Economic Geology, v. 1, pp. 629-643

ECONOMIC GEOLOGY

WITH WHICH IS INCORPORATED

THE AMERICAN GEOLOGIST

VOL. I JULY–AUGUST, 1906 No. 7

LOS PILARES MINE, NACOZARI, MEXICO.

SAMUEL FRANKLIN EMMONS.

LOCATION AND GEOLOGY.

Seventy-five miles south of the International Boundary, in the Valley of the Moctezuma River, in Sonora, Mexico, lies the picturesquely situated town of Nacozari, which has grown up during the last six or seven years around the concentration works that dress the copper ores from the neighboring mine known as Los Pilares.

This mine, whose economic importance may be gauged by the fact that it has already produced over 600,000 tons of copper ore, is one of the many copper properties in the southwest owned and managed by the Phelps-Dodge & Company interests.

The present sketch is the result of a two days' examination of the mine made in November, 1905, when the writer was the guest of Mr. James Douglas, Jr., General Manager of the property, by whose courtesy he was given every facility for its study. Although he feels some hesitation in presenting in these pages the result of so brief an examination, it has, nevertheless, seemed to him that the facts ascertained with regard to the occurrence of the ore present sufficient novelty and interest to justify their publication in spite of the uncertainty that still obtains with regard to certain features of the general geology.

Like many parts of Mexico, the region is one in which the rocks are prevailingly igneous, and apparently of comparatively recent age. Thus, in the 75-mile railroad ride from Douglas, Arizona, to Nacozari, following up the Valley of the Fronteras River and down the narrow gorge of the Moctezuma, the only rocks whose character could be determined, were eruptive tuffs and breccias, generally showing bedded structure, and not very deeply eroded.

The town of Nacozari is situated on the west side of a small, deeply incised river valley surrounded by irregularly distributed hills that form part of the northern watershed of the Yaqui River, the most important river system of the State of Sonora. The only rocks of distinctly sedimentary origin visible from the town stand out in sharply curved outcrops on the face of a high ridge some miles to the northwest, their sedimentary character being indicated not only by the folds into which they are compressed, but also by the limekilns at the base of the outcrops.

Against the steep wall of the valley, opposite the town, are situated the concentration works from whose upper level runs a narrow gauge railway that connects them with the Los Pilares mine, about 5 miles to the southeast.

In frequent journeyings to and fro, on this railway, which winds in and out across the southward trending spurs and ravines in a bewildering series of zig-zags, it could be seen that these spurs are made up of an alternation of darker and lighter eruptive breccias and tuffs, the former generally showing some bedded structure. As the abrupt changes from one rock to another evidently mark fault rather than eruptive contacts no definite idea could be formed as to their relative age, though the general impression received here, and elsewhere, was that the lighter colored and more acid rocks were intrusive in, and hence later than, the darker.

The Los Pilares mine is situated on a northeast and southwest spur that runs athwart the end of the steam railway. The tracks of the latter, however, continue in a mile-long tunnel that runs nearly through the spur, and is operated by electric locomotives. At the further extremity of the tunnel is the main working shaft that rises vertically 600 feet, reaching the surface on the southeast slope of the spur known as Los Pilares Mountain. From this shaft levels run at 100-foot intervals into the various stopes of the mine, and ore chutes connect the different levels with great ore bins in the rock at the tunnel, or 700-foot level. As thus opened, the ore, once broken down in the stopes of the mine, is moved mechanically with a minimum of hand labor. From the ore bin in the mine it passes into the narrow-gauge cars which transport it to the ore bins at the concentrator, and after dressing, the concentrates pass into standard gauge cars to be transmitted to the ore beds of the great smelter at Douglas, Arizona.

