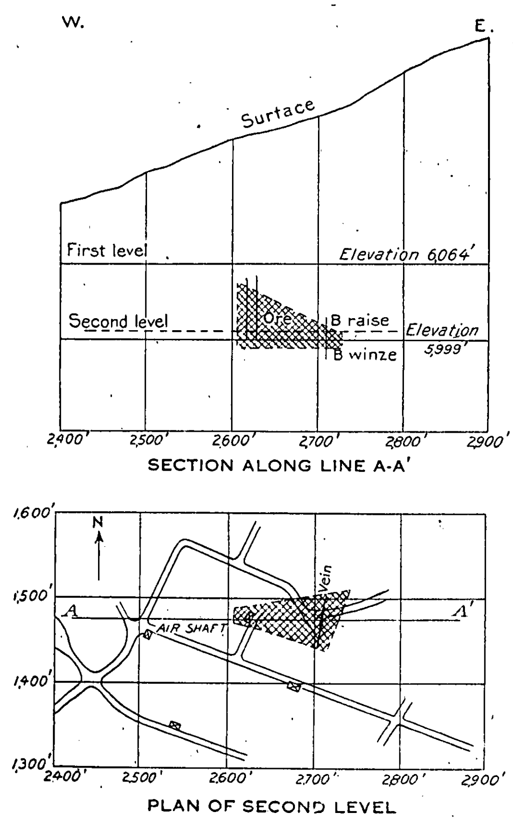


FIGURE 21.—Plan and cross section of block B.

Of special note is the leaching which limits this ore body on all sides. This is particularly well illustrated in 2-drift 4, west of drift 17, where flat-lying chalcocite veinlets are cut by vertical barren seams and veinlets. In places the leaching spreads horizontally along the chalcocite veinlets. (See fig. 22.)

It is reasonable to suppose that this blanket of ore once extended much farther laterally. Its destruction has probably been accelerated by the canyon cutting which affects the old plain cut in rock bordering the desert, though it may have begun at a much earlier date.

Just east of this ore block there is a body of ore following a strong vein that trends N. 60° E. and dips 45°–50° SE. The chalcocite occurs both in the walls and in the vein proper. This ore body descends to a point below the third level and near sublevel B. The extension of the ore along the vein is terminated to the northeast and to the southwest by leaching—that is, descending surface waters have impoverished the vein. At the south end of sublevel B there is a rather strong fissure, probably the downward continuation of this vein; but at this level primary pyrite is exposed. Enrichment never descended to this point. This vein on the third level is joined by a parallel vein of lower dip, and considerable brecciation is evident at the northeast end in drift 26. Decided postmineral movement is indicated by broken mineralized fragments. The structural importance of this vein lies in its relation to the block of ground beneath or west of it. The vein appears to form a hanging wall of what was once an extensive block of enriched ground.

Breccia ore body.—The Breccia ore body is about 750 feet east of shaft No. 3 and extends from a point 10 feet above the third level to a point 100 feet or more below the third level. (See fig. 23.)

The ore occurs within a mass of brecciated country rock—granite and intruded porphyry dikes. On the third level and sublevel B the ore is almost coextensive with the breccia, but lower down the breccia, though heavily mineralized, is not enriched.

In the section on fracturing (pp. 18–19) the origin of this breccia is discussed. Attention will be directed here to certain major lines of fissuring that may be related to the breccia.

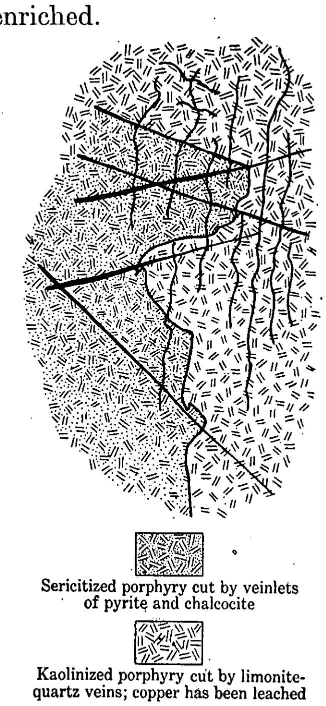


FIGURE 22.—Leaching of chalcocite veinlets and wall rock.

On the second level there is a strong vein following drift 28 which is recognized as the footwall of the ore bodies east of it. This line of disturbance may be recognized in somewhat equivalent fractures on the third level just west of drift 25, and there is a suggestion here that the northeast continuation of this system cuts drift 16 between drift 29 and drift 22. In this connection it is of interest that the Breccia body terminates at this place—that is, just south of drift 29—where also it is in

