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QUICKSILVER-ANTIMONY DEPOSITS OF HUITZUCO, GUERRERO, MEXICO

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ABSTRACT

The quicksilver-antimony district of Huitzuco, Guerrero, Mexico, is roughly estimated to have produced at least 72,000 flasks of quicksilver between the discovery in 1869 and mid-1943, and 738 metric tons of antimony between mid-1937 and the end of 1942. Much of the quicksilver and all the antimony came from one mine, the La Cruz.

The dominant rock in the region is limestone that is probably Cretaceous. When this limestone was broken by compressional faults, massive parts were extensively brecciated along faults, and thinner beds were isoclinally folded. Small stocks of biotite granite porphyry and related rocks, exposed at the margins of the district, later intruded the limestone. The fine-grained material of the breccia was dolomitized, after which there was a more extensive replacement by anhydrite, which selectively replaced larger blocks of the breccia, together with much of the adjacent limestone. Anhydrite readily weathered to gypsum, in which many pits and tubes were dissolved by water from the surface; and terrace alluvium, soil, and other surface rubble slumped into these cavities. Solutions carrying mercury and antimony worked along the dolomite breccia to the connecting rubble-filled cavities, replacing some of the dolomite and rubble with stibnite and livingstonite. This rare antimony-mercury sulfide is the sole primary mercury ore mineral in the district, which in this respect is probably unique. Weathering of the porous rubble decomposed these primary minerals to antimony oxides and cinnabar.

Only one company in 1943 was mining the livingstonite-stibnite deposits in bedrock, but hundreds of independent miners were working the weathered surface deposits. Good livingstonite ore adjoining that in the rubble probably remains undiscovered, but to find it might require extensive exploration. Ore reserves in the district have not been determined, and no estimate can be given even for inferred ore.

INTRODUCTION

The quicksilver-antimony deposits of the Huitzuco district are in a zone extending from 2 kilometers to 4.5 kilometers south of the town of Huitzuco, which is about 26 kilometers (16 miles by speedometer) east of Iguala, the principal city in north-central Guerrero (fig. 7). The road from Huitzuco to Iguala is the only practicable route of transportation. Though rough and unpaved, this road is passable even during the rainy season, which extends from June to October. From Iguala an excellent paved highway and the Balsas branch of the Ferrocarriles Nacionales de México lead to Mexico City. Most shipments from Huitzuco are carried by truck to Iguala and from there to Mexico City by train.

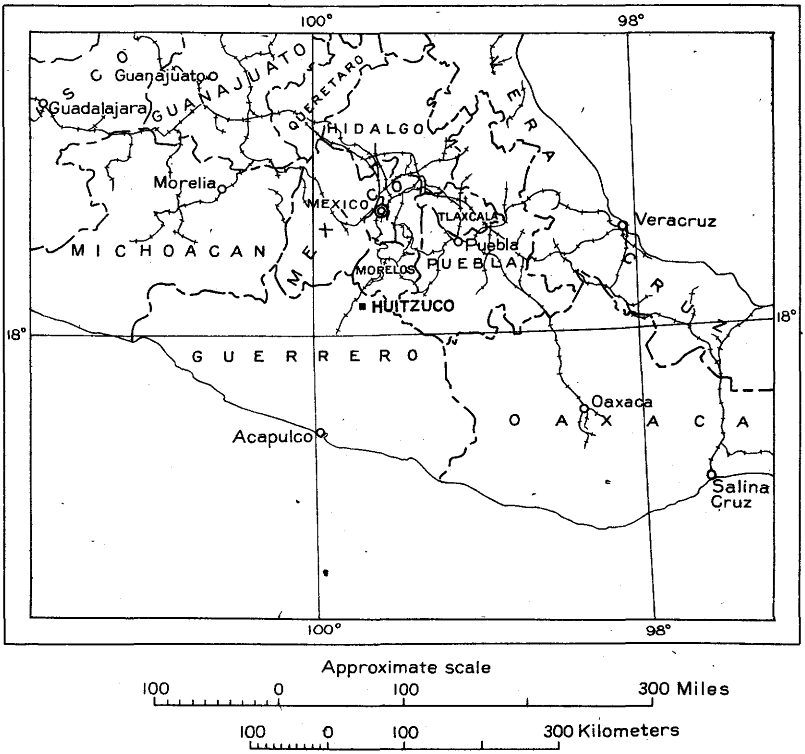

Figure 7.--Index map showing location of Huitzuco quicksilver-antimony district.

Only one large company, the Explotadora de Mercurio de Huitzuco, S. A., was operating in the district in 1943. This company owned the La Cruz mine, by far the greatest producer, and the San Agustín and Agua Salada mines, together with some surface pits worked by independent miners (see pl. 8). Unlike the independent miners, who worked by hand methods, the company used modern equipment, and concentrated the ore at the mine in a flotation plant which, when running at capacity, could treat 160 tons of ore daily. Until November 1942 the concentrates were shipped to Los Angeles for smelting, but since then they were sent to the smelter of Metalúrgica de México, in Mexico City. The La Unión property (pl. 9, and 11 on pl. 8) was being explored by the Minerales de Mercurio y Antimonio, S. A., backed by John H. Alter. A group of perhaps 150 to 200 independent men was working on the La Unión claim. Most of the independent miners, however, were grouped at pits east and south of the La Cruz mine (1-8, pl. 8).

Labor seemed plentiful, and it has a long tradition of mining within the district as well as in other parts of northern Guerrero. The men who worked for the company were organized into a strong union under favorable laws. Besides these there were a large number of "gambusinos" and "buscones," who worked shallow mines on a small scale by hand methods. Gambusinos worked their own claims, whereas the buscones, who were more numerous, worked for themselves on company property. They mined large open pits, and they had access to the upper workings of the La Cruz mine.

Electric power was obtained by the Explotadora de Mercurio de Huitzuco, S. A., from the Cía. Mexicana de Luz y Fuerza Motriz, S. A., over a direct line from Iguala, and was distributed to their three mines, the La Cruz, San Agustín, and Agua Salada.

Geologic field work was done in the district from February to November 1943, as part of a program sponsored by the Interdepartmental Committee on Cultural and Scientific Cooperation, under the auspices of the Department of State. Under this program the Instituto de Geología of the Universidad Nacional de México, the Dirección General de Minas y Petróleo of the Secretaría de la Economía Nacional, and the Geological Survey of the United States Department of the Interior carry on cooperative investigations of geologic and mineral resources problems. Ing. Norberto de la Rosa of the Dirección General de Minas y Petróleo, took part in the field work for several weeks, after which Ing. David Hernández Ortiz, of the same organization, continued. Sr. Germán García Lozano, Jr., gave valuable assistance during the first part of the season.

A geologic and topographic map of the part of the district that contains most of the workings was made on a scale of 1:2,500 with plane table and alidade, using as a base an expansion of the triangulation net from La Cruz to Agua Salada, established by engineers of the Explotadora de Mercurio de Huitzuco, S. A. (pl. 8). Their triangulation point near the main shaft of the La Cruz mine, at the altitude of the shaft collar, was taken as a datum, arbitrarily assumed to be 1,000 meters above sea level. Aneroid readings have indicated that this is in fact its approximate altitude. The regional sketch map (pl. 7) has little control, being merely a rough diagram showing relative positions of large rock masses. The underground geology of the La Cruz and San Agustín mines was plotted on a scale of 1:500, for the most part on maps furnished by the company (pls. 10, 12-18, 22, and fig. 12). As the Agua Salada mine (fig. 13) was flooded, its underground geology could not be studied.

Generous hospitality was offered by Mr. W. J. Moir, general manager for the Explotadora de Mercurio de Huitzuco, S. A., and by Ing. Jesús García Guerrero, mining engineer. Other officials of the company and members of its staff, especially Sr. Néstor de la Torre, mine superintendent, and Mr. E. C. Salisbury, consulting geologist and mining engineer, were cordially cooperative, communicating much valuable information. Mr. John Alter was similarly helpful with regard to the La Unión property. Stimulating discussion in the field was contributed by Mr. W. F. Foshag, who is in charge of the Geological Survey's program in Mexico, by Mr. David Gallagher, by Mr. D. E. White, and by Mr. E. B. Eckel, members of the Geological Survey. The manuscript was criticized constructively by Mr. E. B. Eckel, by Mr. Ward Smith, and with particular care and skill by Mr. F. C. Calkins.

