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Prominent Mines of Junin, Peru

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By Joseph E. Singewald* and Benjamin LeRoy Miller†

SYNOPSIS—A description of three ore deposits of unusual interest. One contains vanadium, another bismuth, and the third, silver. All occur in the western part of the Department of Junin, Peru. The silver and bismuth deposits are near the Cerro de Pasco smelteries, and the Minasragra vanadium deposit is about 18 mi. west of them.

The Minasragra vanadium deposit lies about 18 mi. by trail to the west of the Hauraucaca smeltery. It had been located several times for coal, but was abandoned each time on account of the high sulphur content. In November, 1905, a party of Indians searching for coal brought samples of the material to Antenor Rizo Patron, manager of the Hauraucaca smeltery, who had them analyzed and found that they contained a large percentage of vanadium. The deposit was at once denounced again by E. E. Fernandini, the owner of the smeltery, and Mr. Patron. It happened that D. Foster Hewett was making an examination of vanadium deposits near Yauli for the American Vanadium Co. at the time of the discovery of the vanadium content of this deposit, and consequently visited it. As a result of his investigations the property was purchased by the American Vanadium Co., and since its discovery has supplied about 80% of the world's demand for vanadium. Whereas before its discovery it was something of a problem to meet the demands for vanadium, so remarkable is the richness and size of this deposit that it can be worked only on a relatively small scale in order not to overstock the vanadium market. Mr. Hewett later made other visits to the property, and it is to his careful observations and thorough investigations of the ores, together with determinations of their chemical character by Dr. W. F. Hillebrand, that we owe most of our knowledge of this occurrence. Mr. Hewett's account of it is published in the "Transactions of the American Institute of Mining Engineers" for 1909. Since his last visit considerable work has been done, and at the time of our visit, in the latter part of 1915, it was possible to make a number of observations that lead to conclusions somewhat at variance with those of Mr. Hewett, which will be set forth in this paper.

The trip to Minasragra must be made on muleback from Hauraucaca and requires between 5 and 6 hr., yet it is a trip replete with interest. The first half is across typical rolling pampa lying at an elevation of about 14,000 ft. An occasional llama train is passed bringing in loads of vanadium ore to the railroad or coal to the smeltery or going out to the mines with supplies. At the end of the first hour's ride, one comes in sight of the wonderful "Rock Forest," which lies about 2 mi. to the south of the trail and concerning which one hears so much at Cerro de Pasco. It is an extensive area in which differential erosion has carved the rocks into all sorts of imposing and fantastic shapes and figures that in their variety and number make our famous "Garden of the Gods" appear insignificant. A visit to this place is one of the favorite picnics of the American colony at Cerro de Pasco, and if it were accessible to tourists it would unquestionably be hailed as one of the world's wonders. A short distance farther on one fords the Rio Blanco, on the west side of which the pampa loses its characteristic flatness and becomes somewhat rougher. Much of this part of the trip is along the shores of Lake Punrun, across which is a magnificent range of limestone mountains with the eastern slope so steep as to be practically an escarpment. Quisque is an hacienda, or ranch, belonging to Mr. Fernandini, situated at the foot of the range to the south of the lake. Just before coming to it one crosses a broad, flat valley that slopes down to the lake, and begins the ascent of an outlying knoll amid rough projecting ledges and crags of limestone, and then suddenly finds directly in front of him a most delightful little farmhouse of Spanish style. While resting here a few minutes, we were brought fresh milk by the Indian boys, a kind of liquid refreshment that is rarely served in the high regions of the Andes. Shortly after leaving Quisque, the trail passes through a narrow gorge transverse to the mountains and on the other side comes into the much rougher country in which the vana-

