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SAN JOSÉ ANTIMONY MINES NEAR WADLEY, STATE OF SAN LUIS POTOSÍ MÉXICO

BY
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SECRETARÍA DE LA ECONOMÍA NACIONAL, DIRECCIÓN GENERAL DE MINAS Y PETRÓLEO and UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO INSTITUTO DE GEOLOGÍA
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THE SAN JOSÉ ANTIMONY MINES,

NEAR WADLEY, STATE OF SAN LUIS POTOSÍ, MÉXICO

By Donald E. White and Jenaro Gonzáles R.

ABSTRACT

This is the first of a series of reports on the antimony deposits of Mexico, which are being investigated as part of a cooperative program sponsored by the interdepartmental committee on Cultural and Scientific Cooperation under the auspices of the Department of State, by the Geological Survey, United States Department of the Interior, and the Universidad Nacional Autónoma de México, Instituto de Geología, and the Secretaría de la Economía Nacional, Dirección General de Minas y Petróleo.

The San José antimony mines, on the west flank of the Sierra de Catorce, are east of Wadley, in the State of San Luis Potosí. The deposits were discovered in 1898, and since that time they have been mined almost continuously. Through 1943 the mines have produced more than 170,000 tons of ore containing more than 57,500 tons of metallic antimony, which is about one-third of all the antimony that has been produced in Mexico.

The ore-bearing rocks of the area consist largely of four limestone beds near the top of the Santa Emilia formation, which have been selectively recrystallized and altered to a coarse-grained permeable marble. In accord with Mexican usage, these beds are called "mantos."

All of the rocks have been thrown into asymmetrical folds, which strike north to northeast and plunge northeastward. The folds are cut by northwest-striking faults and fractures. The only igneous rocks that were seen in the region are andesite dikes, and these occur outside of the mapped area, at a place 5 kilometers northeast of the San José mines.

Most of the antimony ore is in the mantos near faults and fractures or is contained within the faults and fractures adjacent to the mantos. Some of the ore in the mantos is localized near anticlinal axes, particularly in places where the mantos have been faulted relatively upward against shale of the San José formation. A smaller part of the ore is in vertical beds on the eastern limbs of asymmetrical anticlines.

In the past the mines have had to depend on bodies of high-grade ore, which can readily be sorted to a shipping-grade product containing 30 percent or more of antimony. The

blocked-out reserves of high-grade ore in antimony mines are always small, for such ore is mined out as soon as it is found, and the size and shape of the high-grade bodies are irregular and are not known until the ore has been mined. Yet in spite of the unpredictable future of mines thus lacking definite reserves, the San José mines have been operating successfully for nearly fifty years.

The future of the mines depends largely upon the development of a milling process for the efficient recovery of antimony from large tonnages of low-grade oxide ores. As a result of the present work, a number of favorable areas for prospecting have been found, but the rate of discovery of new ore bodies is decreasing, while the cost of development per ton of high-grade ore is increasing. If production is to be maintained, the mine must eventually be dependent upon its low-grade reserves.

INTRODUCTION

The San José antimony mines are 11 kilometers east of Wadley, San Luis Potosí, which is 660 kilometers south of Laredo, Tex., on the Laredo-Mexico City line of the National Railroad of Mexico. The mines are on the west flank of the Sierra de Catorce, at an altitude of 2,500 meters. The antimony ore is transported 2 kilometers by tram line or by burros down to an altitude of 2,050 meters, and is then hauled 9 kilometers by truck over a good dirt road to Wadley, at an altitude of about 1,600 meters. From 1937 until 1942, labor conditions made the use of the tram line impracticable, but tramming was resumed in June 1942.

The San José antimony deposits were discovered in 1898. The Cookson interests of England soon acquired control of them and have maintained full or part control continuously until the present time, but the company or companies operating the deposits have undergone a number of changes or reorganizations. The ores were smelted at Wadley until 1930, when the placing of import duties on refined antimony brought into the United States caused a reorganization, with the formation of the Texas Mining & Smelting Co., which built an antimony smelter at Laredo, Tex. This is the largest antimony smelter in the United States, and it operates almost entirely on Mexican ores. Since 1930 the deposits have been mined by subsidiaries of the Texas company—the Republican Mining & Metal Co., Ltd., until 1938, the Compañia Minera y Refinadora Mexicana, S. A., and the Compañia Minera y Refinadora Mexicana, S. A., and the Compañia Explotadora de Minerales de México, S. A., from 1938 to 1942.