HISTORY AND PRODUCTION

Quicksilver minerals were discovered at the Coahuilote workings (3, pl. 8) in 1869, according to a statement by Sellerier in an early report;1/ later writers, however, give 1873-74 as the period of discovery. The property was bought by Sr. Thevenet, who organized the company Urriza Thevenet y Arnais and worked the deposits from 1879 to 1885. Extensive mining started when Sr. Romero Rubio and Ing. Luis Saulny acquired the Thevenet property, together with almost all the other properties that were being exploited. The La Cruz mine was developed rapidly, so that shortly after 1895 the main shaft had reached its present depth of 215 meters (705 feet) and the large ore body on the San Andrés level had been outlined. After Sr. Romero Rubio died, in 1896, the administrators of his estate continued to operate the mine, under the name of Minas Unidas de Cinabrio Cruz y Anexas, for 20 years, and then leased the property to Lewis and Lujan. For some years after Sr. Rubio's death there was little activity, and the mine was abandoned during the 1910 revolution, but a little work was done between 1910 and 1925.

The Explotadora de Mercurio de Huitzuco, S. A., was organized in Mexico City on January 2, 1931, and the mining property was purchased from Cía. Minerales de Huitzuco, S. A., in the same month. As the mine was at that time under water, the new company continued the old practice of buying ore from independent miners as its main source of production until 1934. In 1935, pumps were installed, which made it possible to sample the fills, of which there were a large quantity, and the fills are said to have averaged 1.75 percent quicksilver. On the basis of these favorable results a flotation plant was built. When the fills were exhausted, pillars were mined and new ore bodies were opened. During 1943 the plant treated about 130 tons of ore a day.

Gophering by independent miners preceded systematic mining. Typical products of gophering are large pits and irregular subsurface workings extending from them; such openings have been made in oxidized ore at several centers of mineralization near the La Cruz mine, and also in the La Union, La Concepcion, and La Blanca claims (pls. 8 and 9). The workings at the San Agustín mine, in the Concepcion claim, were the only ones being systematically explored in 1943. Systematic exploratory and mining operations were merely begun by Romero Rubio, and they were not continued by the Explotadora de Mercurio de Huitzuco, S. A., until 1942. In early summer of 1943 the Minerales de Mercurio y Antimonio, S. A., started sinking a shaft in the mineralized gravel at another group of workings, in the La Unión claim.

It has been estimated that during the period of greatest activity, which was in 1940 and 1941, between 1,000 and 1,200 men were working on dumps and in irregular, shallow workings, but during the peak of 1943, there were probably no more than 600 or 700. The number of small retort shacks near dumps, as shown on the geologic map of the region (pl. 8), shows the relative activity of each area, and when tripled it indicates roughly the number of men working in that area.

1/ Compiled from Sellerier, Carlos, El Mineral de Huitzuco, Estado de Guerrero: Minero Mexicano, vol. 33, pp. 301-304, 1898.

Santillán, Manuel, Informe geológico relativo al mineral de Huitzuco, Guerrero: Boletín Minero, vol. 32, pp. 1-2, 1931.

Vaupell, C. W., Mercury deposits of Huitzuco, Guerrero, Mexico: Am. Inst. Min. Met. Eng. Tech. Pub. 842, pp. 2-3, 1938.

Records of Explotadora de Mercurio de Huitzuco, S. A., 1937-43.

Production records prior to 1937 are incomplete, and there is some disagreement between data from different sources, but these data indicate at least the order of magnitude of the production. Up to 1885, according to Halse's estimate,2/ about 30,000 flasks of quicksilver were recovered. Sellerier 3/ reported (see table 3) that the production during the period 1886-96 was 28,870 flasks of quicksilver, although Vaupell 4/ reported that the production from 1885 to 1906, which includes the same period and ten years more, was only 22,116 flasks.

Table 3.—Quicksilver production in Huitzuco district, 1886-96

Year	Average percentage of quicksilver	Flasks
1886	1.0	1,780
1887	1.0	2,229
1888	1.0	2,507
1889	.91	2,496
1890	.91	1,763
1891	.91	3,123
1892	.91	4,806
1893	.62	2,436
1894	.62	2,051
1895	.62	2,800
1896	.62	2,779
Total...............		28,770

From July 1937 to the end of 1942 the Explotadora de Mercurio de Huitzuco, S. A., produced about 7,800 flasks of quicksilver and 738 metric tons of antimony, as shown in table 4.

The La Unión company produced in 1930-32 about 1,120 flasks according to official records, but there is no record of the quicksilver recovered by the many independent miners on the property.

Independent miners sold about 5,000 flasks of quicksilver to Sr. Honorato Castrejón, the principal buyer in Huitzuco, from 1940 to 1943, as listed in table 5. During 1940 and 1941 Sr. Castrejón bought approximately 60 percent of the independent production, and since 1941 he has handled all of it.

A negligibly small portion of the quicksilver bought by Sr. Castrejón came from other places, such as Las Pailas, Huahuaxtla, Coahuilotla, and even Las Fraguas. The independent production fluctuates greatly according to the price of quicksilver, and it tends to diminish during the rainy summer months, when the workings are wet and dangerous and some of the miners turn to farming.

GEOLOGY

The dominant rock of the region is a limestone that is believed to be Cretaceous. The limestone was brecciated by

2/ Halse, Edward, The quicksilver mines and reduction works at Huitzuco, Guerrero, Mexico: North of England Inst. Min. and Mech. Eng. Trans., vol. 45, p. 86, 1895.
3/ Sellerier, Carlos, op. cit., vols. 33 and 34, 1898-99.
4/ Vaupell, C. W., op. cit., p. 2.

compressional faulting, and was folded, at least locally, near the faults. Small bodies of granite porphyry were intruded into the limestone but produced little contact metamorphism. Solutions presumably from the same igneous centers altered some of the limestone breccia and nearby massive limestone to dolomite, and later to anhydrite. Replacement by anhydrite spread farther than the dolomitization, and favored limestone rather than dolomite. In anhydrite weathered to gypsum, water from the surface dissolved cavities, which became filled with gravel and surface rubble from a high terrace. Solutions bearing mercury and antimony then replaced some of the dolomitized breccia and some of the rubble with livingstonite and stibnite; weathering decomposed the livingstonite to antimony oxides and cinnabar.

Table 4.—Quicksilver and antimony production of La Cruz mine, Huitzuco, from July 12, 1937, to October 7, 1943
[From records of the Explotadora de Mercurio de Huitzuco, S. A., at the mine office in Huitzuco]

Concentrates at Huitzuco

Year	Dry weight in kilograms	Percent quicksilver	Quicksilver in kilograms	Percent antimony	Antimony in kilograms
1937.....	496,170	8.27	41,496.2	27.8	137,676.0
1938.....	1,176,567	7.87	92,621.1	25.1	295,764.2
1939.....	908,569	9.33	84,722.1	27.8	252,310.2
1940.....	665,401	7.74	51,466.7	22.9	152,803.6
1941.....	676,075	7.67	51,865.7	25.2	170,021.8
1942.....	518,824	6.29	32,732.6	22.3	118,357.0
1943.....	497,260	5.59	27,904.6	23.0	114,201.4
Totals.	4,938,866	7.75	382,809.0	25.3	1,241,134.2

Recovery at smelter

Year	Quicksilver		Antimony
	Kilograms	Flasks	kilograms
1937.......	36,299	1,052.96	110,778.6
1938.......	83,552	2,423.8	224,190.3
1939.......	37,537	1,031.8	96,470.5
1940.......	42,993	1,247.4	100,586.8
1941.......	44,922	1,303.1	127,725.5
1942.......	25,282	732.7	78,236.2
Totals	270,585	7,791.76	737,987.9