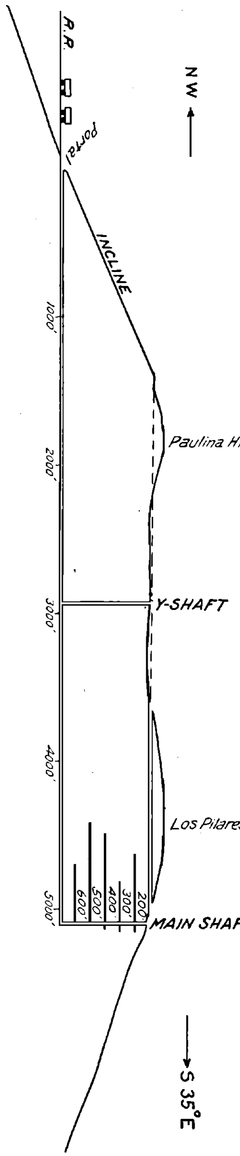

Fig. 44. Profile of Los Pilares Ridge on plane of tunnels and shaft.

The accompanying diagrammatic section through the hill on the line of the tunnel (Fig. 44) will give an idea of the relative position of the various workings. At 300 feet from the portal of the tunnel a vertical shaft rises to the surface, known as the Y shaft, possibly because it stands at the head of a secondary ravine that divides the spur into two parts. Of these two, the first, or northwestern, is known as Paulina Hill, while the further one is the Pilares Mountain proper. Through the top of the latter, on the so-called 100-foot level, runs a tunnel 1,300 feet long through which the ore was formerly transmitted from the working shaft to the head of an incline immediately over the portal or entrance to the present tunnel. The name of the mine is derived from projecting columns, or pillars, of gossan on the summit of the hill about 100 feet above the upper tunnel level.

Country Rocks.—The rock forming the mass of Paulina Hill, as seen in its fresh condition at the portal of the tunnel, is a fine-grained andesite with latite tendency. Even in the freshest specimens, however, the feldspars are much altered and sericitized and the basic-silicates no longer recognizable. The alteration products are largely sericite and chlorite with some calcite. Its dark reddish-purple color is due to considerable amount of microscopic magnetite and hematite with possibly some ilmenite.[1] A little pyrite is also seen in the groundmass. The rock is in great part an eruptive breccia in which the matrix and enclosing fragments are of the same material, and it often shows a distinctly bedded structure.

The rock which forms the mass of Pilares Mountain beyond the Y shaft has a good deal of the external habit in color, weathering, etc., of a rhyolite, yet it shows neither flow structure nor quartz phenocrysts. The general field impression was that it is intrusive in the andesite breccia, yet no eruptive contacts were found by which this could be proved. Where unbroken, it has the general appearance of a massive, homogeneous rock, yet in some specimens a favorable light shows an original breccia structure which is also visible under the microscope. Microscopical examination shows that it is greatly silicified and sericitized. The feldspar phenocrysts are in great measure altered beyond determination, but both orthoclase and plagioclase are seen to be present. In the groundmass secondary quartz occurs, both as interlocking grains, and in fine veins. In the specimens taken from near the surface the little quartz veins have been cracked and the cracks filled with specular iron. The rock is petrographically defined as a quartz monzonite, if intrusive, though from a study of the average specimens Mr. Woolsey was inclined to think that it might be a highly altered and silicified variety of the Paulina andesite.

[1] The microscopic examination of thin sections of the specimens gathered was kindly made by Mr. Lester H. Woolsey and Mr. Waldemar Lindgren.

A diabase of distinctly later age traverses this monzonite. It is a dense, dark colored rock which in its fresher condition shows phenocrysts of feldspar. The microscope shows it to be a plagioclase rock of even, holocrystalline texture, which contains augite and some hornblende, and as decomposition products calcite, chlorite, and serpentine. A little secondary quartz in fine veins, but no pyrite, was found.

ORE DEPOSITS.

Character of the Ore.—The ore of the Los Pilares is remarkably simple and uniform, both in structure and composition. It is essentially a breccia of which pyrite, chalcopyrite, and quartz constitute the original cementing material, for, although much of the more massive rock is more or less impregnated with metallic sulphides, this impregnation has thus far proved commercially negligible.