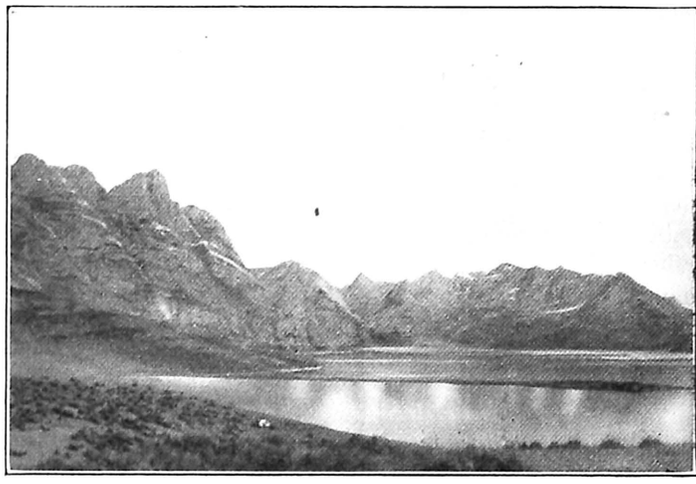

FIG. 1. VIEW OF LAKE PUNRUN, LIMESTONE MOUNTAINS IN THE BACKGROUND

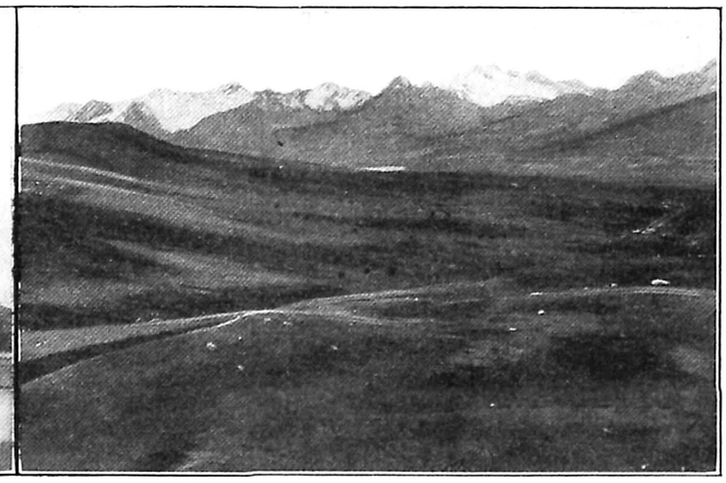

FIG. 3. A VIEW OF THE COUNTRY NORTH OF MINASRAGRA, JUNIN, PERU

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dium deposit is located. There is now an almost continuous ascent to the elevation of 16,500 ft., at which the mine lies. At this altitude living conditions are primitive, both as to house comforts and food. But if one is a lover of nature in its grandest moods, there are compensating features. Overlooking the mine but a short distance to the west is another imposing range of mountains, likewise formed by a thick series of heavy-bedded limestones, which are capped by numerous glaciers and snow fields; while to the north one looks for miles along a broad, flat valley on the slopes of which countless llamas are grazing, with the horizon formed by a distant ice-capped range. The trip to Minasragra would be worth while even if there were no such reward as seeing that unique vanadium deposit.

Geology of the Minasragra Deposit

The general topographic characteristics of the region have already been indicated. The sedimentary rocks are of Mesozoic age and in the area between the two limestone ranges consist of red and green shales with a few thin layers of limestone in the lower part. The ore deposit occurs entirely within red shales in the upper part of the series. These red shales contain abundant gypsum both as intercalated beds and as a network of stringers and veinlets filling joints and cracks in them. In a gypsum bed exposed at the south end of the mine are patches of native sulphur. Outcrops of dikes and irregular masses of igneous rocks are abundant, ranging in composition from quartz porphyry to diabase.

The orebody is a lens-shaped mass having a length of about 300 ft. and a maximum width of 30 ft.; oriented with a strike approximately parallel to that of the inclosing rocks, but with a westerly dip supposedly steeper than that of the shales. It is made up essentially of quisqueite, coke and patronite. Quisqueite is a black lustrous hydrocarbon, coke a dull-black vesicular hydrocarbon, and patronite a greenish-black mineral that is a sulphide of vanadium. Analyses of these minerals given in Hewett's paper are shown in the accompanying table:

MINERAL ANALYSES ACCORDING TO HEWETT

	Patronite, %	Quisqueite, %	Coke, %
Sulphur, soluble in CS_2	4.50	15.44	0.64
Sulphur, combined	54.29	31.17	5.36
Carbon	3.47	42.81	86.63
Hydrogen	....	0.91	0.25
Nitrogen	....	0.47	0.51
Oxygen, by difference	....	5.39	4.64
Water, at 105°	1.90	3.01	None
Ash	....	0.80	1.97
Vanadium	19.53		
Iron	2.92		
Nickel	1.87		
Silica	6.88		
Titanic oxide	1.53		
Alumina (phosphoric acid)	2.00		

Also small amounts of ferric oxide, manganese chromic oxide and alumina.