Table 5.—Quicksilver production of independent miners, 1940-43 (in kilograms)

	1940	1941	1942	1943
January.....	2,300.1	5,075.8	4,962.0	2,715.5
February....	1,909.1	5,294.8	6,823.2	4,081.6
March.......	2,437.4	5,571.4	6,111.3	7,965.7
April.......	3,390.4	4,073.0	5,823.6	6,011.3
May.........	3,328.5	4,589.3	5,441.5	5,640.3
June........	2,436.0	3,996.3	4,193.5	2,777.3
July........	1,841.2	3,719.8	2,505.0	2,359.0
August......	1,734.8	3,843.8	4,117.8	4,747.1
September...	3,540.2	861.0	3,841.9	2,640.7
October.....	3,033.8	2,871.0	3,910.7	2,671.7
November....	2,446.7	5,392.7	3,074.3	....
December....	2,779.1	3,327.5	3,246.9	....
Totals....	31,177.3	48,616.4	54,051.7	41,610.2

TOTAL. 175,455.6 kilograms or 5,086 flasks

Rock units

Limestone.—The oldest rock in the district is gray, fine-grained, massive limestone, which weathers light bluish gray. Within the area that was geologically mapped, few outcrops of limestone project above the slope rubble and calcareous surface crust. In these outcrops the limestone is generally massive, so that the attitude of the bedding can rarely be determined except by the orientation of siliceous nodules. Although all of the limestone exposed in the region is massive, some apparently was thin-bedded, for part of the dolomite and anhydrite that replaced limestone is thin bedded (fig. 8, A).

Along the faults, some of the limestone was notably brecciated. The breccias consist of angular and subangular fragments, some of which are as much as 20 centimeters across, although 5 centimeters is a more usual size (see fig. 8, B). These fragments are embedded in a matrix of fine-grained limestone, which has a distinctive pinkish-gray tint in some places but elsewhere has a gray color much like that of the fragments. Irregular fissures through the breccia contain banded, coarse-grained calcite, which is colloform where it does not completely fill the cavities. Such material is notably well displayed in the gully northwest of the El Real ruins and in the area shown at the northwest corner of the geologic map (pl. 8). That the breccia is of tectonic origin, and not an intraformational sediment, is indicated by its general alinement northward across the regional trend of the beds. This breccia should not be confused with the hard, caliche-cemented surface crust on many of the limestone hillsides. The crust weathers gray like the old breccia, but on freshly broken surfaces the matrix is light buff or cream-colored, enclosing the dark-gray fragments of limestone and limestone breccia.

The massive limestone considered Cretaceous 5/, contains fragments of fossils, some of which are apt to weather to somewhat siliceous nodules. Diagnostic features, however, have been obliterated in all those that were seen.

Terrace gravel.—An old alluvium deposited on an old erosion surface in this district is worthy of special consideration, because it contains some quicksilver deposits. South of the district, this alluvium rests undisturbed on a well developed surface that is probably part of one of the peneplains in northern Guerrero. Figure 9, A, shows the profile of the surface south of San Agustín mine. The boulders, cobbles, and pebbles in the alluvium consist of various igneous rocks and of limestone, limestone breccia, and a little siliceous siltstone and chert; they thus differ considerably in general make-up from the underlying bedrock, which consists of anhydrite, limestone, and granite porphyry. Anhydrite and gypsum are notably scarce, if not altogether lacking, in the old alluvium—as they are, also, in the later alluvium of the floodplains, even among anhydrite hills—and no cobbles of dolomite were seen. On the hills around the mines, which are lower than the peneplain, the terrace alluvium has slumped down the slopes, mixing with clayey soil to form a typical slope rubble without stratification (fig. 9, B); but the cobbles of rhyolite and limestone which are found on isolated hills of anhydrite are clearly remnants of a capping of transported material. Solution cavities in anhydrite and gypsum, and

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5/ Santillán, Manuel, op. cit., p. 2.

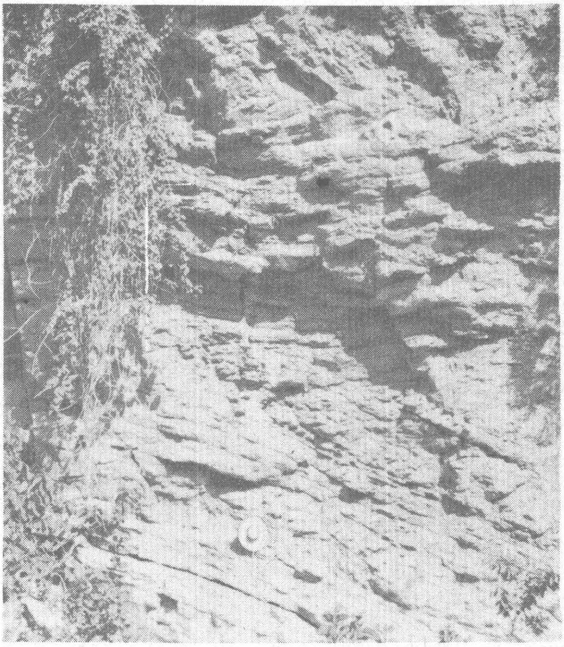

Figure 8, A.—Isoclinal folds in cliff between San Agustín and Agua Salada mines.

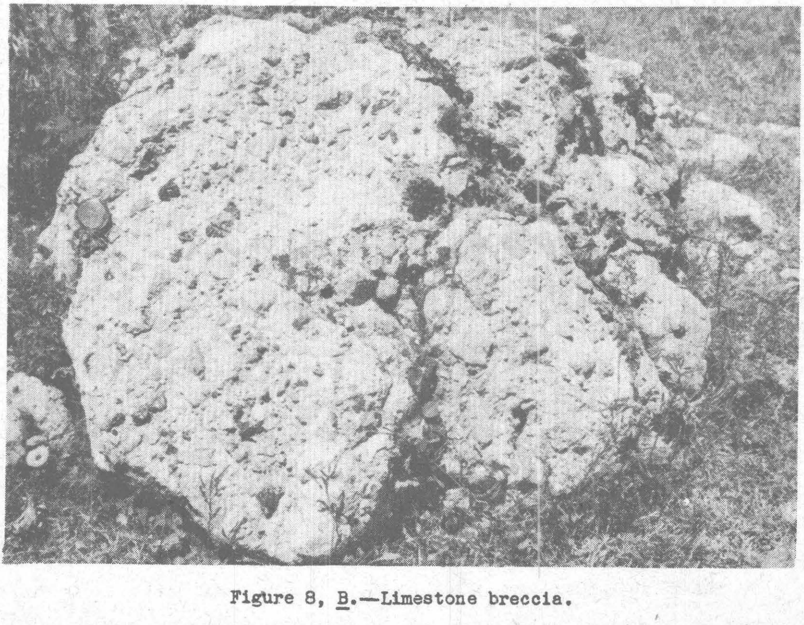

Figure 8, B.—Limestone breccia.

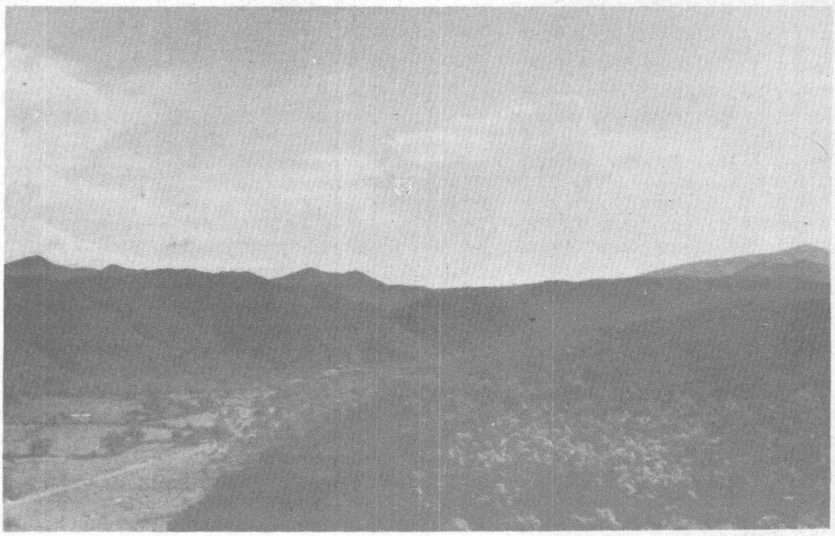

Figure 9, A.--Profile of high terrace south of San Agustín mine.

