Geology of the Exposed Treasure Lode, Mojave, California.

BY COURTENAY DE KALB, LOS ANGELES, CAL.

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THE Exposed Treasure gold-mine has, for the past four years, been one of the largest producing mines of Southern California, its annual output having constituted 1 per cent. of the total gold and silver production of the entire State. At the present moment the property is idle, owing to the large quantity of water encountered on the lower levels, which will require the installation of a powerful pumping-plant before operations can be recommenced. Moreover, a prompt change in the character of the ore has occurred at water-level, which makes imperative an extensive campaign of development in the region of the unoxidized ores before a plant adapted to their treatment can be definitely decided upon.

The character of the changes encountered in these deeper ores makes the geology of this deposit a matter of importance, not only for the immediate district, but for the desert region of Southern California in general, where many mines exist having in the oxidized belt conditions that, in many respects, resemble those in the Exposed Treasure mine.

The deposit is situated in an apparently isolated butte about 2.5 miles south from the town of Mojave, on the Mojave desert. The butte, though apparently isolated, is in fact geologically part of an extinct volcano, known as Soledad butte, which rises out of the plain 1.5 miles SW. of the mine, to an altitude of 4,650 ft. above sea-level. Other buttes also rise from the desert plain toward the south and east, and again to the westward, all being closely related geologically to Soledad butte,—the whole constituting a single system as to origin and time. Since the end of the period of active volcanism in this region, there has been extensive denudation, the ancient plateau having been dissected during an epoch of apparently excessive precipitation. The plateau is known, through well-borings in the gravel-fill of the desert, to have been cut down to a depth of 1,600 ft. below the present general level of the desert, and a reconstruction of Soledad butte from the angle of rest for lapilli, deduced from remnants of the ancient ash-cone still remaining, shows that it may have towered to a height 2,500 ft. greater than it now possesses. Other evidences of great activity in denudation on the Exposed Treasure butte are quite in accord with this estimate for Soledad.

Fig. 1 is a map of a part of the Mojave desert and the Tehachapi mountains,—Soledad butte being shown near the center.

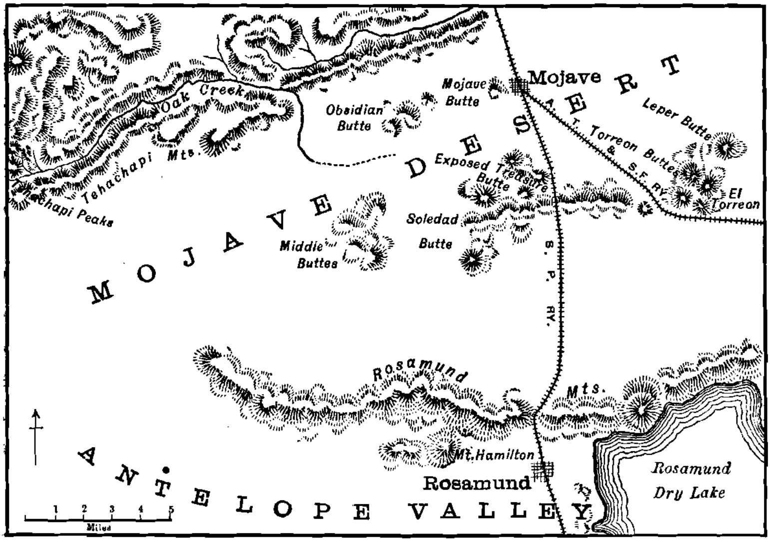

FIG. 1.—MAP OF A PORTION OF THE MOJAVE DESERT REGION, SOUTHERN CALIFORNIA.

The floor of the plateau consists of typical granite, extending to an unknown depth; and, being identical with the granite in the Tehachapi mountains, 5 miles to the northward, it is presumable that we have here the granites underlying the Tertiary sedimentaries, which still constitute the characteristic feature of the Tehachapi mountains in their eastward extension from the line of the Southern Pacific Railway, although all traces of such sedimentary rocks are wanting toward the west, where this range culminates in the tripartite Tehachapi peak, 8,052 ft. high.