Small pockets and nests of pyrite are locally abundant, and of interest is the occurrence of a small quantity of a reddish-yellow nickeliferous sulphide of iron to which the name bravoite has been given by Hillebrand. The patronite at the surface has undergone oxidation, and the vanadium close to the surface occurs in the form of hydrated oxides, of which there appear to be a red variety and a brown variety. At a depth of a few feet these give way to a greenish-black oxidation product.

A quartz-porphyry dike cutting across the shales has its outcrop shifted at the ore deposit as if it had been faulted, and Hewett regards the orebody as having been intruded along this fault plane, or fault zone, in a plastic or even liquid condition, as a mass that was probably homogeneous; and that from it the minerals forming it now segregated in a sequence which he determined from a study of polished sections to be quisqueite, coke, patronite. In the hanging wall he thinks there has been some penetration of the patronite into the shales, saying, "Patronite appears to have had the peculiar property, under the conditions of temperature and pressure that existed at the time of the intrusion of the mass, of being able to permeate the porous country rock, even to the degree of saturating it." Replacement of the shales he thinks has taken place only through vanadium solutions formed by the oxidation of the patronite and says, "In some places the solutions have almost entirely replaced portions of the shales, and at other places the vanadium minerals have been precipitated in the cracks and open spaces in the crushed zone."

No positive evidence was seen to indicate that the orebody represents such an intrusion into a definite fault, but rather that it represents a replacement of the shales along a zone of crushing. At the south end of the mine, in a cut made to tram out waste, beyond the limits of workable ore, there is a distinct replacement of certain of the shale layers, which diminishes in amount with increasing distance from the rich ore. A 3-ft. bed of gypsum intercalated in the shale here has not succumbed to replacement. The ore is in the oxidized state and hence may represent replacement by oxidized vanadium solutions in the manner described by Hewett. Better evidence is obtained underground. In the lowest tunnel, 120 ft. below the surface, one can pass from shale to ore through various stages of replacement; and even where the shale is completely gone, the fact that the ore is now found where shale originally existed is unmistakably shown by the complete preservation in much of it of the network of gypsum stringers so characteristic of the shale. Where the mineralizing action has been most intense, the gypsum stringers have been removed and the evidence of replacement destroyed. In the underground workings several gypsum beds are encountered, and even where the overlying and underlying shale is completely replaced by ore, they have persisted, but little affected by the mineralization. A few cases were seen where the gypsum has yielded to a slight extent and contains narrow lenses and stringers of ore. These observations indicate that the gypsum could not entirely resist the mineralization; and it is not surprising, therefore, that the network of narrow gypsum stringers has been removed in a large part of the main mass of the ore.

The faulted quartz-porphyry dike described by Hewitt is the high ledge in the left background of the opencut shown in Fig. 4 and the ridge projecting from the center of the pit to the left of it. According to his view the fault that located the intrusion of the orebody occurred subsequently to the intrusion of this dike. Doubtless, when work first began here, the shift in the dike seemed to be due to a clean-cut fault, but as exposed now in the opencut, it is practically impossible to decide whether the dike was intruded into a curved fissure or whether there was a later movement in the zone of crushing that caused an offset along its strike. Underground the offset is less pronounced than at the surface. Certain it is that there has been no well-defined faulting subsequent to the intrusion of the dike, but at most a slight movement in the shear zone in which the orebody is localized. Then again it appears probable that the dike is later than

the ore deposition. Its top has a westerly pitch so that although it outcrops at the surface on the east side of the mine, on the west side it lies some distance below the surface. Furthermore, the ore lies directly on top of the dike and at the contact has the appearance of having been baked or metamorphosed by it, and the orebody comes up to the dike on either side without increase or decrease in width. Another feature of note is that the dike has not been affected by the mineralizers. In other words, if the dike was present when the mineralization took place, the mineralizers were wholly unaffected by its presence—they did not spread at the contact nor did they diminish in quantity or activity there; yet they had no effect upon the dike itself and flowed out over its top, removing all the shale resting on it. It is true that a similar phenomenon is presented by the gypsum beds, but gypsum is a chemical compound of an entirely different