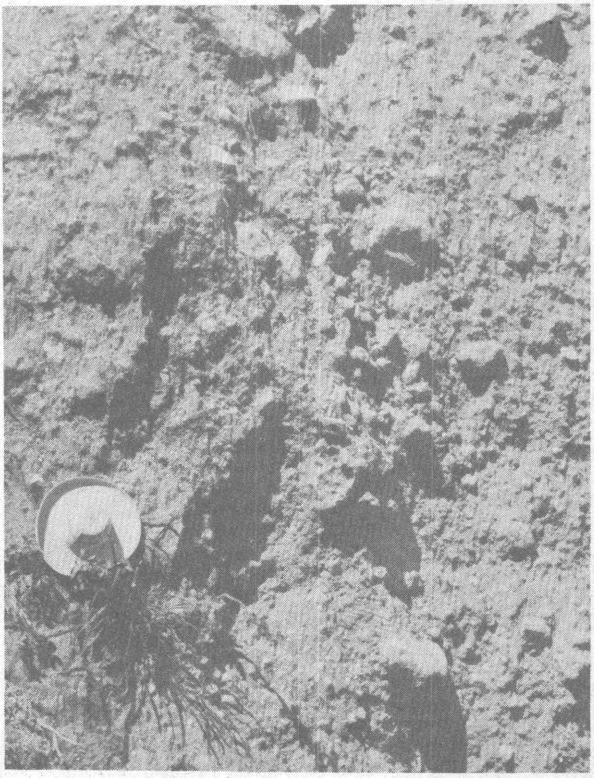

Figure 9, B.--Terrace gravel in typical mineralized rubble, La Unión pit.

sinkholes in limestone, have been filled with this slumped material, together with some that has been washed in by storm torrents.

Large areas on the geologic map are shown as terrace gravel. This gravel is mapped wherever it obscures the underlying rock, although in some places it is known to be of considerable thickness and elsewhere no more than a veneer. On the ridge back of San Agustín mine, from El Baluarte (10, pl. 8) to La Unión (11, pl. 8), the formation is 15 meters thick on the western part, as indicated by projecting the contacts and as checked by intermediate workings, and at the La Unión shaft it is more than 40 meters thick. On much of the hilly surface east and northeast of La Blanca workings (9, pl. 8), on the other hand, surface pits demonstrate that the old alluvium is relatively thin.

Contacts between gravel and older rocks are represented on the geologic map in some detail where the gravel is underlain by anhydrite, as it is, for example, in the area north of the La Cruz mine. For in areas of gravel-capped anhydrite, rubble-filled solution cavities extend to unpredictable depths, and possibly some of them contain ore. Where the bedrock is limestone, as along the western border of the area mapped, the gravel areas do not have this economic interest and are omitted or outlined in less detail.

Igneous rocks.—No igneous rocks crop out within the mining area, but several intrusive bodies are exposed not far outside the borders. A small stock of biotite granite porphyry between anhydrite and limestone is exposed about 1½ kilometers southeast of La Unión (pl. 7). In the steep hill about 1½ kilometers east of Huitzuco there are exposures of biotite granite porphyry belonging to the igneous complex which forms the prominent range north of town, together with its foothills. Along the border of the complex, porphyry dikes and sills, possibly of dacitic and andesitic composition, are intruded into limestone. Some of the stream-borne material from the north is typical rhyolite.

Biotite granite porphyry from the stock southeast of La Unión is medium to light gray, faintly tinged with violet. Phenocrysts of quartz and biotite are conspicuous, and feldspar abundant, in a finely granular groundmass. The largest quartz grains are about 5 millimeters in diameter but mostly near 2 or 3 millimeters, and the biotite individuals are about 1 or 2 millimeters, and the grains in the groundmass are less than 1 millimeter in diameter. The porphyry seems to grade upward into a fine-grained rock, which may be a dacite porphyry, for it contains much less quartz than the granitic porphyry, and hornblende in place of biotite. Flow structure in the fine-grained rock dips vertically. The contacts of these rocks with limestone and anhydrite are concealed and no contact-metamorphic rock is exposed.

Rocks formed by replacement.—Both the dolomite and the anhydrite in this district have been formed by hydrothermal replacement of massive limestone and of fault breccia in limestone. Near Apipilulco, about 30 kilometers southwest of Huitzuco, another zone of gypsum, which also may be anhydrite where not weathered, has been considered a hydrothermal replacement of limestone.6/ The little dolomite that crops out at Huitzuco is mostly in the strip between the Trinidad shaft and the Coahuilote pit, where it forms irregular masses in a zone of anhydrite.

6/ Santillán, Manuel, Geología minera de las regiones norte, noroeste y central del Estado de Guerrero: Inst. geol. México, Bol. 48, pp. 98-99, 1929.

Thin beds of dolomite a few centimeters thick, interbedded with the anhydrite and lying in recumbent folds, are exposed in the cliff between San Agustín and Agua Salada mines (fig. 8, A). Much of the dolomite is black, though some is gray or mottled and banded. All of it is coarse-grained and rather porous. Some rock resembling dolomite seemed to be limestone, as it effervesced in dilute hydrochloric acid. Different parts of an outcrop that appear homogeneous may react differently to acid. Underground the distinction between dolomite and limestone is sharper; all the carbonate rock in the mines, except on the lowest level of La Cruz mine, is dolomite. Some of the dolomite forms pods, lenses, and more irregular bodies in anhydrite, but much more of it has forms inherited from the small fragments of limestone breccia and the fine-grained matrix or gouge which it has replaced.

Anhydrite and gypsum grade into each other, and in some places they are intermingled, so that it is often impracticable—and often also, unnecessary—to say which is present or which predominates. Contrary to strict accuracy, therefore, in some places where the material in question may be either anhydrite or gypsum or both, it will be referred to as anhydrite.

Anhydrite is weathered to gypsum at the surface. It occupies an oblong area about 5 kilometers long and 1½ kilometers wide that extends from a point north of the La Cruz mine southward beyond the mining district, as shown on the generalized map of the regional geology (pl. 7). Much of the anhydrite in the area mapped in detail is overlain by terrace gravel, especially in the southern part (see pl. 8).

Where it is not covered by transported rubble, the anhydrite supports little vegetation and forms conspicuous white hillsides. Prominent cliffs of anhydrite, capped and protected from erosion by the limestone that marks the upper limit of replacement, rise from the floodplain along the road to the San Agustín mine.

When examined at close range, the anhydrite and gypsum appear dominantly white, but are banded with gray and black in different proportions and spacings. In general there is little gray. Some of the anhydrite, especially underground, is as black as the dolomite. The banding tends to lie parallel to the original bedding, although in some places it was controlled by transverse joints. The anhydrite is fine grained, and the gypsum disintegrating at the surface has a sugary texture.

Residual masses of limestone and dolomite enclosed in anhydrite tend to be lenticular or to form thin sheets. The smaller masses are crossed by veinlets of anhydrite, which divide them into angular blocks. The residual inclusions in the mines are dolomite, but those on the surface between the mines are limestone.

Structure

The regional structure is difficult to decipher, for the bedrock is largely covered by surface crust, by old and new alluvium, and by rubble; vegetation is generally heavy; the limestone is massive and has few local marker beds; and the trend or location of alteration contacts is unpredictable. It has nevertheless been established that, before mineralization, the rocks were brecciated along certain zones and were folded isoclinally near the breccias, and that later compression faulted the ore and breccia. Joints and other fractures have controlled solution of cavities in the limestone and anhydrite.