The granite itself has been invaded by extensive pegmatite flows, determining the position of a low range of hills, which—for want of a name—I have for convenience called the Rosamund mountains. Pegmatite dikes also exist on the Exposed Treasure butte, and on the Torreon group of buttes, 5 miles to the eastward. As the Torreon group is connected with Soledad by a practically continuous chain of low hills, all lithologically related to Soledad, it may be fairly assumed that the original lines of weakness, contributing as one cause to the subsequent volcanic eruptions in the district, were those established by the pegmatite flows from the lower portions of the old granitic magma. It is worthy of note that these pegmatite dikes rarely show, by samples taken at random, a value in gold lower than 20c. per ton, and many of them, particularly in the Rosamund mountains, often assay as high as $1 per ton. The granite itself is never barren, but seldom carries more than 0.001 oz. of gold per ton. The absolutely universal dissemination of gold throughout all rocks in the entire district, requiring no refined methods of analysis to determine its presence, is a noteworthy circumstance.

The great mass of Soledad butte, as well as of its outlying hills, some of which were solfataras of the central volcano, consists of intensely acidic rhyolite-porphyry. Extensive fissuring has occurred in every direction, and all fissure-planes and zones have been further silicified, with abstraction of the alkaline feldspars, resulting in rocks often superficially resembling quartzite, sometimes possessing a porcelain-like texture, and a quality of resonance which has led to their being locally called phonolite. The fissuring has mostly occurred under slowly applied pressure, which has induced flowage of the porphyry, and even has caused it to become intrusive as dikes through the upper portions of the parent-rock. The flow-lines developed in the massive porphyry often give the rock the appearance of being contorted slates, while, on the other hand, the flow-dikes possess a granitoid structure which, on field-examination, would lead to their being presumptively identified as quartz-diorite. Microscopic investigation, however, proves that these dikes are only crushed rhyolite-porphyry, squeezed into crevices in the surrounding mass of porphyry and adjacent granite. No granite exists on Soledad at a higher elevation than 600 ft. above the desert-level, but it shoulders upon the neighboring buttes, and exists in isolated masses, these being remnants from the denudation that has almost obliterated all traces of the dikes of porphyry that must have extended upward through the uplifted granite.

In Fig. 2 the relation of the porphyry to the granite is clearly shown, the remnants at the points of deepest denudation on the mountain mass demonstrating the previous existence of

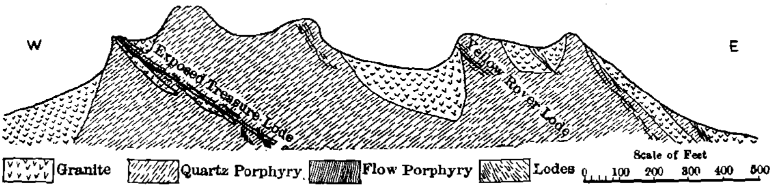

FIG. 2.—CROSS-SECTION OF EXPOSED TREASURE BUTTE.

large granite masses above. Fig. 3 is a sectional view showing the bottom of one of these wedges of granite in an adit tunnel on the Yellow Rover claim of the Exposed Treasure Mining Co. The fracturing of the lower point of the granite, and

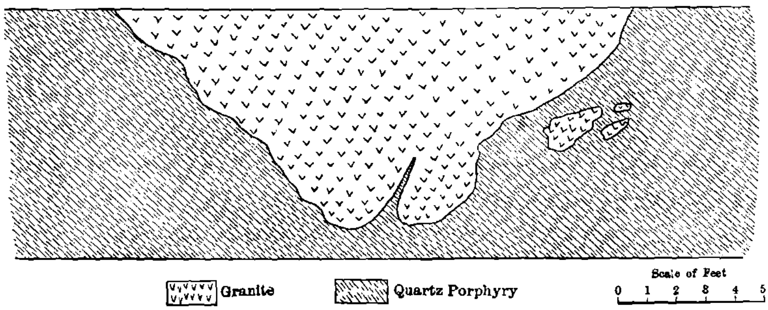

FIG. 3.—LOWER POINT OF GRANITE WEDGE UPLIFTED BY QUARTZ-PORPHYRY.