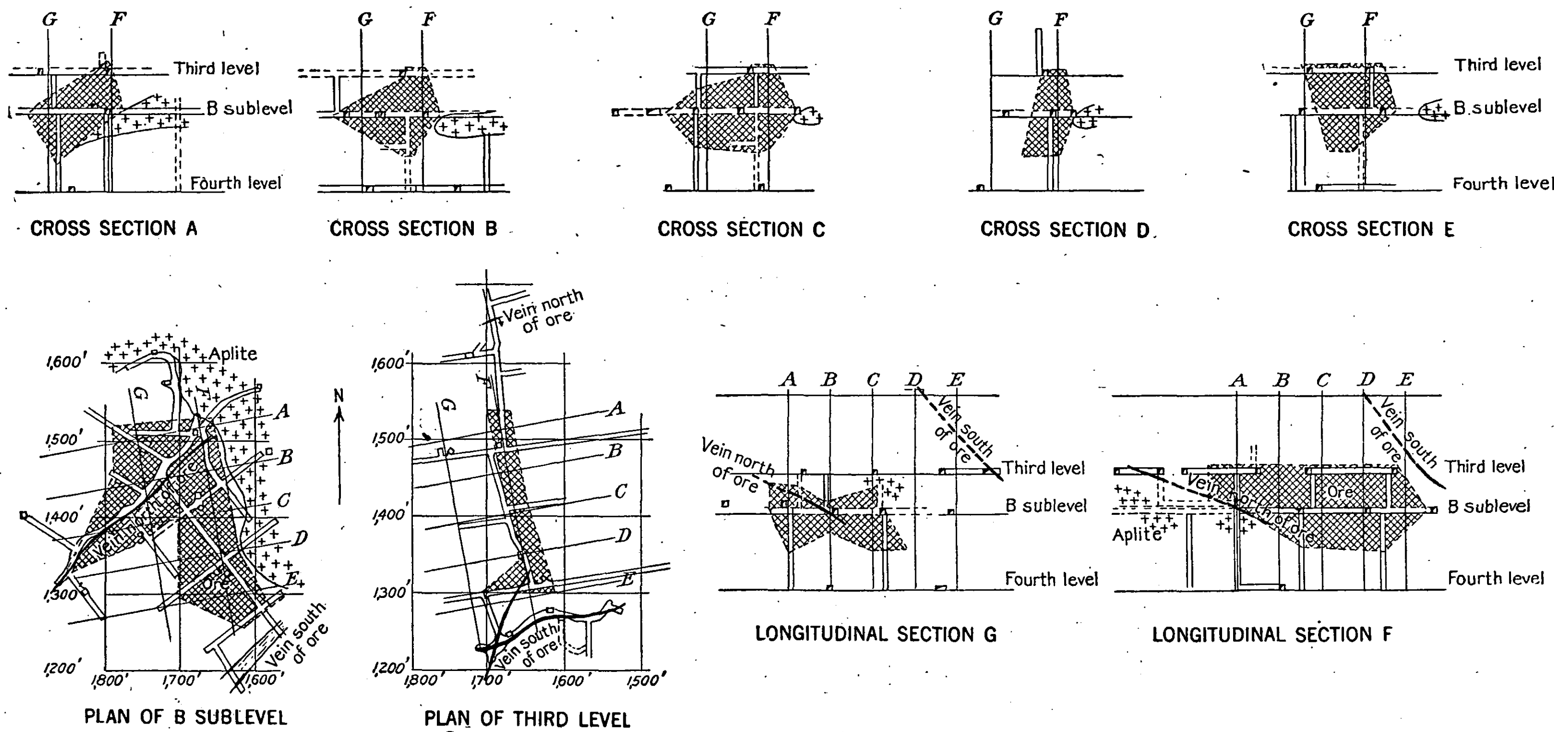


FIGURE 23.—Plans and cross sections of Breccia ore body.

contact with a dike of considerable size exposed in the drift to the north. This fracture system therefore is a footwall boundary for all this is more breccia to the north, or in the footwall; and lower down, on the fourth level, this condition is more noticeable, for the north