Folds.—Isoclinal folding may have been widespread, but few of the folds are exposed. Some are expressed by dark banding in anhydrite at the surface near the Trinidad shaft of the La Cruz mine, and others by thin residual beds of dolomite in anhydrite exposed in the cliff between the San Agustín and Agua Salada mines (fig. 8, A). The exposed folds are recumbent and strike nearly north. They are older than the ore mineralization and probably contemporaneous with the major pre-mineral faulting.

Faults and other fractures.—A major zone of brecciation, earlier than the mercury-antimony mineralization, was opened by many of the workings in the La Cruz mine, from the Socavón level near the surface to the San Martín level, 230 meters below the collar of the shaft. The zone trends about N. 40° W. above the San Andrés level, and its general dip is about 35° SW.

Another fault zone, which intersects the first, is marked by a zone of poorly exposed limestone breccia that trends northward on the surface from a point southeast of the tailings pond to the gully northwest of El Real ruins, and by an ore shoot that trends northward from the Rosita stope up to the El Carmen level.

Tonguelike masses, 2 to 3 meters thick, of dolomitized fine-grained breccia and gouge extend into gashes in the wall rock. These are well exposed in three dimensions on the San Cayetano, Santo Natalia, and San Antonio sublevels in the La Cruz mine (pl. 15) and the -40 level of the San Agustín mine (pl. 22). The attitude of the gashes (see geologic sections, pls. 19-21, 24) suggests that the fault movement was reverse.

The dolomitized fault zone of the San Agustin mine heads north toward the La Cruz zone, but the lack of intermediate exposures prevents tracing a connection. Likewise the northward trend of the La Unión mineralization toward the El Coahuilote workings suggests another parallel fault, but that, again, cannot be proved because of alluvial cover. These projected lines are merely hypothetical. It is nevertheless probable that in general the alteration follows a series of north-trending fracture zones.

Postmineral faults were seen only underground, where they are marked by extensive slickensides and by fluting, graphite, and pulverized ore but by little breccia. It is therefore understandable that, because of the lack of stratigraphic markers, these faults are lost in the poor exposures at the surface. The most prominent of them forms the bottom of the big stope on the San Andrés level. Deep fluting indicates that the direction of movement was along the dip, and in spite of the gentle dip, which ranges from 10° to 25°, displacements of old breccia and ore demonstrate that the movement was normal. Minor faults in the Rosita stope, although they displace the ore normally (see sec. A-A', pl. 19) are prominently fluted nearly horizontally, which may mean that the stress was compressional. Most of the faults swing in strike and dip, are short, and interlace with one another.

The approximate alinement of some sinkholes in limestone, and of solution cavities in anhydrite, may mark faults or, more likely, joints. The line of sinkholes extending N. 70° W., shown in the northern part of the areal map, is roughly parallel to the most pronounced and best-defined system of joints, which strikes N. 70°-85° W. Further parallelism is shown by the drainage in the western part of the area, outlined more extensively on the regional sketch map. Less well developed joints trend roughly north-northeast.

In summary, the major pre-mineral structures are faults that trend northward and northwestward, and the postmineral fractures, principally joints, trend between northwest and west.

Figure 10, A.—Vertical tubes dissolved in gypsum at El Socavón level, La Cruz mine; B.—Tubes dissolved in gypsum at the surface.

Solution cavities.—The anhydrite contains vertical tubes which are of exceptional interest (see fig. 10, A and B). Large tubes filled with rubble are locally called "trojes" because of their resemblance to the cylindrical corn-cribs of the region, and the smaller ones are called "tecontles." Some of the tube filling contains ore.

The tubes are most numerous near the surface, where many merge laterally to form composite tubes. The tube diameters are larger near the surface. At the La Cruz mine, some of the tubes at the surface can be seen to have diameters of several meters, and some on the Socavón level, about 35 meters below the surface, are only a few centimeters in diameter. This seems to result in greater measure from lateral merging of a large number of small tubes than from gradual widening of individual tubes. Some tubes show a series of bulges. In horizontal section the small tubes are circular and resemble drill holes whereas the larger ones may be circular, oval, or scalloped, or may have greater irregularities.

Vaupell 7/ has stated that these tubes were formed by the action of hot springs and geysers, and other geologists have expressed orally their agreement with this view. The fluting and chambering have been regarded as the result of mechanical abrasion by particles that were forced upward by the violent action of the geysers. It has further been pointed out that the tubes are similar to those made by the cutting and abrasive action of drills, that they are vertical, that they are in a zone of hydrothermal activity, and that their rarity required a rare process such as the action of geysers. But this theory leaves unanswered the questions why geysers bored vertical holes rather than more or less inclined ones; why the holes diminish in number with depth, being rare even on the shallow Socavón level; why they are not found on the lowest levels if the action came from below; and why geyser deposits or remnants of them are not found near the vents.

A simpler explanation, raising no such difficulties, is that the tubes are the result of solution by water descending from the surface. Some may be merely enlargements of joints, and the more even slender tubes may be the work of dripping water, which when the cavities were once started would deepen them vertically provided the water seeped out fast enough through rock pores or minute joints at their bottoms. The tubes would be enlarged by water trickling down the walls.

The principal evidence in favor of this origin is as follows: Surface water dissolves channels in gypsum even more effectively than in limestone. The verticality of the holes immediately suggests the agency of the vertical force, gravity, acting on trickling water, or, still more effectively, on freely falling water. Well developed rillmarks on steep outcrops of gypsum tend to become vertical, and in some cases they become nearly tubular. The rarity of perfect tubes in other regions may depend on the fact that the conditions necessary to their formation are seldom found together. Some of these conditions are: uniformly and easily soluble rock; porosity, minute joints, or other ways of escape for the water, keeping the tube essentially empty, which in turn requires a low water table, and a readily pervious screen of some such material as gravel to prevent the tubes from becoming clogged with debris.

ORE DEPOSITS

Minerals

The quicksilver-antimony ore of Huitzuco is mineralogically simple. In unweathered bedrock the quicksilver is in living-

7/ Vaupell, C. W., op. cit., p. 5.

stonite ($HgSb_4S_7$) and the antimony is partly in livingstonite and partly in stibnite (Sb_2S_3). In the weathered surface deposits the principal ore mineral is cinnabar (HgS), although metacinnabarite (HgS), and terlinguaite (Hg_2ClO) have been reported 8/ among the associated antimony oxides and barcenite.

The following minerals have been reported in the Huitzuco ore, according to Vaupell: guadalcazarite (near the composition of cinnabar but containing up to 4 percent zinc), tiemannite (HgSe), onofrite (Hg(S,Se)), and "other rare arsenides and selenides of mercury, antimony, and thallium."9/ None of these were seen by the writers.

Pyrite is scarce, and gangue minerals are negligible. The ore is accompanied, however, by native sulfur, selenite, calcite, graphite, and, at one place, by fluorite.

Most of the livingstonite in the Huitzuco ore forms columnar subhedral or anhedral crystals up to 10 centimeters long, in radiating groups or less regular aggregates replacing dolomite, but much of it is in finer-grained masses. The mineral is lead-gray and easily scratched by a fingernail (hardness 2); it has perfect cleavage, high specific gravity (4.81), and red streak. It closely resembles stibnite, from which, however, it may readily be distinguished by its red streak, or even by the reddish coating made by rubbing it. The stibnite is typical, and will not be described further.

Stibnite and livingstonite are closely associated in various proportions, although either can be found alone. Both replace dolomite. Formerly it was thought that the proportion of antimony increased with depth, but the operators of the mines in 1943 said that a certain antimony-quicksilver ratio is characteristic of each particular ore body without relation to depth. At the San Agustín mine the ratio of antimony to quicksilver was said to be even decreasing downward from perhaps 10:1 to 6:1. The ratio in average ore from the La Cruz mine at that time was 4:1.