The San José mines have produced more antimony than any other district in Mexico, and they have been surpassed in production by only one or two other districts in the world. The production, insofar as it is known, is summarized in the table below. There is no detailed record of production from 1898 to 1905, but during that period the Republican Mining & Metal Co., Ltd., produced about 48,000 tons of ore from all of its properties in Mexico. Of this total, probably at least 24,000 tons was produced from the San José mines. The production of ore by years is as follows:

Antimony production, San José mines

Year	Ore (metric tons)	Sb content (percent)	Sb content (metric tons)
1898-1905	24,000*	35*	8,400*
1906	2,736	35*	957*
1907	4,130	35*	1,446*
1908	4,903	35*	1,718*
1909	5,330	35*	1,866*
1910	6,508	35*	2,279*
1911	4,754	35*	1,665*
1912	4,237	35*	1,483*
1913	3,724	35*	1,304*
1914	1,734	35*	607*
1915	136	35*	48*
1916	537	35*	188*
1917	6,076	35*	2,127*
1918	3,828	35*	1,340*
1919	2,936	35*	1,028*
1920	355	35*	124*
1921	539	35*	189*
1922	15	35*	5*
1923	**	--	---
1924	**	--	---
1925	2,894	35*	1,013*
1926	3,694	35*	1,293*
1927	5,491	35*	1,920*
1928	7,028	35*	2,460*
1929	9,877	35*	3,456*
1930	No record	--	No record
1931	7,527	35.67	2,686
1932	4,062	37.59	1,528
1933	2,829	37.75	1,068
1934	5,811	29.49	1,713
1935	5,023	26.56	1,334
1936	8,164	22.42	1,831
1937	7,592	21.10	1,602
1938	3,640	24.92	907
1939	4,416	28.02	1,237
1940	5,641	30.57	1,724
1941	4,471	34.81	1,558
1942	4,850*	35	1,700
1943	4,924	36.7	1,808
Totals	174,412		57,612

*Approximate
**No recorded production

In doing the field work on which this report is based, an area of approximately 14 square kilometers was mapped on a scale of 1:4000, with a contour interval of 20 meters. The month of April 1942 was spent in surface mapping with a plane table and alidade, and two weeks in May were spent in mapping the underground geology on the mine levels. The stopes and interlevel workings were not mapped, because they are very extensive and the necessary time was not available. The mine was re-visited by White for a period of 3 days in August 1943.

The writers are greatly indebted to all of the company personnel at Wadley for hospitality and cooperation, particularly to Mr. C. A. Stover, General Manager of the Cia. Minera y Refinadora Mexicana, S. A., and of the Cia. Explotadora de Minerales de México, S. A., and to Mr. Vicente Cisneros, Mine

Superintendent of the San José mines. Mr. V. L. Kegler, President of the Texas Mining & Smelting Co., has been very helpful in furthering the work and in supplying information on the history of the deposits and the record of past production. The company's topographic map, covering 2 square kilometers of the principal workings, has been incorporated into the topographic and geologic map of the whole area, and the triangulation system established by the company was of great use in establishing control for the plane-table mapping. The company's mine-level maps were used as a base for the underground mapping.

This is the first of a projected series of reports on the antimony deposits of Mexico, which are being investigated, as part of a cooperative program sponsored by the Interdepartmental Committee on Cultural and Scientific Cooperation under the auspices of the Department of State, by the Geological Survey, United States Department of the Interior, and the Universidad National de México, Instituto de Geología, and the Secretaría de la Economía National, Dirección General de Minas y Petróleo.

GEOLOGY

Stratigraphy

Four formations have been mapped in the area (see pls. 45 and 46). The names for these formations are based on local usage. The oldest is the Caliza del Fondo, consisting of blue-gray limestone and limy shale. Next is the Santa Emilia formation, consisting of limestone, which contains the principal ore bodies in the region. The formation is about 250 meters thick, but nearly all the antimony ore is in the upper 40 meters. The Santa Emilia formation is overlain by the San José formation, which consists of limy shale in the lower part and of interbedded shale and limestone in the upper part; and the San José grades upward into the Corona formation, which is lithologically similar to the Santa Emilia but contains only a little antimony ore.