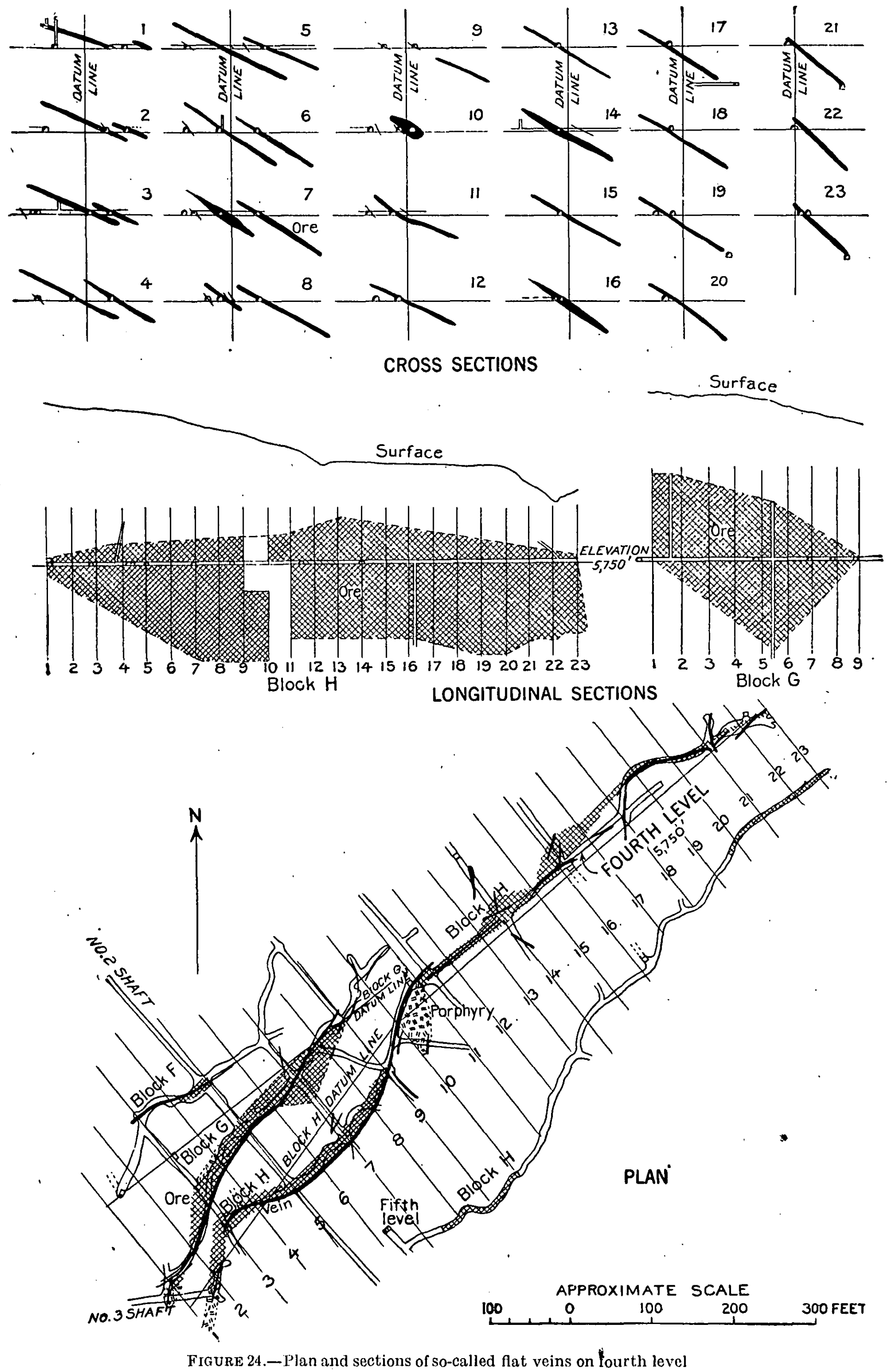


FIGURE 24.—Plan and sections of so-called flat veins on fourth level

mineralized ground. On sublevel B a strong fissure traverses the breccia near its northern limit and may well belong to this same system or region of crushing. Here, however, there extension of the breccia lies north of the point where this fracture system should appear.

A second important fracture system is noticed first on level No. 2 as a hanging-wall feature. Beneath it and between it and the footwall system just mentioned are all the ores on this level. On the third level it appears as a prominent vein system overlying the Breccia ore body. On sublevel B the workings do not reach it, but on the fourth level its downward continuation may be recognized with considerable certainty, and here it corresponds to the south end of the brecciated country rock. From these facts it would appear that the Breccia body, though following a line of dislocation nearly at right angles to the prevailing strong fissures in this vicinity, is contained within a block limited by two very prominent zones of movement. As suggested above, this broken piece of ground probably resulted from collapse connected with distention of the crust during intrusion.

Veins on fourth level.—Three veins are developed on the fourth level. (See fig. 24.) They constitute roughly parallel ore bodies of considerable importance. The northwest vein (footwall vein) strikes N. 60° E. and dips about 30° SE. The middle vein and the southeast vein (hanging-wall vein) strike on the average about N. 40° E. and dip about 40° SE. The plane of these two veins is a warped surface, and their strike therefore varies from place to place.

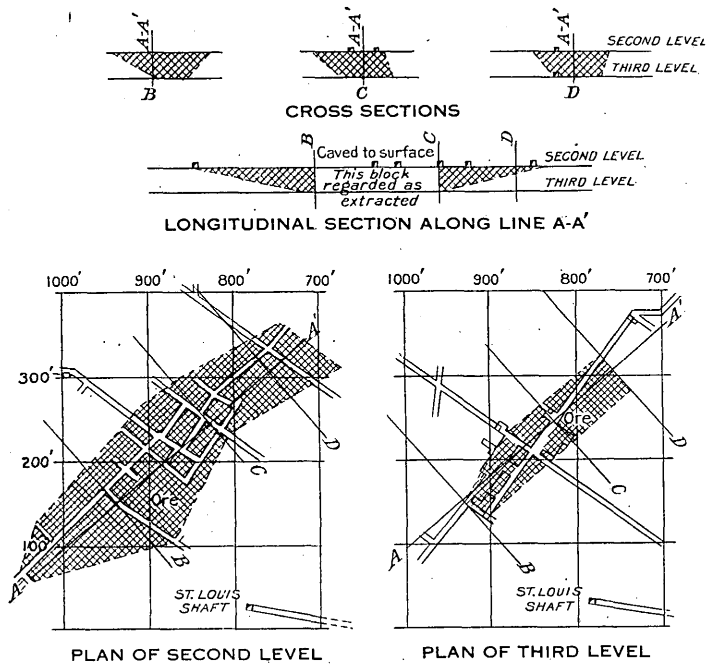


FIGURE 25.—Plans and sections of Protection ore body.