Beside copper, iron, and sulphur, it contains practically no other metal. In some places there is a very little zinc, but no lead is known to exist. There is a trace of gold and less than an ounce of silver to the ton. Arsenic may be present in small amount, but has not been determined. The primary ore minerals are pyrite and chalcopyrite, the products of secondary enrichment being bornite and chalcocite, the former apparently in the larger proportion. In the gossan, as is often the case in arid regions, the limonite is almost entirely altered to specular iron. In the 1300-foot tunnel, at the 100-foot level, which is within the oxidized zone, only slight traces of pyrite were found, and, though its copper values had been leached out, the ore still retained its characteristic breccia structure, and at a little distance might have been mistaken for the normal copper ore.

The outward appearance of the ore is most striking, owing to the strong color contrast between the brass-yellow, iridescent purple, or blue-black, of the metallic cement, and the white rock fragments, and its singularity is heightened by the peculiar shape of a large proportion of these fragments which resemble a mass of broken potsherds, being relatively thin, often curved, and shell-shaped. In the average ore these are mixed in the greatest confusion with a lesser proportion of fragments of other forms, generally angular, sometimes slightly rounded, and varying in size from a pin head to masses several feet in diameter. Figure 2 is a photographic reproduction of an average specimen of rich

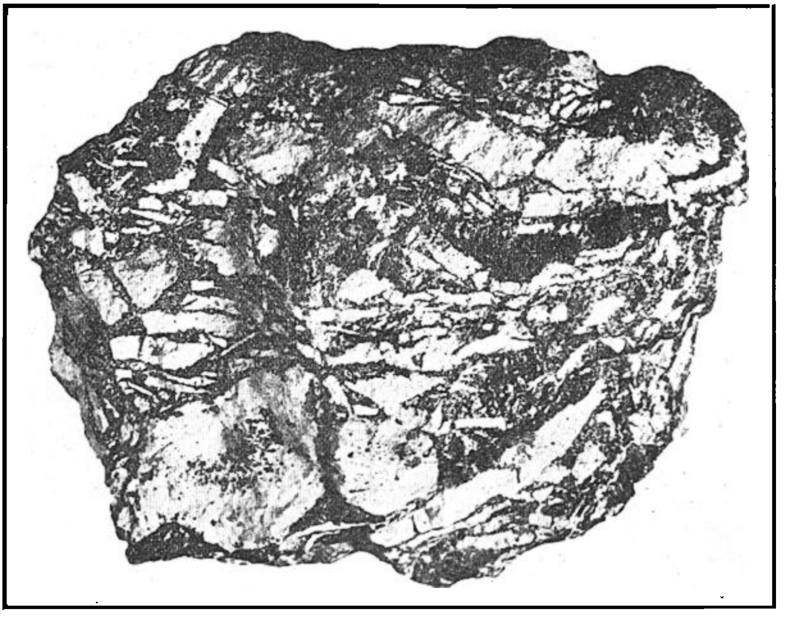

FIG. 45. Specimen of rich breccia ore. Light parts are fragments of country rock; darker part is metallic cement.

ore in which the metallic matrix appears to consist of about equal proportions of bright pyrite, chalcopyrite, and bornite, with a relatively smaller amount of dull-black chalcocite. Closer examination, however, shows that the bornite and chalcocite form only a thin veneer over the faces of the pyrite, and that the latter forms the mass of the filling of the larger interstices, and, in rare cases, develops into well-defined crystals. For the most part, pyrite is massive or mixed with finely granular quartz. Quartz often forms a thin layer on the outer surface of the rock fragments, in which case their interior is mostly barren of metallic sulphides. The larger angular fragments, as shown in the specimen, have, however, sometimes a slight interior impregnation of pyrite.