The Caliza del Fondo was not studied or mapped in detail. The base of the formation was not seen, but the oldest rocks that crop out in the mapped area consist of blue-gray limestone overlain by gray limy shale. The original bedding in the shale has been almost completely obliterated by steeply dipping fracture cleavage. The total thickness of the formation is more than 120 meters.

The Santa Emilia formation consists of about 250 meters of blue-gray limestone in beds half a meter to 3 meters thick. Some poorly preserved fossils were found in the formation; their age could not be determined definitely but is probably Upper Jurassic.

The upper part of the formation is of most interest, since it contains the antimony ore, most of which is found in four limestone beds, called "mantos," at or near their intersections with northwest-trending faults and fractures. In some parts of Mexico, the term "manto" is applied to an ore-bearing bed of limestone that lies nearly horizontal. In this report, however, the term is applied, regardless of dip, to certain beds selectively recrystallized, for the most part to white marble, which contain much of the ore but are not ore-bearing in all places.

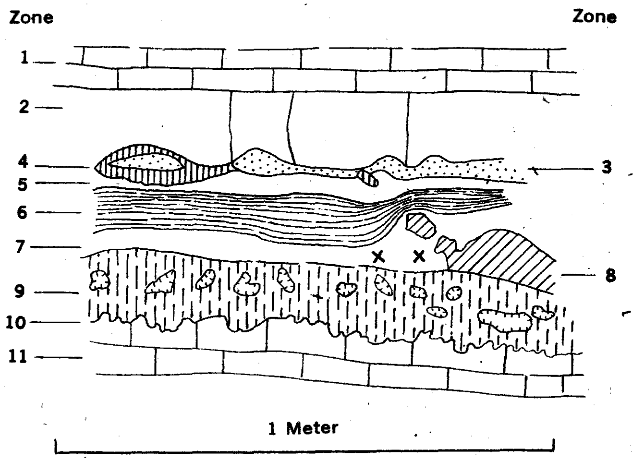
The Santa Emilia formation is conformably overlain by the San José formation, which has a total thickness of from 60 to 120 meters. The lower 25 meters of the San José formation consists of black carbonaceous limy shale with a few beds of limestone, each several centimeters thick. The proportion of limestone to shale increases in the upper part of the formation, which grades into the overlying Corona formation, consisting predominantly of limestone. The limestone of the Corona formation is blue-gray, being very similar in appearance to the limestone of the Santa Emilia formation except that it contains few beds more than 1 meter in thickness. Chert lenses and concretions of iron oxide are abundant, and the weathered surfaces of occasional sandy beds are cream-colored or pink. The upper part of the formation as it is known in the mapped area contains shale, interbedded with limestone. The total thickness is at least 200 meters.

The Corona formation is more fossiliferous than the Santa Emilia formation and is the only one in the district whose age has been fairly well determined by paleontologic evidence. Although its fossils are not well preserved, they indicate, according to Professor F. Contreras, Sección de Paleontología, Instituto de Geología de México, that the formation is probably of Upper Jurassic age.

Description of the mantos

The uppermost manto, commonly called the first, contains more antimony than any of the others. It lies from 6 to 8 meters below the top of the Santa Emilia formation, and it can be recognized readily everywhere in the mapped area, not only on the surface but also in the San José mine. This manto, which has a total thickness of 1/2 to 1 1/2 meters, differs from the others in that it consists of two parts. The upper part is a layer of hard, blue-gray, siliceous rock, from 10 centimeters to 1 meter thick, which may originally have consisted either of sandstone or of cherty limestone. The lower part almost everywhere consists of white marble. Part of this marble is moderately fine grained; part of it is coarse-grained and porous, with numerous solution cavities up to several centimeters in diameter, which are lined with calcite crystals. On the lower levels of the San José mine (see pls. 47 and 48) and in the downthrown fault blocks, the fine-grained marble is apparently more abundant than the coarse and porous variety. The antimony minerals are found only in the coarse-grained and porous marble and in the broken parts of the upper siliceous zone. The accompanying sketch (fig. 18) illustrates the relationships within the first manto near the south end of the San Juan level, where the manto contains a little antimony ore, not minable under present conditions.