near-by inclusions of granite in the rhyolite, are particularly interesting. Noteworthy, also, is the fact that no contact metamorphism has occurred, the granite being almost as fresh in contact with the porphyry as within the granite masses themselves. The rhyolite-porphyry on the Exposed Treasure butte, and on nearly all the hills surrounding Soledad, has evidently flowed into its present position in a pasty condition, and at no greatly elevated temperature. At the south-eastern end of the Exposed Treasure butte, however, and at the volcanic stock constituting the Torreon, where solfataric phenomena were present, the porphyritic character of the eruptive disappears entirely; although in the center of the present porphyry dome on the Exposed Treasure butte the phenocrysts are splendidly developed, often attaining a major axis 1 in. in length, in a ground-mass which has undergone epidotization. In the mines in Soledad, where the porphyry has been revealed at considerable distances from the surface, the phenocrysts are not usually so well developed, and the ground-mass shows less alteration to epidote; it is also often quite fresh, and unchanged by the formation of secondary minerals, except in so far as silica has been introduced, as previously explained.

That Soledad was an active volcano is clearly proven by the important remnants of the ash-cone lying around the base of the mountain, notably abundant on the east side. There exists, moreover, on the west side of the mountain, a mass of volcanic tuff, buried under nearly 1,000 ft. of subsequent effusive rhyolite, the tuff having been compressed until it has developed horizontal cleavage, splitting the rock into layers of from 0.25 to 2 in. thick, as perfectly as the bedding-planes of a shale. This compressed tuff-remnant, 30 ft. in thickness, as revealed by denudation, makes it evident that there must have been at least two periods of volcanic outbursts connected with the effusion of the rhyolite alone.

The great acidic magma found its relief-vent chiefly at Soledad butte, but the uplift was general over a large area, and other vents existed at the Middle buttes, 4 miles west of Soledad; Mojave butte, now an inconspicuous hillock, where the rhyolite just emerges above the desert sands, 2.5 miles north of the Exposed Treasure butte; and Leper butte, a twin white shaft of quartz-porphyry standing solitary on the plain about 2 miles NE. from El Torreon,—the latter being the best type of volcanic stock in the district, though another fair example is found at the southeast end of the Exposed Treasure chain of buttes. The rhyolite also appears in the Rosamund mountains, and at Hamilton butte. My explorations in the Tehachapi mountains have failed to reveal any extension of the rhyolites into that range.

Subsequent to the rhyolite eruptions there was an outflow of andesites through extensive fissures in the Tehachapi mountains, forming one great system of dikes across the eastern edge of the Tehachapi plateau, and another 3 miles ENE. of the great Tehachapi peak. This outflow also reached the surface at Obsidian butte in the desert, and at one point on the ENE. flank of Soledad butte.

Three distinct periods of faulting are traceable in the Exposed Treasure butte, the first being a series of clean-cut fractures, approximately S. 80° E., with a maximum horizontal displacement of over 20 ft., and a vertical displacement of about 5 ft., the fissuring being unaccompanied by crushing or brecciation. One effect of this faulting was to oppose porphyry against granitic faces, thus disturbing the original relations of the dikes and the intercalated granite masses.