Throughout the ore mass one frequently finds bomb-like masses of dense country rock, practically free from metallic impregnation, in size from a small cannon ball upwards, and which when freed from their matrix often form an almost perfect sphere. These furnish an explanation of the thin sherd-like fragments in the breccia, for it is seen that their outer surface has flaked off in thin concentric layers like the leaves of an onion, quartz and metallic sulphides having filled in the gradually enlarging cracks between successive layers, thus showing that the ore solutions have produced an effect in the interior of this rock mass similar to that which weathering does upon certain igneous rocks near

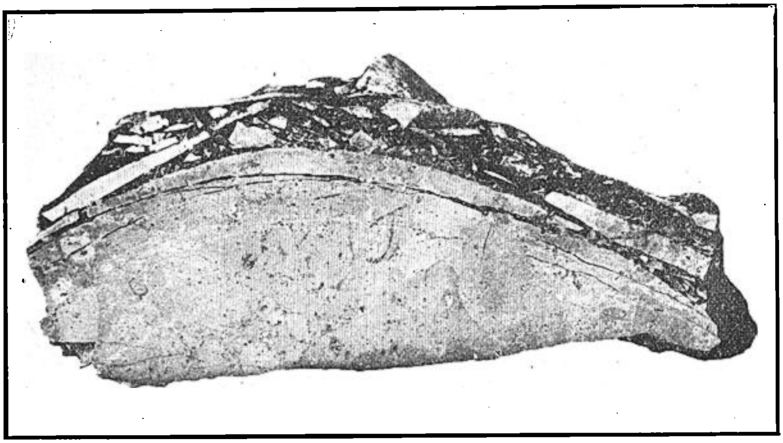

FIG. 46. Part of the shell of a bomb in the breccia ore.

the surface. Figure 46 shows a portion of the outer shell of one of these bombs in which the process of shelling off by the introduction of thin films of quartz and pyrite along the curved cracks is readily seen. On the polished face of the interior portion of the bomb an original breccia structure can still be faintly distinguished, and a few, but not all, of the darker spots on that face are minute crystals of pyrite. In immediate contact with the outer surface of the bomb the cement is largely made up of quartz, enclosing comminuted fragments of country rock, while further away it contains an increasing amount of chalcopyrite and pyrite. Whether some of the chalcopyrite may not be due, like the bornite and chalcocite, to secondary concentration could not be definitely determined, but this was suggested by the apparent far greater proportion of this mineral in the ore of the upper levels rather than in a corresponding position on the tunnel level.

Distribution of Ore.—The manner of occurrence of the ore is as singular as its composition and structure. It is not a vein deposit, nor does it occur in what might be called a chimney or stock. From a first inspection of the drifts and stopes, shown on the mine maps, one might be led to think that in the interior of Pilares Mountain is a huge dome-shaped boss surrounded by a shell of ore a hundred feet or more in thickness. This appearance may perhaps be understood by an inspection of figure 47, which is a sketchy reproduction of the main drifts on the 400-foot level, in which the squares represent roughly the areas stoped in the southeastern part of the hill from which has come the greatest part of the ore mined up to this time. The stopes and drifts, both above and below this level, are singularly like it in form, varying mainly in their relative extent. They have not been represented, however, as they would unnecessarily complicate the drawing, nor have the workings in the ore bodies near the Y shaft, as they are too distant, but the relative position and direction of the two tunnels are indicated. (Figure 47.) Observations along the two tunnels, and in other drifts in the interior of the hill, show that, in point of fact, the ore is not confined to the outer shell, but that the whole mass of Pilares Mountain between the two shafts is more or less impregnated with ore, though not always of a quality that would pay to work under existing circumstances. The original deposition, as well as the secondary enrichment, which has rendered the ore rich enough to work, are both dependent on dynamic movements that have taken place along certain fracture planes. To illustrate this, these structural features, which have had to do with the unusual concentration of ore in the southeastern part of the mine, have, in the sketch represented by figure 47, been emphasized by indicating their intersections with the mine workings on each level of the mine as far as they could be observed. They will be described somewhat in detail.