In the San José mine there are three other ore-bearing mantos, besides the upper one, which lie respectively about 16 meters, 28 meters, and 36 meters below the top of the Santa Emilia formation. These mantos, unlike the highest one, cannot be recognized everywhere in the mapped area. They are characterized by a coarse-grained texture and by a white, light-gray or cream color contrasting with the dark blue-gray color of the unaltered limestone. The mantos contain abundant solution cavities, whose long dimensions are commonly parallel to the stratification, and because of these cavities the mantos are much more permeable than the adjacent unaltered limestone. The lower mantos commonly contain some silica, but far less than the upper manto. These lower mantos can generally be distinguished from each other within the San José mine. The second manto, about 8 meters stratigraphically below the first, ranges from 1 1/2 to 5 1/2 meters thick and is on the average about 1 3/4 meters thick. Two beds of clay, each from 5 to 10 centimeters thick, are sometimes found about halfway between the first and second mantos, but the second manto is generally without positively identifying characteristics.



Zone
1 Blue limestone, not recrystallized.
2 Siliceous part of manto, 20-30 cm. May originally have been a limy quartzite, but more probably chert disseminated in limestone, afterward partially recrystallized. Lower part porous, with carbonate dissolved out. Vertical fractures filled with calcite.
3 High-grade antimony oxide, after stibnite.
4 Light-gray chalcedony with small crystals of antimony oxide after stibnite.
5 Calcite, coarse-grained, with crystals up to 1 cm. in diameter; the calcite is white, light pink, or stained brown with iron oxide.
6 Banded zone, with stratification (?) banding in gray, white, or brown iron-stained calcite, finer-grained and apparently later than calcite of 5 or 7.
7 Calcite in large white crystals, with traces of cinnabar (crosses).
8 Inclusions (?) of fine-grained siliceous rock, probably derived from zone 2.
9 Zone of recrystallized calcite, mostly brownish in color at top and bottom, but lighter in color near middle, with numerous vugs or solution cavities. Cavities are up to 10 cm. in diameter and are lined with white calcite crystals up to 1/3 cm. in length.
10 Stylolite contact.
11 Blue limestone, similar to zone 1.

Figure 18.—Sketch of first manto, San Juan level, San José mine.

The third manto is from 11 to 17 meters below the second. Its thickness ranges from 1.3 to 6 meters and is on the average about 3 meters. In parts of the mine the third manto is complex, consisting of recrystallized beds separated by thinner beds of normal unrecrystallized limestone. In the west-central part of the San Pedro level the sequence consists of the following, from top to bottom:

0.45	meters	reddish clay shale	
1.2	"	normal limestone	
3.2	"	recrystallized manto	Third manto
.50	"	limestone	Third manto
.70	"	manto	Third manto
.30	"	limestone	Third manto
.70	"	manto	Third manto

A marker bed of clay shale 1.2 to 2.5 meters above the third manto makes this the most readily recognizable of all the mantos except the first. The clay bed ranges in thickness from 15 centimeters to 1 meter, and is on the average about 25 centimeters. None of the other clay or shale seams separating the limestone beds exceeds 10 centimeters in thickness.

The fourth manto is generally about 8 meters below the third, but the recorded range is from 3 1/2 meters to 9 meters. It is similar to the second manto in that positively identifying characteristics are lacking. Its thickness is about 3 1/2 meters on the average but ranges from 2 meters to 10 meters (the latter in a crosscut in the west-central part of the San Pedro level, where the third manto is only 3 1/2 meters above the fourth). Its greater average thickness is therefore of assistance in distinguishing the fourth manto from the second, but for positive identification of an unknown manto, its relation to the first or third must be determined.

In several places an extra manto not identifiable with any of the above is found. In the San Felipe tunnel of the Santa Emilia mine, a manto 30 centimeters thick occurs about halfway between the normal second and third mantos. In the northeastern part of the San Pedro level near the San Elías fault the obscure relationships must be explained either by complex structure or the presence of an extra manto.