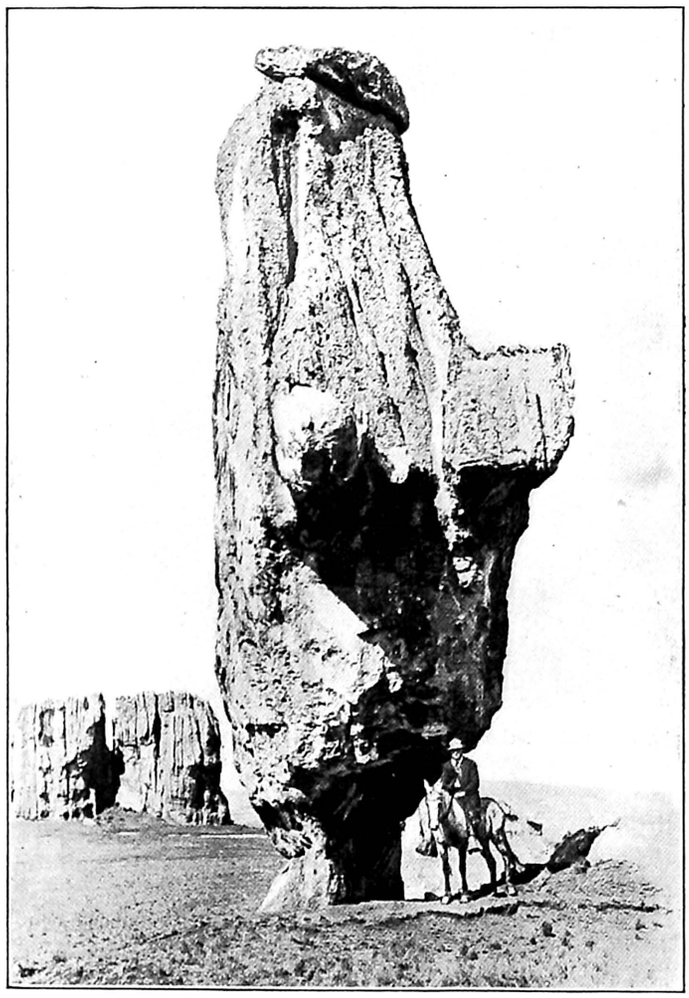

FIG. 2. A TYPICAL VIEW IN THE ROCK FOREST, PERU

nature, and it is conceivable that mineralizers capable of replacing the chemical constituents of shale might not be able to remove gypsum. But chemically, the quartz porphyry is similar to the shale, or at least similar enough to make it difficult to see how such widespread complete replacement of the shale could have been effected and the dike have escaped completely. The weight of evidence now available, therefore, would indicate that the dike is an intrusive across the ore deposit and deflected in that zone of crushing either at the time of its intrusion or by a small later movement.

As to the nature of the mineralizers there is little that one can say, since the deposit stands in a class by itself. Not even in its vicinity has careful search revealed another deposit like it. That they were of a peculiar nature is evidenced not only by the chemical composition of the ores, but also by the fact that they acted so vigorously on the shales and produced so little effect on an otherwise comparatively easily soluble substance as gypsum. Hewett regards the deposit as an extreme phase of differentiation from asphaltite under the stimulus of the igneous intrusions. But whether such a view is consistent with the new interpretation of the localization herein set forth is questionable.

When the mine was first opened, the oxidized ores were worked in the opencut on the outcrop, and the merchantable ore carried about 20% V_2O_5. Later, attention was directed to the sulphides at greater depth and a roasting plant erected in the valley below the mine, and now the entire output comes from the sulphide ores. A tram track from the roasting plant enters an adit that cuts the deposit 120 ft. below the surface and is connected with the opencut by a raise and ore chutes, so that the ore mined in it is taken out through the adit.

In 1909 the roasting plant was built to burn out the sulphur and increase the vanadium content of the marketable material. This plant consists of four hand-operated, double-tier reverberatory furnaces, with a capacity of about 80 tons. The ore to be roasted is fed at one end of the upper tier and slowly worked over to the other end, where it drops to the lower and is worked in the same way to the discharge end. The time consumed in passing through the furnace is two days. At the temperature of the furnace it is self-burning until all but 3% of the sulphur is expelled, when coal must be added to reduce this to ½%. The fuel used is a semianthracite packed on llamas from some small coal deposits in the region. The roasted ore carries 50% V_2O_5. The quisqueite is not removed in this roasting and is still present in the roasted product.