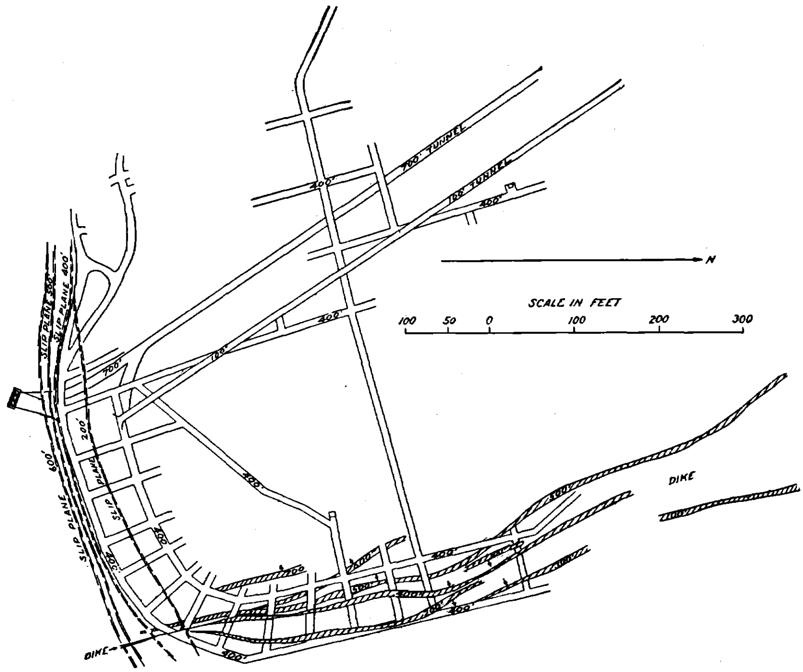

FIG. 47. Los Pilares Mine—projection of main drifts on 400-foot level, with intersections of dike and slip-plane.

The earlier of the two faults, which is designated on Figure 47 as the slip-plane, crosses the station on each level a short distance north of the main shaft and runs in a nearly east and west direction parallel to the main drifts of this part of the mine. It is a singularly clean, smooth plane of movement without clay selvage, sometimes made up of several closely-spaced planes. At one point 21 such planes were counted in a width of less than 2 feet. It stands nearly vertical, having a dip of about 70° to the south and in strike shows a tendency (which is more marked on the upper levels) to bend northward at either extremity.

The passage from solid, practically barren monzonite, to mineralized breccia, as one crosses the slip plane on the successive levels, is remarkably sharp. Pyrite is first seen in thin, vertical seams on the inner planes of movement beyond which the whole mass is typical breccia. At first the cement is made up mostly of metallic sulphides, then of an increasing amount of quartz and groundup fragments of country, the sulphides decreasing in a general way with the distance from the fissure. At irregular intervals throughout the mass are found the barren bombs.

The second plane of movement is seen about 250 to 350 feet east of the shaft, where it crosses the slip plane nearly at right angles, its average strike being a little west of north. It is called by the miners "*Caliche*," and, as first seen, had the appearance of a thin, black clay selvage. Following it along the strike it proved to be a dike of very dark diabase that had been subjected to movement and intense compression, so that in places it is drawn out to a mere knife-edge seam and then enlarged to six or eight, and even fifteen, feet in thickness. In these thicker parts, which have a somewhat lenticular form, the original rock structure is readily distinguished in the interior, while the outer surfaces are changed to a plastic clay. In a general way it forms the eastern limit of the ore as far as present developments show, but in places typical breccia ore is found on the outer or eastern side of the dike—in one place over a hundred feet in length. As shown by the projections (figure 4) this dike has a wavy, curving direction, both in strike and dip. In its upper part it dips outward, or to the east, but changes in direction at the 300-foot level, and below the 700-foot level, as shown by drill cores, its dip shallows to 65° west.