As in all other parts of these mines, a fissure is not formed by a simple break but involves numerous anastomosing veins. The vein systems are simply places where the greatest movement has taken place within blocks of thoroughly shattered ground.

Between the eastern (hanging-wall) and middle vein the rock is sufficiently impregnated with chalcocite to make ore. The quantity of ore ultimately extracted will depend on the price of copper. In many of the workings on the fourth level in the vicinity of these veins primary pyrite, scarcely or not at all enriched, is common. Obviously on veins enrichment descends deeper than in the less fractured wall rocks. Oxidation, which is a later feature, is attacking the unenriched pyrite, as well as the veins, a fact which supports the view expressed above that present conditions of oxidation in these deposits are radically different from those existing when the chalcocite was formed. The erosion and canyon cutting now in progress are permitting the surface waters to remove chalcocite.

Other bodies.—East of these three veins are a number of isolated occurrences of ore, seven in all, connected for the most part with prominent fractures. Their location is indicated on figure 18 (p. 40). Also 300 feet east of shaft No. 2, on the fourth level, and 500 feet S. 10° E. from the shaft, are small bodies of ore in brecciated granite. There is nothing unusual in their occurrence, and they will not be further mentioned. The possibilities for development of additional ore are discussed below (p. 51).

MINES NEAR LEOPOLD.

With the exception of the East ore body, the deposits near Leopold were practically inaccessible in 1915, and the following descriptions are taken from a report on the properties by E. F. Pelton.

Protection.—The Protection ore body (fig. 25) is 900 feet N. 75° W. from the Sampson shaft, between the second and third levels.

It is about 400 feet long and from 50 to 80 feet wide. A part of its central portion has been extracted. It is evident from the plans of the second and third levels that the size of the deposits decreases in depth, and that probably little ore will be developed below the third level. Exploration to the northeast and southwest, however, may discover more ore.

St. Louis.—The St. Louis ore body (fig. 26) is a small deposit 600 feet N. 75° W. from the Sampson shaft, between the second and third levels. The ore follows a strong N. 60° E. vein that dips 40° SE. It is lean below the third level.

West.—The West ore body (fig. 27) is part of the pillar of the Sampson shaft. It extends westward about 750 feet between the first and fourth levels. What remains of the ore body consist of scattered blocks left from previous square-set stoping. About 75 per cent of the ore is now below the third level. The West ore body follows a strong N. 70° E. footwall vein dipping 30°–45° SE. The width and good grade of the stopes are partly accounted for by intersection with a N. 20° W. system of fractures.

Sampson.—The Sampson ore body (fig. 28) is 400 to 800 feet east of the Sampson shaft, between the tailing tunnel and the fourth level. It now consists of scattered blocks left from previous stoping. About 75 per cent of the ore remaining lies in a fairly compact block toward the east end of the ore body. It is clear that this ore body also is connected with a system of fractures dipping southeastward.

East.—The East ore body (Pl. X) is 900 feet east of the Sampson shaft. It extends from the oxidized zone 25 feet above the second level to unenriched pyrite about 20 feet below the fifth level. It is an irregular block with a maximum thickness of 210 feet, overlain by about 225 feet of soft kaolinized barren porphyry. If it is like the Sampson and West ore bodies, there will be found at its top a gradation from good chalcocite ore to barren oxidized ground through a distance of about 14 feet.

The St. Louis vein,[41] which forms the northern footwall of this ore block, extends from the second level to a point 30 feet below the