The minerals associated with the ore in unoxidized deposits are much more widespread than the ore minerals themselves. Native sulfur forms pockets as much as 30 centimeters long in ore and much smaller pockets and stringers in rock associated with ore, but it is also found in gypsum on the surface hundreds of meters from known ore. Large single crystals of clear selenite were noticed only near ore, where they were associated with sulfur. Finely powdered graphite is concentrated along postmineral faults. Calcite forms irregular stringers throughout the limestone and dolomite, with no special relation to the ore. The only fluorite seen was rather fine-grained and sparse; it occurred in the ore on the San Martín level of the La Cruz mine.

The chief minerals of the oxidized ore are powdery cinnabar and barcenite. Barcenite, which was first recognized at Huitzuco 10/ and called a new mineral, seems to be a mixture of antimony oxides, cinnabar, and powdery calcite. The antimony oxides, which are black and massive, in some places form pseudomorphs after livingstonite. Cinnabar and calcite are sprinkled irregularly through them.

8/ Santillán, Manuel, op. cit., p. 3.
Vaupell, C. W., op. cit., p. 11.
9/ Vaupell, C. W., idem.
10/ Mallet, J. W., On barcenite, a new antimonate from Huitzuco, Mexico: Am. Jour. Sci., 3d ser., vol. 16, pp. 306-309, 1878.

Types of ore deposits

The primary ore at Huitzuco, so far as known, was formed by deposition of livingstonite and stibnite from hydrothermal solutions, which replaced dolomite relatively near the surface.

The primary ore has been the greatest source of production, and it alone has been mined systematically. The ore of the La Cruz, San Agustín, and Agua Salada mines is of this type. Primary ore generally follows zones of dolomitized breccia diagonally and somewhat irregularly up the dip of the breccia, forming bodies that, being here and there sheetlike, are known locally as mantos. Considered in detail, the ore shoots are series of connected pods and lenses, and in some places they are rather sinuous and variable in dip (see Espíritu Santo, pl. 12). Ore has been followed downward continuously along one series in the La Cruz mine for about 400 meters, and the bottom was not in sight. According to the operators, this ore consisted mainly of closely spaced parallel lenses in a block about 110 meters long, 50 meters wide, and 40 meters high. The stope left by mining it was most accessible on the San Andrés level of the mine (see pl. 16). Individual ore shoots are relatively small (pls. 12 and 22), and some rich pockets of livingstonite are less than a meter in diameter.

In the secondary ore, the chief minerals are cinnabar and oxides of antimony, which are presumably decomposition products of livingstonite and stibnite. The antimony oxides in many specimens are pseudomorphous after livingstonite or stibnite or both. Powdery cinnabar is so thoroughly disseminated through the pseudomorphs that it seemed impossible to separate enough of the oxide for analysis, and this intimate association strongly suggests that the original mineral was livingstonite. Probably all or nearly all of the cinnabar is secondary after livingstonite, for cinnabar is found in the weathered gravel containing pseudomorphs after livingstonite but not in the adjacent unweathered rock, which contains stringers of livingstonite, and is extremely rare in the hundreds of meters of mine workings in unweathered rock. Much of the dusty cinnabar in the rubble is concentrated along clay streaks and pockets, which is thought to indicate that the secondary cinnabar was redistributed, perhaps mechanically, and in places concentrated by water circulating from the surface. It is chiefly this type that is worked by the many independent local miners.

Distribution

Ore deposits that reached the surface were densely concentrated east and south of the La Cruz mine, in the northern part of the district. There was a much smaller elongate group at La Unión, southeast of the La Cruz mine, some deposits at the San Agustín mine, west of La Unión, and relatively few others. The distribution of the ore deposits can be inferred from that of the workings shown on the geologic map of the district (pl. 8), and their relative importance from the number of retort shacks and dumps around them. The two largest dumps, however, are waste from La Cruz mine, and they fed some of the retorts near them. A few other retorts nearby were charged with livingstonite ore from the old adit of the La Cruz mine.

The best-defined alinement of ore deposits at the surface, both locally and regionally, is slightly east of north. This trend is well illustrated by the surface workings at La Unión (11, pl. 8), all of which lie near a line that points toward the workings at El Coahuilote and Gambetta (3 and 4, pl. 8). At the San Agustín mine, also, the zone of workings, though not the line of retorts, trends northward, and if projected it would aline roughly with the important pits called Las Viejas, La Tumbaga, and La Sorpresa (5, 6, and 7, pl. 8). Even the few workings at El Baluarte (10, pl. 8) trend northward, parallel to the outcrop of the livingstonite vein at Agua Salada. East of the La Cruz mine a secondary alinement along which there are many workings extends N. 70° W. The workings follow this trend from El Baco (1, pl. 8) through Los Colorados (2, pl. 8) to El Coahuilote (3, pl. 8) and slightly beyond. A less regular, parallel zone 30 to 50 meters farther south extends from Gambetta (4) through the workings of Las Viejas (5, pl. 8) to the workings farther northwest. This secondary trend is parallel to the lines of drainage and sinkholes described under structure (pp. 60-61).

This analysis of the distribution of the ore suggests that the deposits in bedrock follow the northerly trend of regional mineralization but that at intersections with the fractures of westerly trend, especially in the rubble-filled cavities dissolved along them, the ore bodies fall in line transversely.

Origin

The earliest geologic activity that affected the localization of the ores took place when compressional stresses gave rise to faults, along which breccias were formed in massive limestone, and isoclinal folds in the less massive beds. Intrusion of igneous magma probably occurred soon after. The ore-bearing solutions, however, cannot have issued directly from the masses of biotite granite porphyry exposed south of the district, for boulders of it form part of the mineralized rubble associated with the ore. The southward rake of the two mined masses of livingstonite ore, and the southward dip of the north contact of the anhydrite as determined in the lower levels of the La Cruz mine, suggest that these masses were deposited by solutions that emanated from igneous centers under the mining district or south of it.

This hydrothermal action had several effects, ore deposition being the latest. First, some of the limestone, together with much of the gouge and finger-grained breccia in the fault zones, was replaced by dolomite, but some unreplaced limestone was left in the large blocks in the breccia. The unreplaced limestone of the breccia, as well as the limestone bordering the fault zones, was then replaced by anhydrite. Anhydrite was changed to gypsum in the zone of weathering, and pits and cavities were formed—by downward-moving surface waters, as the writers believe—in the gypsum. These openings were later filled, by slumping, with material derived chiefly from early alluvium, remnants of which now cap terraces south of the San Agustín and La Unión mines (see fig. 9, A).

It was probably after all this had occurred, perhaps in Pleistocene time, that ore deposition began. A final resurgence of hydrothermal solutions deposited livingstonite and stibnite, which selectively replaced dolomite and some of the rubbly fill of large cavities that were favorably situated. Continued weathering oxidized the livingstonite and stibnite in the fill, the chief product of this change being cinnabar and dark oxides of antimony.

The age of the livingstonite relative to the rubbly fill of cavities, that is whether the livingstonite was deposited in the rubble or whether it was a clastic constituent of it, is difficult to establish. The distribution of the relatively insoluble oxidation products of livingstonite in pockets throughout the fill has a bearing on the age of the deposits and has been explained in three ways: hydrothermal deposition of ore minerals in the rubble, preferred by the writers; tearing off and dragging upward of ore minerals in bedrock by mud-geyser activity, suggested by Vaupell;11/ and detrital accumulation from weathered outcrops of livingstonite in the surrounding area, as suggested by Halse.12/ Reasons for believing that the cavities were not formed by geysers have been discussed (p. 62). It also seems improbable that detrital ore minerals from the surface accumulated in pits because they are virtually lacking in the surrounding slope rubble, and because they are present in only a few of the many pits in the mineralized zone. The possibility that the ore-bearing pits were formed directly on the outcrops of livingstonite and developed downward along veins is rejected because the antimony oxides were not concentrated at the bottoms as the pits enlarged, and were not buried by the rubble from a terrace deposit that filled the pits, as in B (3) of figure 11 but were irregularly distributed throughout the fill, as in A (4) of figure 11.