That it is later than the slip plane is readily proved where their intersection is visible. The former ends abruptly on the face of the dike, but its continuation is traceable through the country rock on the other side, whereas the dike crosses the slip plane without break in its continuity. Rounded fragments of ore are also found in the clay selvage, while the interior of the dike is free from any impregnation of sulphide, even microscopic.

This great mass of richer ore, whose exterior limit is defined by these two planes, and which, as shown by the maps, has a somewhat curving outline, is said to have been worked for a length of 1,300 feet along the arc of the so-called circle, whose chord is 800 feet across. The stopes of richer ore extend from a short distance below the 100-foot level down nearly to the 500-foot. Below this the ore is said to be falling off in grade, so that it can no longer be broken down in mass, as above. It is thus evidently to secondary enrichment that it owes its quality as pay ore. Above these limits, the copper is leached out; within them is the greatest concentration of the richer sulphides and, while they can still be observed in the lower levels of the mine, it is evident to the eye that they are in decreasing proportion. The actual amount of ore in the hill, aside from the question whether it can be mined under present conditions—that is, carries an average of 3 per cent. of copper—must, however, be something enormous.

Pilares Ore Body.—About 400 feet north of the main shaft is the Pilares ore body; so-called because it is directly under the outcrop of that name. It is newly opened and on the 400- and 500-foot levels only, and its relations to the fracturing were not so clearly seen, but a strong northeast fissure, 4 inches in width, was observed to run through it on the 500-foot level, and immediately under this, on the 700-foot, or tunnel level, is a strong vertical fault zone, with 5 or 6 feet of fault material. For a little distance on either side of this fault the rock is massive but soon passes into typical breccia again, in which here and there are patches of 3 per cent ore. It is significant that at the southern end of the drifts, on the 500-foot level, are a series of open cracks and holes, rounded out interiorly, and evidently old water courses. One of them, which traverses a part of the ore body, was seen to be filled with loose crystals of pyrite which had evidently been disintegrated by the passage of the waters.

On the main tunnel, a little beyond the Y shaft, or at about 3,000 feet from the portal, another diabase dike is cut, of rather irregular form, and having a general north and south direction, which follows another ore body mainly developed by the upper workings of the Y shaft, which were not visited. In these upper levels the dike is said to thin to a mere clay seam, while the ore is found now on one side, now on the other, but does not extend far into the hill. On the tunnel level 60 feet beyond the dike is the contact between brecciated and somewhat mineralized monzonite, and the Paulina andesite, which is a vertical fault contact. In the other direction from the dike, or toward the center of the Pilares Mountain, the brecciated ore extends for a short distance and is succeeded by about 600 feet of massive rock, rather darker in color than the average monzonite, in which pyrite occurs only in narrow seams or veinlets. This rock is crossed by many northeast fracture planes of which there are two prominent ones having each 6 inches of soft, ground-up material. From beyond the last of these, or about 3,700 feet from the portal, to the main shaft, extends the typical light colored breccia which carries pyrite, mostly as cement to the breccia, but occasionally in irregular patches. In it are occasional masses of massive monzonite up to 100 feet through, generally bounded by movement planes, which are often rounded and resemble bombs on a large scale.

CONCLUSIONS.

Leaving out of consideration the question whether the acid Pilares rock is an intrusion in the Paulina andesite, or simply an area of silicification of the latter, the observations outlined above seemed to have defined with reasonable certainty three epochs in the geological history of these deposits:

1. An epoch of dynamic movement which produced the fault planes, of which the slip plane is a type, and resulted in a shattering of the greater part of the mass of Pilares Mountain, which was accompanied, or followed, by the introduction of silica and metallic sulphides that cemented the shattered fragments into a breccia.