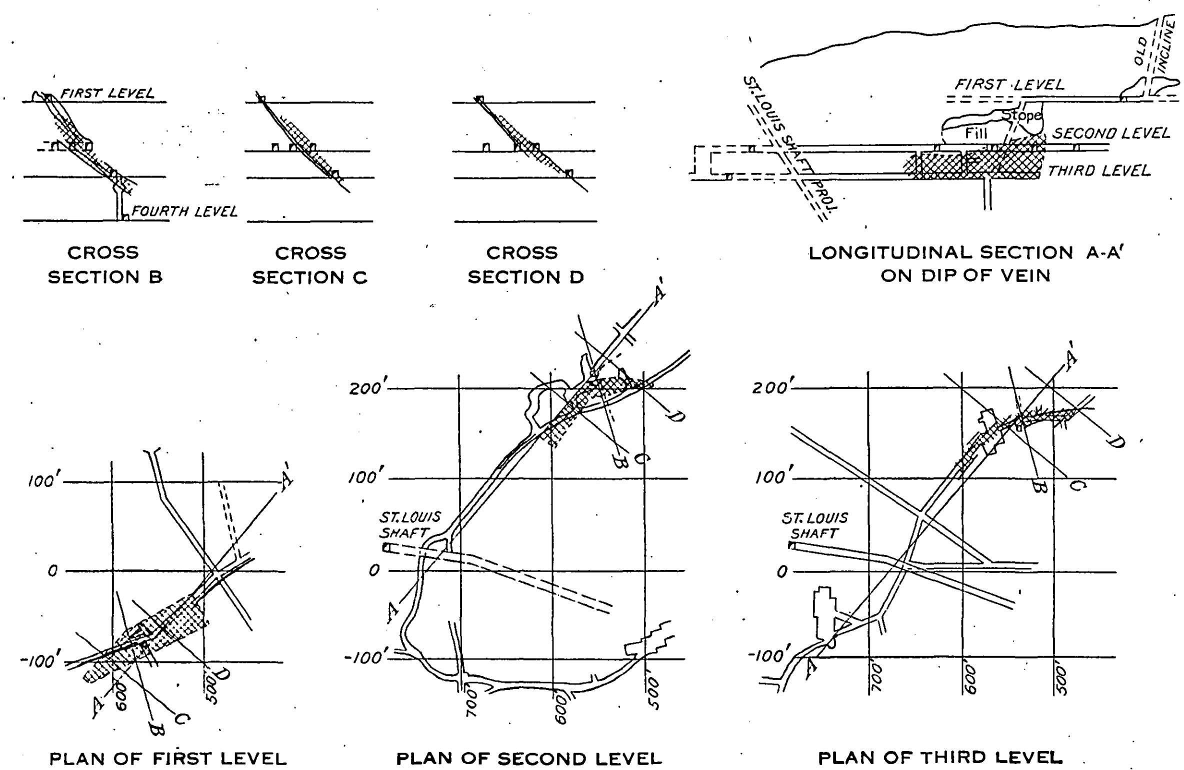


FIGURE 26.—Plans and sections of St. Louis ore body.

[41] Not to be confused with the St. Louis ore body, west of the Sampson shaft.

fifth level. The ore-bearing portion is about 200 feet long, 100 feet high, and in places 30 feet thick. It dips about 45° SE., and the pitch of the ore is about 23° NE. (See Pl. X.)

The northern boundary of this ore body follows the southeastward-dipping St. Louis The ore body is isolated and lies about 200 feet west of the main tunnel and about 1,500 feet southeast of the portal. There is no unusual feature about this ore body. A plan and cross section are given in figure 29, and the azimuth of the principal fractures in Plate IV (p. 16).