The second movement produced extensive rupture under shearing strains, resulting in excessive crushing of wide zones, traversing the rhyolites and granites indiscriminately, nearly at right angles to the direction of the earlier fault-planes. There are two related systems of shear-zones, one consisting of 9 parallel zones, each the *locus* of a vein, comprising also the Exposed Treasure vein, having an average course nearly due north and south, and splitting up into numerous branches in a NNW. direction, where they run into the other set of shear-zones, likewise palmate at the western end, where they merge into the related fault-system in the center of the great rhyolite boss constituting the mass of the Exposed Treasure butte. The course of this second set of shear-zones is S. 60° E., leading it directly into the solfataric stock at the southeast end of the ridge, where it again splits into numerous finger-like branches. It is, moreover, less continuous than the major system of shear-zones, and was seemingly caused by resultants of the original force, which met with a resistance in the homogeneous Exposed Treasure boss of rhyolite, producing a complicated branching of fractures. The north and south zones, therefore, may be spoken of as primary, and the NW–SE. zone as secondary. Magnificent grooving, like the best examples of glacial grooving to be seen in the north, occurs in many places on the foot-wall of the Exposed Treasure vein, in one stope an area of more than 100 by 300 ft. being furrowed into parallel waves, some of which are 200 ft. long, 18 in. high, and approximately 3 ft. from crest to crest. These groovings bear N. 33° E., and dip 31° 15′ from the horizontal, while the dip of the foot-wall on which they occur is 34° 30′ N. 80° E. Closely corresponding evidences of the direction of movement are found throughout the mine, as deep as 800 ft. from the outcrop, and for over 1,000 ft. in length. The amount of throw or displacement has been measured with certainty at one point, from one original cross-fault, showing in the foot-wall, to its mate in the hanging-wall, revealing a total movement of the hanging-wall of 32 ft. toward the NNE. Similar evidences in the Yellow Rover and Boston mines, parallel with the Exposed Treasure mine on the east side, indicate that we here have shearing-zones accompanied by block-faulting on a large scale, the general movement being due to an approximately horizontal thrust coming from the direction of Soledad butte.

These parallel shear-zones, now converted into metalliferous lodes, with extensive chutes, and lenses of pay-ore, all dip toward the east, those which outcrop at a considerable elevation having a steeper angle of dip (even as much as 60°) for a certain distance, then flattening rather abruptly to inclinations varying between 32° and 38°, gradually growing flatter in depth until, in the lower workings of the Exposed Treasure mine, the dip is only 27°. Furthermore, at the same absolute elevations, these parallel veins maintain identical dips, so that the parallelism is almost perfect throughout.

After this fissuring of the region, extensive silicification occurred, apparently unaccompanied by replacement. It was evidently a mere cementation of the crushed zones with silica, probably extruded from the cooling rhyolite mass in a colloidal condition, resulting in masses and infinitely ramified veinlets of chert, along with which was consolidated much FeS_2 as cubic pyrite. Kernels of this chert and its included breccia—the latter now consisting of granite and again of rhyolite, depending upon whether the fissure at that point was traversing one or the other of these two formations—are found frequently in both the Exposed Treasure and the Yellow Rover mines, and they rarely contain as much as 0.02 oz. of gold and 0.05 oz. of silver per ton, with complete absence of copper. This is universal throughout the mines of this group.

On practically all joint-planes throughout the unfaulted portion of the rhyolite boss (through the most highly porphyritic and unaltered portions equally with those where alteration has been profound), the same skeleton of cherty silica occurs, stained blackish-brown from iron oxides. On Soledad butte this extrusion of the overplus of magmatic silica is even more marked, but it contains a much smaller proportion of iron.

After this period of shear-faulting and subsequent cementation by silica, the veins or lodes were again subjected to faulting, in this case there being apparently no horizontal component, ordinary normal faults being produced. The effect was to re-brecciate the old cemented shear-zones. The formation of the metalliferous veins now commenced, the product being typical replacement-deposits. The silicates in the original breccia were, to a large extent, replaced by silica and metallic sulphides in the deeper portions, calcite becoming more abundant at higher levels until it finally became the predominant mineral, filling the interspaces between the cherty skeleton which had formed the cementing matrix of the earlier breccia. The calcite was of a liver-brown color, from mechanically contained manganese and iron compounds, and as the calcite in the upper portions of the veins dissolved away in advance of the denudation, the liberated manganese and iron oxides, together with clay, worked their way downward, so that in time great bodies of ore remained, consisting of a siliceous skeleton filled with a soft blackish-brown mixture of ferruginous clay and manganese dioxide, having much the appearance of an impure "bog" manganese. Throughout these masses were numerous blocks of the original cemented breccia, and the secondary breccia recemented with silica and calcite.