2. An epoch of eruptive action during which the diabase dikes were introduced; and

3. A subsequent dynamic movement that opened new cracks through which the surface waters could enter.

The peculiar breccia that has become ore is not an eruptive breccia, produced by explosive vulcanism, nor is it a friction breccia consisting of broken and dragged-in fragments between the two parallel walls of a fault fissure, yet it has certain features of resemblance to either. It resembles the former in the uniform composition of fragments, in its great extent, and its want of regular, well-defined boundaries; for, while its limits on the plane of the tunnels and shafts are fairly well known, they are, apparently, not determined in directions more or less normal to this plane. It is quite possible, however, that the brecciated area may have something of the circular form that it is conceived to have by those who are working in it, for it is known that circular ore bodies, or so-called chimneys, often result from the mineralization of a shattered area, enclosed by three or four intersecting fault planes. It resembles a friction breccia, on the other hand, in that it has been produced by dynamic movements, and the ore fills the interstices between the fragments; but the shattering has taken place, not between the walls of the fissures, but at some distance outside of them, while the rock immediately adjoining the fault walls is generally massive or sheeted. Although the interdependence of the rock shattering and the faulting produced by the dynamic movements seems fairly well established, it is not easy to conceive why this peculiar form of brecciation was the result. It may be well to state that many more planes of movement than those mentioned above were observed, and that, doubtless, a great many more exist than were noted in such a hasty study, so that it may be assumed that every part of the brecciated mass is surrounded by fault planes. If we further assume that the movements along such fault planes communicated to the adjoining rock something in the nature of vibratory shocks, of an intensity probably proportional to the extent of the movements, and that such shocks were transmitted in waves, where there was no interference, as in the immediately adjoining rock, the transmitted movement might have no mechanical effect, or result only in some parallel sheeting. When, however, these waves were crossed by waves of other fault movements in the vicinity, by interference there might result a violent shattering of the rock mass. If the general mass of the rock had already suffered decomposition by the introduction of heated solutions and gases along preexisting joint planes, the angular masses bound by such joints would have been decomposed in concentric zones, producing the observed tendency to flake off in curved shells when the shattering actually took place.

The introduction of the ore-bearing solution must have been subsequent to the shattering, but probably followed it very closely, since the ores were precipitated in the interstices rather than as the replacement of an already existing cement. While at greater depths these solutions may have ascended along the fissures, in the horizons now under observation it is evident that they had spread out more or less through the whole shattered area, though more concentrated along certain zones to which they found readier access.

The cause of the introduction of the diabase dikes was evidently a deep-seated one and possibly beyond the reach of present observation. It may be assumed that they followed cracks produced by some later movements, and, as shown above, they are parallel to some zones of mineralization and transverse to others.

The most important determination from an economic point of view is that of the location and extent of the channels produced by later movements which, by admitting surface waters, would have led to the secondary enrichment that has made the ores merchantable. Such a determination, especially in a relatively arid country where evidence of actually percolating moisture is not readily apparent, would require a more detailed and extended study than the present. Probably the strongly brecciated zones are still more or less permeable, but that there has been movement since the intrusion of the dikes is proved by the existence of old water channels cutting the ore bodies, and by the squeezed and drawn-out condition of the dikes themselves. Furthermore, the only considerable flow of water observed in the mine was found at the northernmost intersection of the dike by the 500-foot level; hence, it may be assumed that in the search for new ore bodies of enriched ore, it would be advisable to follow the general course of the dikes in ground not yet explored.

The study of these deposits has proved especially interesting to the writer, because of a certain analogy between them and a new type of deposits which are proving of increasing economic importance. These are the bodies of disseminated cupriferous pyrite along shattered zones in porphyry that have been sufficiently enriched to admit of successful reduction by ore dressing and concentration, such as are being worked at Bingham, Utah, and Ely, Nevada. It is believed that the Los Pilares region is well worthy of a more complete and detailed geological study.