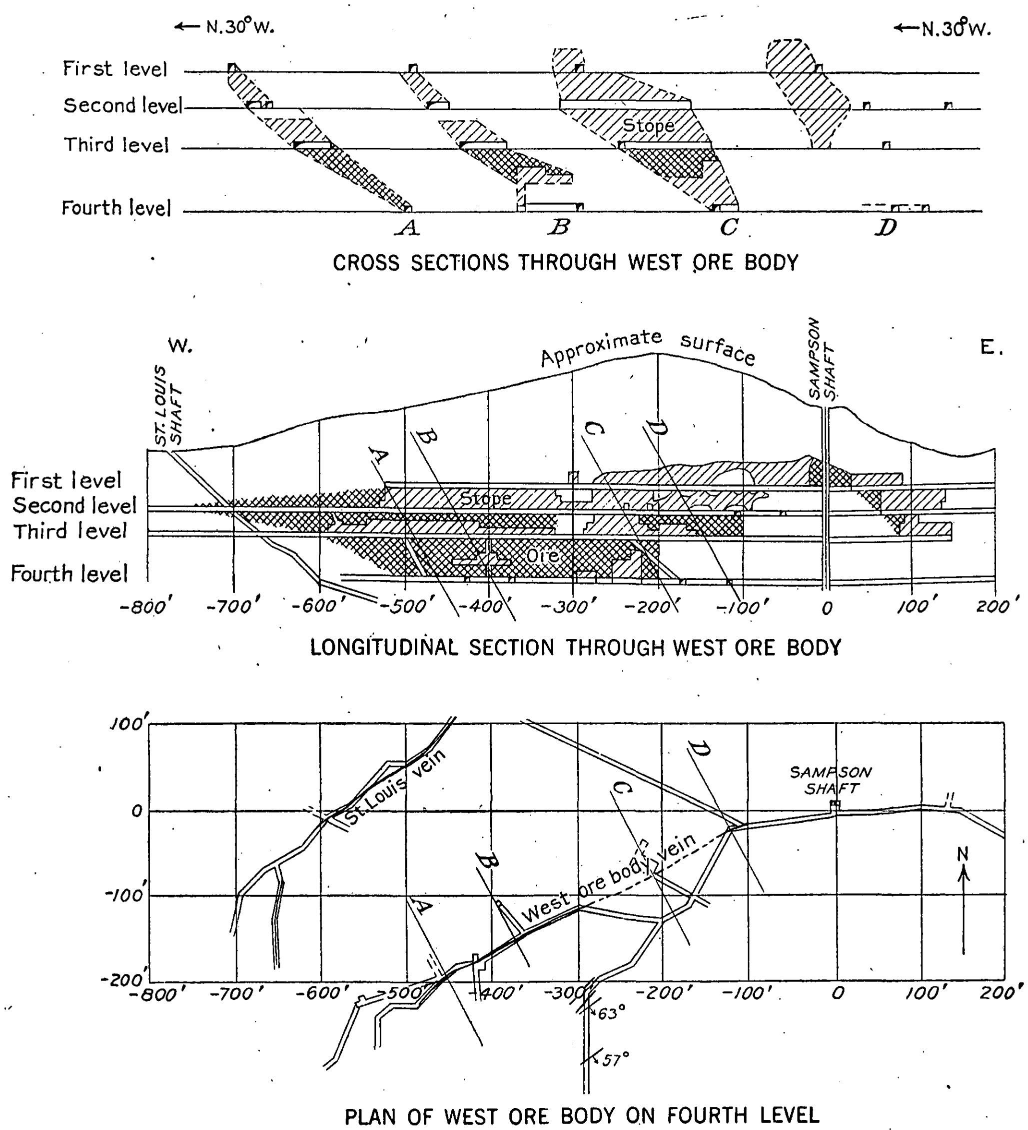


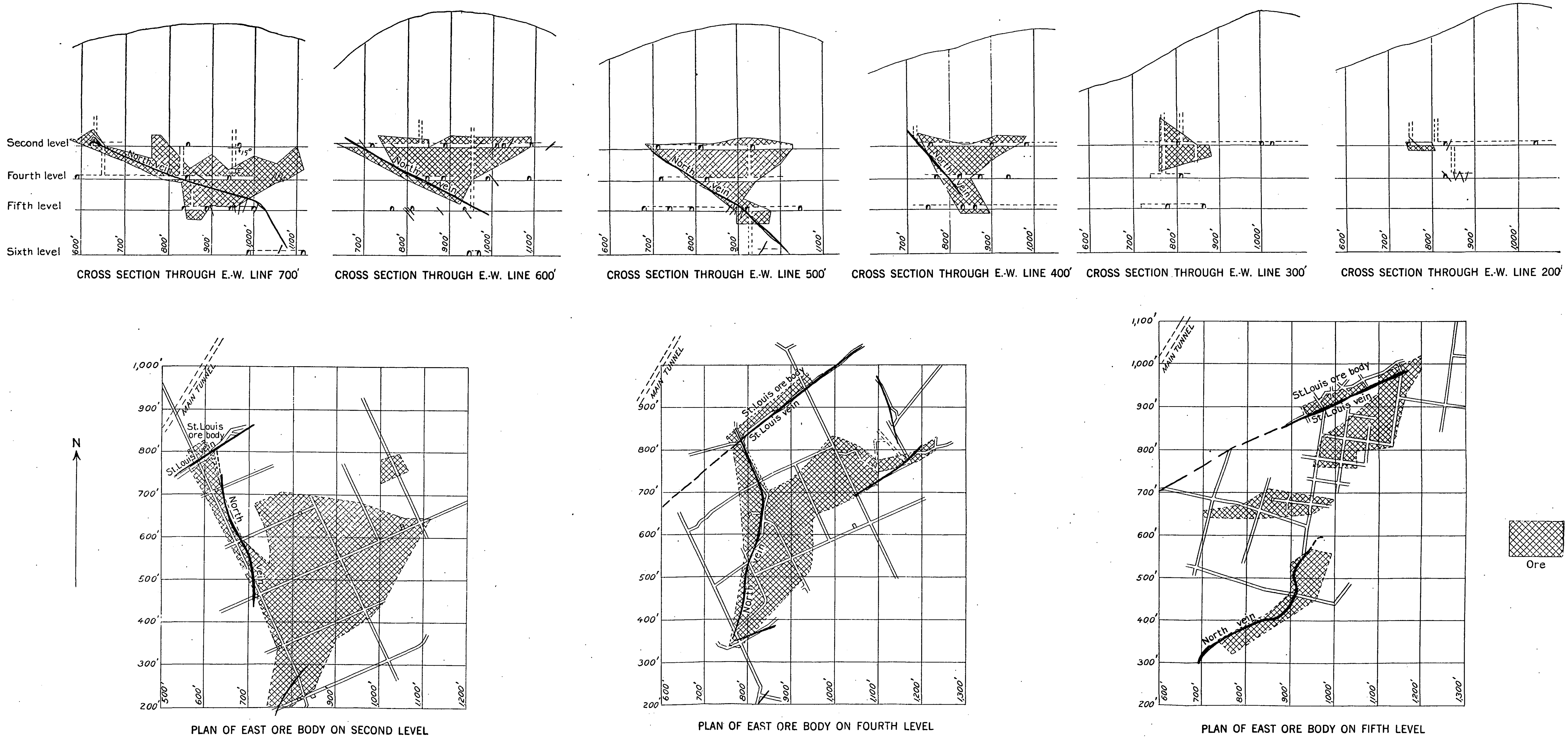
FIGURE 27.—Plan and sections of West ore body.

vein, and the western limb is defined by the North vein, which trends west of north and dips at a low angle to the east. These two systems determine the strong pitch of the ore body to the south and east.