The San Gregorio Bismuth Mine

The San Gregorio bismuth mine is the property of E. E. Fernandini, the owner of the Hauraucaca smeltery, and is situated about a mile to the southeast of that smeltery on the west side of the Cerro de Pasco railroad and three miles south of Fundicion, the Cerro de Pasco smeltery. It is near the base of a small knoll that rises above the pampa to an elevation of about 150 ft. The hill consists of sandstone that varies in texture from quartzitic to saccharoidal, and it is in a brecciated mass of this rock that the ore deposit is found.

The ore consists entirely of oxidized bismuth compounds and is said to be principally the arsenate. It occurs together with a yellow-to-brown colored clay as a matrix of the brecciated sandstone. In places it fills the interstices between the sandstone fragments in the form of the light-yellow bismuth compounds, but more generally it impregnates the yellow and brown clays that make up most of the matrix. The crude ore averages about 3% bismuth. The deposit has been worked in an opencut with a length of 1,000 ft. and a width of 80 ft. At a depth of 20 to 30 ft. below the surface, the bismuth content is said to become very low, and as yet no sulphobismuthides or corresponding bismuth minerals have been encountered of which the deposit may represent the gossan. It is not at all clear whether the ores were deposited in their present condition, or whether they represent the oxidized rem-

nant of primary minerals of a different character; or, if the former is the case, whether they were deposited by ascending or by descending solutions. Consequently the source of the bismuth cannot be explained. All that can be said is that the ore has been localized in the shattered brecciated portion of the sandstone.

As is well known, the world's bismuth market is controlled by a rigorous trust, which assigns to each producer the amount of bismuth that he may furnish. The San Gregorio mine is a party to this agreement, so that its actual production is no criterion of its potentiality as a producer. The tonnage in sight is sufficient to supply the world's demand for bismuth for many years, and it could be produced profitably at 30c. per lb., whereas the average price is $2. The annual mine production of bismuth is a little over 300 tons, and of this the San Gregorio mine is allotted 25 tons. The mine has been in operation about ten years, and during this time the ores have been concentrated in a mill at the Hauraucaca smeltery to yield 20% concentrates, which have been the marketed product. At the same time, a pile of 10,000 tons of middlings averaging 5% bismuth has accumulated, which is now being treated by lixiviation. The material is first roasted and lixiviated with sodium chloride and sulphuric acid. Bismuth sulphide is precipitated from this solution by adding sodium sulphide, and from it native bismuth is recovered by smelting. Mining operations have been suspended, and the entire allotment of bismuth is being obtained by the treatment of these middlings, which are ample to last for a number of years. The Colquijirca silver mine is on the eastern slope of the hill on the opposite side of which, and about 1½ mi. to the southwest, is La Fundicion, the Cerro de Pasco smeltery. The mine is owned and operated by E. E. Fernandini. The daily output at the present time is 80 tons of ore averaging 70 oz. Ag per ton. The lowest grade that can be profitably worked is about 50 oz. Ag. The ore is treated at Fernandini's Hauraucaca smeltery, by concentration and smelting.

The country consists of a series of limestones underlain by shales in which are intercalated beds of coarse and fine conglomerates with a shaly matrix. Within the limestone series itself are impure shaly beds and beds of sandstone of very local occurrence. The formations have a north-south strike and a general easterly dip which has been modified by two minor synclines.

The ore deposit consists of two beds of ore intercalated in the limestone series, which represent replacements of the limestone, and they are separated by a parting of variable thickness but averaging a little more than 2 in. Owing to the folding, the ore horizons outcrop at four points across the section. These outcrops are marked by a series of trenches on the hillside resulting from the extraction of the gossan ores in years gone by. Similar replacements, but on a smaller scale and not resulting in workable ores, have been encountered at lower horizons by the crosscut tunnel. Orebodies such as these with considerable horizontal extent are called *mantos*, which is the Spanish for "mantle" or "covering."