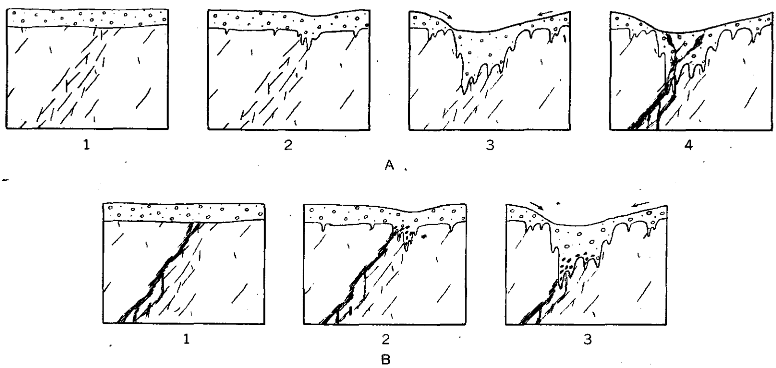

Figure 11.—Diagrammatic sections showing (A) development of rubble-filled solution pits largely before quicksilver-antimony mineralization in contrast to (B) development of pits entirely after mineralization. The distribution of ore at Huitzuco is in accordance with (A). A, (1) Fractured rock overlain by terrace alluvium; (2) pits dissolved by downward moving water; (3) enlarged solution pits filled with rubble from terrace alluvium; (4) quicksilver-antimony mineralization of bedrock, and erratic mineralization of rubble throughout pits. B, (1) Mineralized bedrock overlain by terrace alluvium; (2) vein fragments in rubble of pits formed at vein: (3) fragments of vein concentrated near vein in bedrock and buried by rubbly fill of enlarged pits.

If the ore mineralization was contemporaneous with the antimony deposition in Oaxaca not far southeast of Huitzuco, it is older than the cavity fill, because according to White and Guiza 13/ the antimony is clearly related to quartz porphyry

11/ Vaupell, C. W., op. cit., p. 6.
12/ Halse, Edward, op. cit., p. 82.
13/ White, D. E., and Guiza, Reinaldo, Antimony deposits of Los Tejocotes district, Oaxaca, Mexico: U. S. Geological Survey bulletin in preparation.

dikes that have been considered by earlier workers to be Tertiary. The gravel fill at Huitzuco is from a terrace that is probably Pleistocene, and contains cobbles of porphyry that is probably Tertiary,14/ as in Oaxaca. It seems preferable, however, to correlate the Huitzuco mineralization with the Pleistocene quicksilver mineralization of cavern fill near Coacoyula, about 40 kilometers southwest of Huitzuco.15/

The question why the rare mineral livingstonite, rather than the combination of cinnabar and stibnite that is more usual in other districts, was deposited has not been satisfactorily answered. The answer may be connected with the fact that the dolomite, in which the livingstonite is enclosed, is itself enclosed in anhydrite; for, although dolomite is not uncommon in quicksilver deposits, anhydrite associated with quicksilver is exceptional.

Reserves

No estimate of the reserves in the district has been made; it seems impossible, indeed, to estimate reserves of even inferred ore.

The location and size of the ore bodies cannot be predicted in advance of mining. The independent miners work a pocket of ore as long as it can be mined profitably, then follow traces until a new pocket is found. The known surface deposits have been worked laterally to their economic limits, and in the summer of 1943 they were being followed downward. But as the workings deepen mining costs increase, so that only the higher grades of ore can be mined. Unless new zones are discovered, therefore, which is unlikely in the more productive but well prospected northern part of the district, the production by independent miners working under present conditions will taper off. In the southern part of the district, however, new surface deposits of minor importance may be uncovered by systematic prospecting, as is suggested by the accidental discovery of good ore southwest of the La Unión shaft.

Exploration in the La Cruz mine was done with short diamond drills, a method which failed to give reliable quantitative information, doing little more than to indicate where mining should be continued. It was impossible, at this mine, to predict from the geology where an ore shoot would end or where it would pinch or widen. The ore in the San Agustín mine was almost equally unpredictable, but there is some geologic basis for expecting better ore; the ore in surface trojes may extend down to sinuous ore bodies of the primary type. The ore near the surface at San Agustín was like that at La Cruz but in smaller masses.

Hardly any underground exploration has been done except in the La Cruz mine. An extensive program of exploration at other favorable places should disclose good deposits of ore.

14/ Santillán, Manuel, op. cit. (1931), p. 3; op. cit. (1929), p. 68.

15/ de la Rosa, Norberto, García Lozano, G., Jr., and McAllister, J. F., The Coacoyula quicksilver district, unpublished information, February 1943.

Suggestions for prospecting

The surface has been rather well prospected, especially in the northern part of the district. Systematic trenching and panning on the ridge southwest of La Unión and southeast of San Agustín might possibly disclose new cinnabar deposits in rubble. In November 1943 a rich pocket was uncovered in the rubble 250 meters southwest of the La Unión shaft.

Better results might be obtained by prospecting for livingstonite ore underground. The known livingstonite ore was indicated at the surface by oxidized ore deposits in rubble. Places where other large deposits in rubble were mined should therefore be prospected to the livingstonite roots in bedrock, and the livingstonite then followed in search of pods and lenses of ore. A cheaper but less effective method would be to drill a close pattern of diamond-drill holes at the pits. It should not be assumed, however, that the livingstonite continues vertically below the surface deposit, as apparently was assumed in the program of underground prospecting in the La Cruz mine, under the Las Viejas pit (5, pl. 8). It is more probable that the ore pitches southwestward, like the shoots in the La Cruz and San Agustín mines, and drilling should accordingly be concentrated southwest of the pits.

The most promising areas lie south and west of the Las Viejas and La Sorpresa pits (5 and 7, pl. 8). Another favorable locality is at La Unión, especially southwest of the main pit. A thorough program would include prospecting of ground less definitely favorable. Holes might be drilled at depth southwest of Gambetta (4, pl. 8); at El Baluarte (10, pl. 8), to determine whether the deposits join the San Agustín shoot; and below the flood plain about 700 meters north of the La Unión pit, where the La Unión zone may intersect a westerly trending fracture.

The best way to explore the San Agustín ore body is to continue mining down the shoot. From the adit level to the -48 meter level this shoot is similar to the Socavón-Espíritu Santo bodies, though on a smaller scale. Both of these are shoots composed of lenses and pods in dolomitized breccia; they steepen and flatten, and pinch and swell from place to place, and one opened into the very large central ore body of the La Cruz mine. Both, also, ended upward in well mineralized cavity fillings.

All the livingstonite ore has been in dolomite, associated with anhydrite. Anhydrite and gypsum may therefore serve as guides to prospecting, but primary ore is not likely to be found in them except where they enclose some dolomite.

Mine descriptions

The extent and position of the underground workings are sufficiently shown by the mine maps and sections. It may be useful, however, to offer some generalizations on their geology.