In the upper part of the veins, chrysocolla was a fairly common mineral, occurring both in the residual blocks of recemented breccia and lying detached in the soft manganiferous filling. It is also evident that the latest faulting had at places, temporarily at least, produced open fissures, as the occurrence of water-worn boulders, from the size of small pebbles up to 6 in. in diameter, would indicate. At one point in the Exposed Treasure vein, 40 ft. from the present outcrop, was a very remarkable mass of several tons of such surface *débris*, cemented by calcite, while smaller pockets of such gravel, and isolated boulders, are common everywhere near the outcrop.

As stated before, while the lodes are continuous, and often of great width, sometimes being 40 ft. and more from wall to wall, the pay-streaks, from 4 to 15 ft. in width, lie in well-defined chutes and overlapping sheets or lenses. It is noteworthy that only those chutes or lenses which now reach the surface contained important quantities of calcite and manganese dioxide. In the deeper-seated lenses, which had no direct connection with the outcropping upper lenses, the absence of the above-named minerals is conspicuous, the ore here being entirely siliceous, except for residual blocks of the original breccia cemented by chert. The processes of decay, however, have extended also to these deeper-seated masses, the alteration consisting in sericitization and kaolinization, the latter applying chiefly to remnants of the old granitic breccia. The result has been to produce a semi-friable mass, including kernels and blocks of all sizes of the harder unaltered ore. Chrysocolla is also fairly abundant, and copper carbonate occurs universally, often in large amounts. The remnants of the earlier chert-filling, while frequently heavy with pyrite, contain no copper, but the residual masses of the unaltered secondary quartz always contained chalcopyrite in considerable quantities, along with marcasite, galena, and sphalerite. These kernels also presented another interesting phenomenon, illustrative of the processes of decay still going on. They were always surrounded by the friable sericitized ore, becoming "honey-combed" nearer the kernel, the latter being discolored by large amounts of the green copper carbonate, and even copper sulphate. Near the outer portion of the harder mass the chalcopyrite had been either converted into bornite or coated with a film of this mineral. Within the kernel the chalcopyrite remained unaltered. It appeared that during protracted epochs of drought, to which the desert is subject, the moisture had been withdrawn from these kernels by the combined action of evaporation and capillarity, the copper sulphate in part reacting with the chalcopyrite to produce bornite, and in part either crystallizing out on evaporation, or becoming partly converted into the carbonate. It was also uniformly found that such unaltered copper-bearing kernels were richer in the precious metals than the altered friable ore. The altered ore bore manifest signs of extensive leaching, and where it had become almost completely decolorized by the removal of iron, the precious metal contents had nearly disappeared, and such ore never contained copper except in the form of chrysocolla.

The absence of sulphides in all the ores, except in the cherty skeletons, and in the undecomposed kernels of hard ore, was very complete. The mill-concentrates (150 into 1) had an average composition of SiO_2, 30; FeO, 37 (mostly from Fe_3O_4); and MnO_2, 12 per cent. These concentrates never contained more than 1.5 per cent. of sulphur.

In the lower friable siliceous ores, the ratio of gold to silver was as 1 to 12, while in the upper mangano-calcitic ores the ratio was as 1 to 72. Assays of gold-scale, and of coarse gold panned out, from all parts of the mine, showed a remarkably uniform alloy of 1 part of gold to 0.461 part of silver. The silver in the upper portion of the mine was present almost wholly in the form of silver chloride.

On the assumption, from the evidence, that the abundance of chlorides would prevent the leaching-out of the silver and its reconcentration below water-level, and that the ferric and cupric sulphates would have abstracted large quantities of the gold, which would be re-deposited lower down together with the copper in the form of secondary enrichments, it was natural to predict an ore below permanent water rich in these metals, and relatively lean in silver. It would be difficult to conceive a nicer justification of theory than that which was afforded when development at length extended below water-level. The ore consisted of a hard bluish-gray mass of original chert-cemented breccia, re-cemented by quartz, with partial replacement of the granite and quartz-porphyry by silica, heavily impregnated with sulphides, among which were considerable quantities of chalcopyrite, bornite, and some covellite. The gold-content of the ore had increased 150 per cent. above the average in the friable siliceous ores on the upper levels, and the ratio of the gold to silver was as 1 to 2.