Bison.—The Bison ore body is about 400 feet long, 60 feet wide, and 50 feet high. The country rock is granite with porphyry dikes.

OLD WORKINGS ON THE GROUND OF THE SAVANNAH COPPER CO.

On Plate VI (in pocket) is shown the location of a number of prospects or mines that are now no longer operated. The following notes are presented as a matter of record. It is doubtful if any of these prospects will be operated except when copper sells at a very high price.



PLANS AND SECTIONS OF EAST ORE BODY, TYRONE DISTRICT.

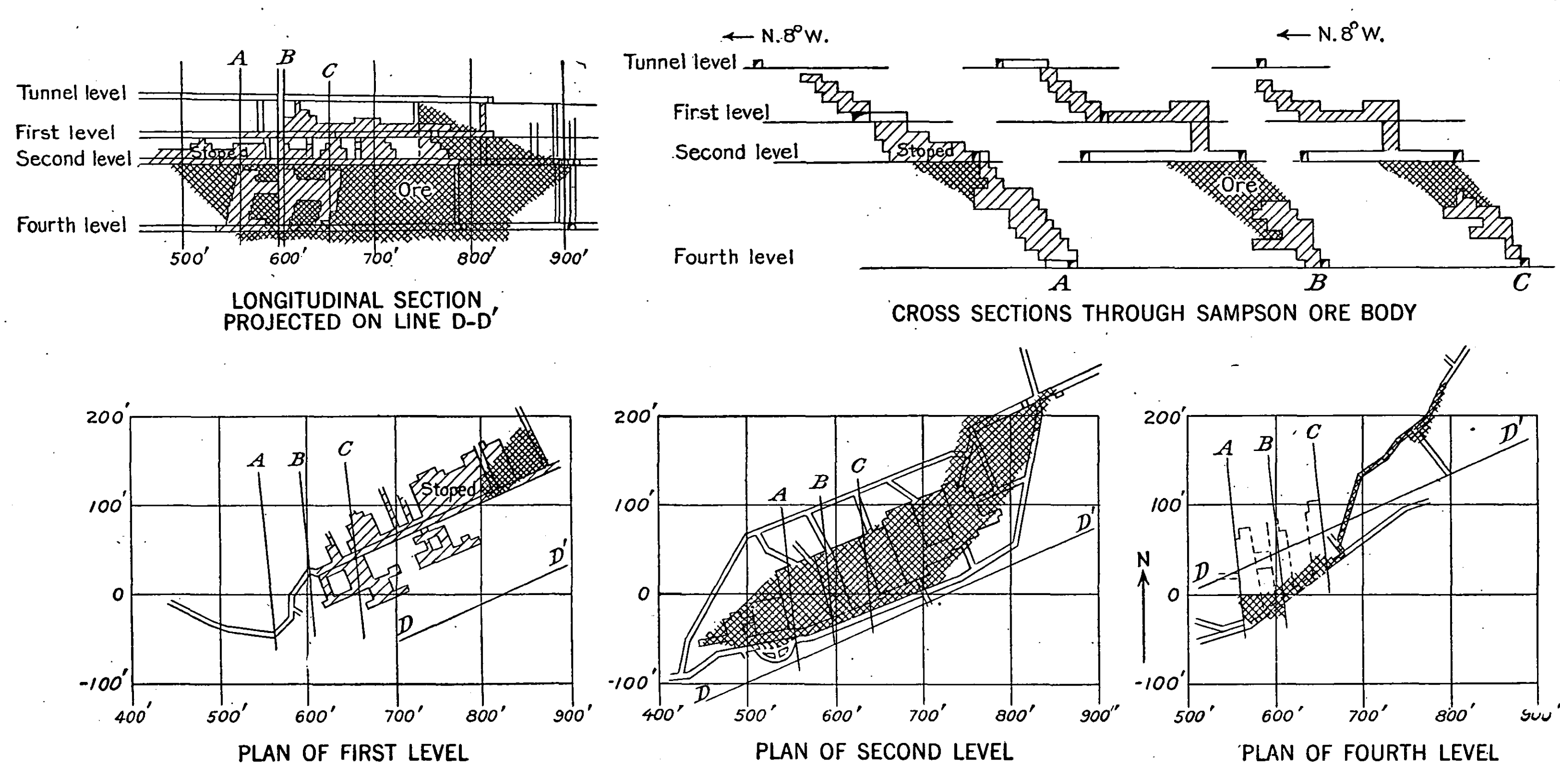


FIGURE 28.—Plans and sections of Sampson ore body.

At the Oquawka mine 300 to 400 tons of 4 per cent chalcocite occurred in a vein dipping 60° N. There was no ore at the 300-foot level. The tenor of the ore decreased in a 30-foot winze from the 200-foot level.

At the Boone prospect a north-south vein dips 80° E. Carbonate ore running as high as 30 per cent in copper was shipped, but the prospect did not turn out well.

At the Klondike mine a north-south vein has been mined to a depth of 60 or 70 feet, where primary pyrite was found.

At the Copper Gulf there is a vein carrying a little copper, with some oxidized ore at the surface.