The limestone has been replaced chiefly by black, chert-looking silica and by pyrite. In some places the *manto* consists almost wholly of the chert, at others almost entirely of pyrite, and then again both minerals are present in abundance. Associated with these minerals, in subordinate amount but in sufficient abundance to be a prominent constituent of the ore, are galena and barite, and the amount of silver the ores carry seems to be closely related to the quantity of these minerals present. The smaller *mantos* referred to in the foot wall consist almost entirely of pyrite and are unworkable on account of their meager silver content. On the other hand, the quantity of galena and barite is not an invariable indication of the quantity of silver the ore carries. It is found that when these minerals are coarsely crystallized, there is less silver than when they occur in smaller crystals, a difference that is especially marked in the case of the galena. The barite in particular occurs in druses and small cavities as a network of interpenetrating tabular crystals, and it and the galena to a less extent have the appearance of hving been introduced later than most of the silica and the pyrite. Associated with the minerals already

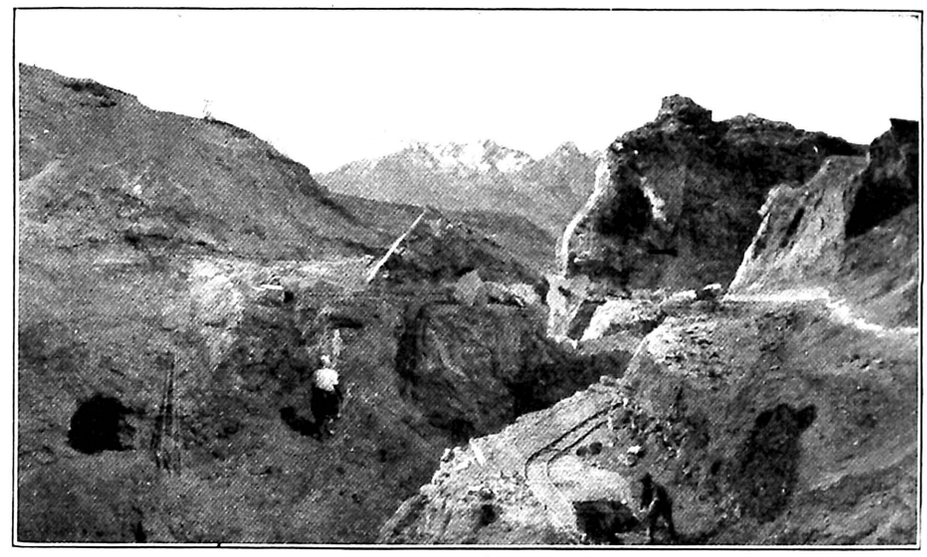

FIG. 4. THE MINASRAGRA VANADIUM MINE, JUNIN, PERU

mentioned, especially in the south end of the mine, a little chalcopyrite is encountered here and there. In the richest ores a little tetrahedrite and probably other "sulphurets" can be recognized.

The mine is remarkable for the magnificent specimens of native silver in the form of coils and clusters of wire silver that is affords. The oxidized zone is not now accessible, but in the sulphide zone there are local areas that have been subjected to the action of oxidation, usually along some zone of disturbance and fracturing, and in these the partly oxidized ores frequently abound in the native silver. Its most common habitat is in the spaces between the interlocking tabular crystals of barite, where it may be found alone or adhering to some of the sulphides, very commonly to the tetrahedrite or other "sulphurets." We are indebted to the kindness of Julio N. Arce, the manager of the mine, for several really wonderfully specimens of this kind.

The mine is developed by means of a tunnel over 1 km. in length and a shaft from the surface which meets the tunnel about 700 m. from the portal, as shown on the cross-section. Mining is now confined to the portion

of the orebody below the tunnel level, and the ores are taken out through the tunnel level. Drifts have been run along the strike of the *mantos*, 350 m. to the north and 300 m. to the south, without reaching their limits. From these drifts, close to the tunnel, three inclines 60 and 10 m. apart have been sunk on the *mantos* with a length of 90 m. and levels at each 30 m. The dip of the ore beds in these workings ranges from 35° to 25°. Most of the output comes from this part of the mine, where there is a rich oreshoot averaging over 100 oz. Ag per ton. The *mantos* here have a thickness of 12 m. including a parting of 2 m., and the entire thickness is removed by square-set mining. Adjoining this oreshoot on the south and continuous with it is ore of the same appearance that carries only 5 to 10 oz. Ag per ton and is hence unworkable. This is a striking example of the extreme variation in the silver content of the ores, so that although the *mantos* are continuous throughout the extent of the mine, they consist of workable ore in restricted areas only.

The mine is equipped with modern, electrically driven machinery and has about it an appearance of efficiency that is not commonly seen in the small, locally owned mines of South America.