La Cruz mine.—Weathered ore in the El Baco pits (1, pl. 8) led downward successively to livingstonite ore on the Socavón level, to the rich pockets of the Espíritu Santo stope, to the steep lenses of ore on the San Blas level, and to the big stope between the Carmen and San Andrés levels (pls. 10-15, 17-18). The largest stope is 110 meters long, 50 meters wide, and 40 meters high without pillars. At the San Andrés level (pl. 16) it connects with another stope on the west, which is nearly as long and 30 meters wide, and which tapers downward for about 30 meters. The big stope was bottomed by a post-ore fault that ranges in dip from 10° to 25°. In spite of the low dip the movement was normal, with a horizontal displacement of about 30 meters directly down the dip. The displacement of the ore is

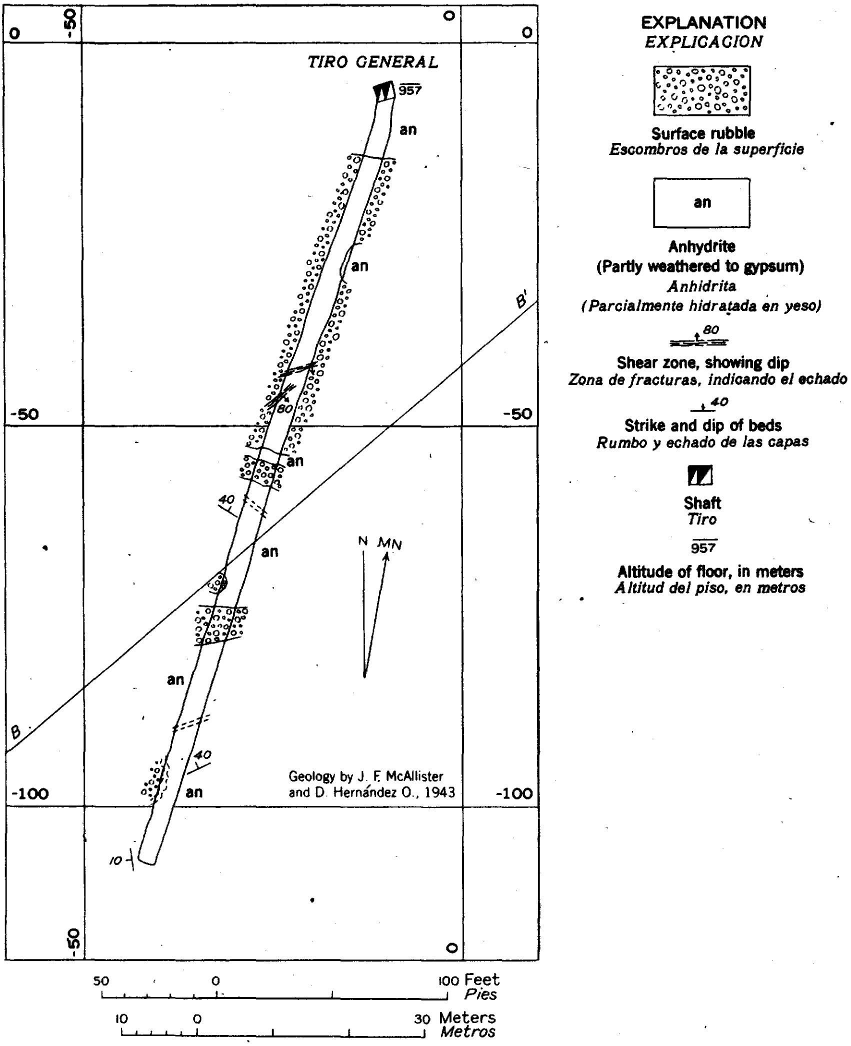

Figure 12.—Geologic map of La Ratonera, La Cruz mine.

indicated by the location of the stopes on the mine map (pl. 16) and in the geologic sections (pls. 19-21). Below the fault, the ore shoot continued down the Rosita stope to the San Martín level, where it was being mined in November 1943. The face was then 235 meters below the collar of the main shaft, and drill records showed that the ore continued downward.

Sampling was found by the operators to be unreliable in determining grade of ore in the mine; inspection gives results as satisfactory. Mill heads carried about 1.3 kilograms of quicksilver to the metric ton and about four times as much antimony. The cut-off grade was 0.9 kilograms of quicksilver to the metric ton.

San Agustín mine.—The shallow workings of the San Agustín mine (pls. 22-24) explore a livingstonite ore shoot that pitches diagonally down dolomitized breccia. No large bodies of ore have been found down to the -48 level. Otherwise the deposits are similar to those in the La Cruz mine.

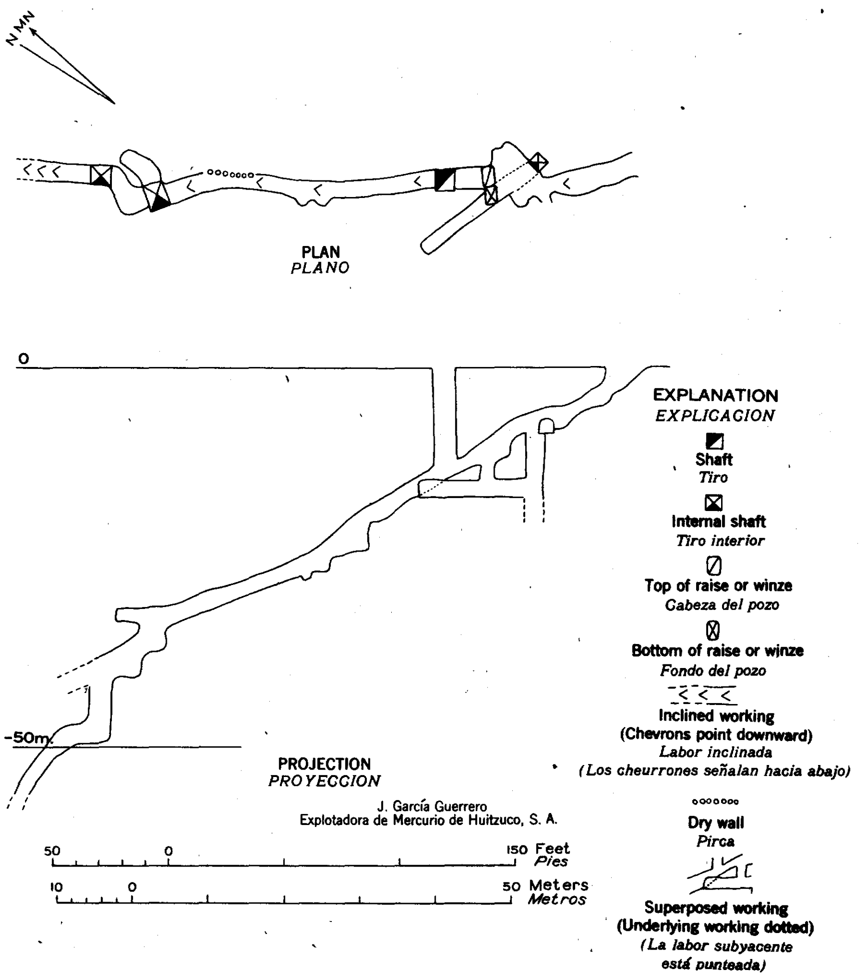

Figure 13.—Plan and projection of Agua Salada mine.

Agua Salada mine.—The Agua Salada mine (fig. 13) was not being worked in 1943, and was then flooded. It is on the only livingstonite vein that is known to crop out, but the vein is too slender to be worked profitably.

Workings in surface deposits.—The pits are shown on plate 8, and their distribution has been discussed. The largest pit is the La Sorpresa, which is about 100 meters long, 50 meters wide, and 15 meters deep. In 1943 the vertical workings continued down 45 meters farther in somewhat consolidated rubble that contained workable pockets of cinnabar. Columns of gypsum bedrock, which reached up to the surface, were irregularly distributed through the rubble, and these now stand out as isolated pinnacles. Some contain stringers of livingstonite.

The other pits and surface workings are similar though smaller. Composite grab samples of the finer material remaining in the walls were assayed with the results given below:

	Percent quicksilver
Los Colorados	0.06
North side of El Baco	.04
South side of El Baco	.05
South side of El Baco	.04
East side of El Baco	.03
La Primavera	.11

Only the sample from La Primavera (12, pl. 8) represents ore that was being burned. A composite grab sample, taken by Mr. G. C. Ridell, of ore that was being burned at La Unión in April 1942 assayed 0.13 percent quicksilver and 0.32 percent antimony. Comparison of samples of ore with samples from the pit walls shows that the surface deposits have been mined laterally to their economic limits.

APPENDIX

Conversion table

Metric	English
1 centimeter	0.39 inch
1 meter	3.28 feet
1 kilometer	0.62 mile
1 kilogram	2.20 pounds
1 ton	2,204.62 pounds or 1.10 short tons
34.5 kilograms	1 flask