TENOR OF THE ORE.

The minimum amount of copper in the rock necessary to constitute ore in the Tyrone district, as elsewhere, is determined by a balance between total costs of mining and the price of copper. In 1915 prospective tonnages had been calculated on three different bases, a minimum of 1.75, 2.00, and 2.25 per cent. At that time rock containing 2 per cent was considered ore. A considerable tonnage had been blocked out averaging 3.16 per cent, more than twice as much averaging 2.31 per cent, and these two amounts together averaged 2.58 per cent. By reducing the minimum to 1.75 per cent these tonnages were doubled. Just what percentage of copper the rock must contain to be considered ore will therefore depend on many factors, among which the price of copper is all-important.

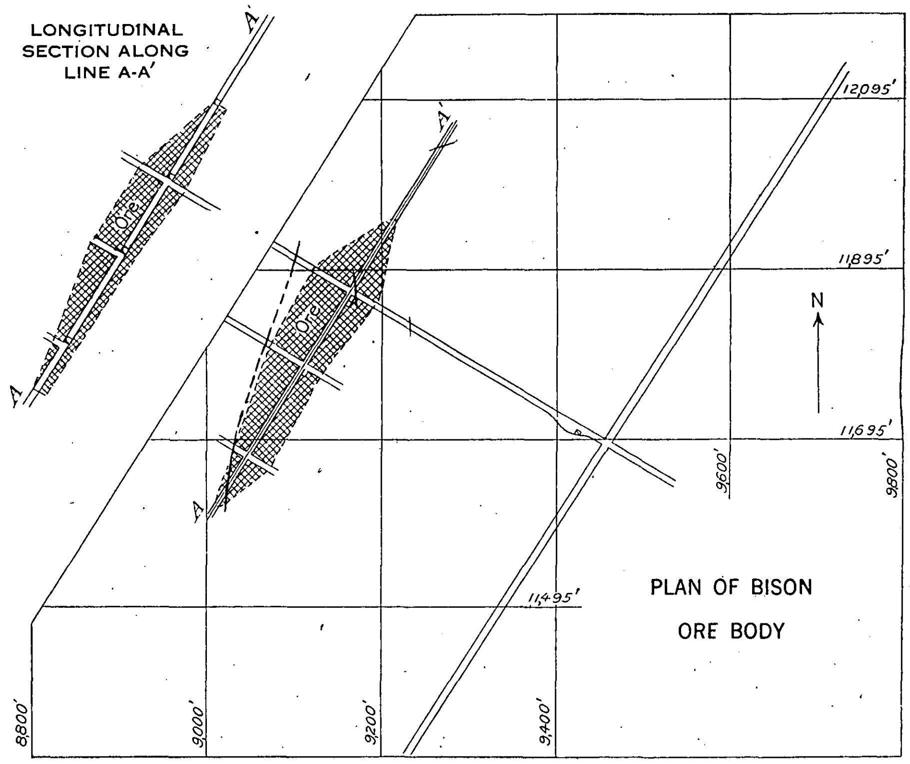


FIGURE 29.—Plan and section of Bison ore body.

At the Old Virginia workings an east-west vein dips 45° N. There are four or five levels. Water stands 25 feet below the collar of the shaft. The vein is stoped for a length of about 100 feet between the surface and the 100-foot level. The ore was carbonate and averaged better than 10 per cent of copper. The change to chalcocite takes place at about the 100-foot level.

The workings of the Gettysburg mine were not accessible. The shaft is an incline dipping south in the vein. There is a drift on the vein at a depth of 300 feet, but the prospects are not good. A little ore was found from the surface down to a depth of 60 feet.

PROSPECTS FOR ADDITIONAL ORE BODIES.

Exploration east of the developed territory, by drilling, has not been very encouraging. The physiographic history of the region points to a briefer period of enrichment to the east, under the gravels, than in the area to the west. Moreover, results of mining show that there is some lowering of grade of the ores progressively eastward, thus supporting the theoretical considerations.

Ore should be more plentiful under the hills than in the valley, there having been less impoverishment there by erosion and the accompanying leaching.

The fractured and altered rocks across the Mangas Valley may be intrusives of later age than the quartz monzonite porphyry at Tyrone, and this fact must be considered in speculating on the possibilities of ore in those rocks. If they are younger than the Tertiary lavas, then the prospect of finding ore in them is lessened, for nowhere in the Silver City region have commercial bodies of disseminated copper ore been found in these late intrusives. The intense alteration of these rocks, however, makes their character and age uncertain. Structural relations whereby a decision might be reached as to this point were not discovered. Such petrographic evidence as could be gleaned from studies made with a microscope indicates that the rocks represent a later period of intrusion.

Prospecting will probably then most profitably be confined to the principal zone of fracture, and within this zone to those portions of most intense fracture, under hills and in the general region between Leopold and Tyrone. The areas farther south, in the ground formerly controlled by the Savannah Copper Co., are in a measure already prospected by drill holes and shafts. That portion of this territory, under hills, which has not been prospected deserves at least a certain amount of preliminary drilling.

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