Migrating solutions are believed to have caused the selective recrystallization of the four mantos, which may originally have been more permeable than the adjacent beds. Solution and redeposition of calcite may have been very important factors in determining their recrystallization as well as their high degree of permeability. They could then have been selectively mineralized by later antimony-bearing solutions. On the other hand, the limestone beds may originally have contained gypsum, similar to some of the Upper Jurassic limestones of the Colorado Plateau region,1/ where the solution and transportation of gypsum has produced porous beds resembling in some ways the mantos of the Wadley area. Regardless of the origin, the

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1/ Cross, Whitman, and Ransome, F. L., U. S. Geol. Survey Geol. Atlas, Rico folio (no. 130), pp. 17-18, 1905.

Burbank, W. S., Revision of geologic structure and stratigraphy in the Ouray district of Colorado, and its bearing on ore deposition: Colorado Sci. Soc. Proc., vol. 12, no. 6, pp. 172-176, 1930.

Burbank, W. S., Structural control of ore deposition in the Uncompahgre district, Ouray County, Colo.: U. S. Geol. Survey Bull. 906-E, pp. 211-212, 1940.

recrystallization was earlier than and probably unrelated to the antimony mineralization, for it is found everywhere in the mapped area, its distribution being apparently independent of the structural features that controlled the deposition of the antimony.

The two accompanying sketches, illustrating relations in the third manto (figs. 19 and 20), suggest that the origin of the mantos is complex, that they differed from the adjacent

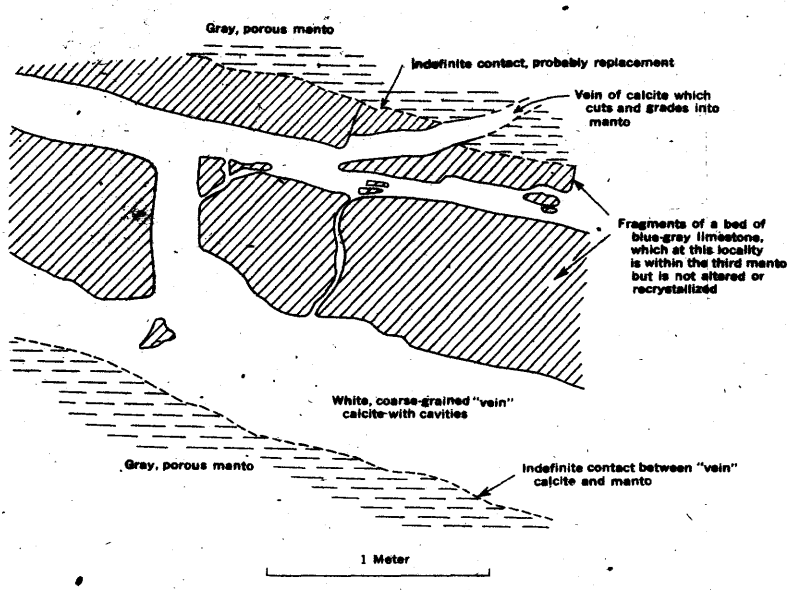

Figure 19.—Part of third manto, General level, San José mine, 350 meters east of portal.

limestone beds in physical or chemical characteristics, and that solution and redeposition of calcite played a very important part in their origin. Another sketch, illustrating relations in the second manto (fig. 21), suggests that the recrystallization of limestone may in some places cross the boundaries of the limestone bed that forms a manto to affect an adjacent bed that is for some reason locally more favorable. The relations in the area that has been sketched are believed to be due to selective recrystallization of parts of two beds, rather than to the faulting of a single bed.

Two thick beds near the base of the Santa Emilia formation are recrystallized, so that they resemble the ore-bearing mantos, but they are not known to contain antimony.

Structure

The structural pattern of the area consists of a system of north- to northeast-trending folds, cut by northwest-trending faults (see pl. 45). The anticlines commonly plunge to the northeast and are asymmetrical, with gently dipping west limbs and steeply dipping or overturned east limbs. Some of the folds are minor, generally involving only the top part of the

Santa Emilia formation and the lower part of the San José formation and dying out downward in the limestone and upward in the shale. This type of folding is well seen near the portal of the General level of the San José mines, and also east of the Arroyo de las Pilas, in the eastern part of the mapped area (see section B-B', pl. 46).

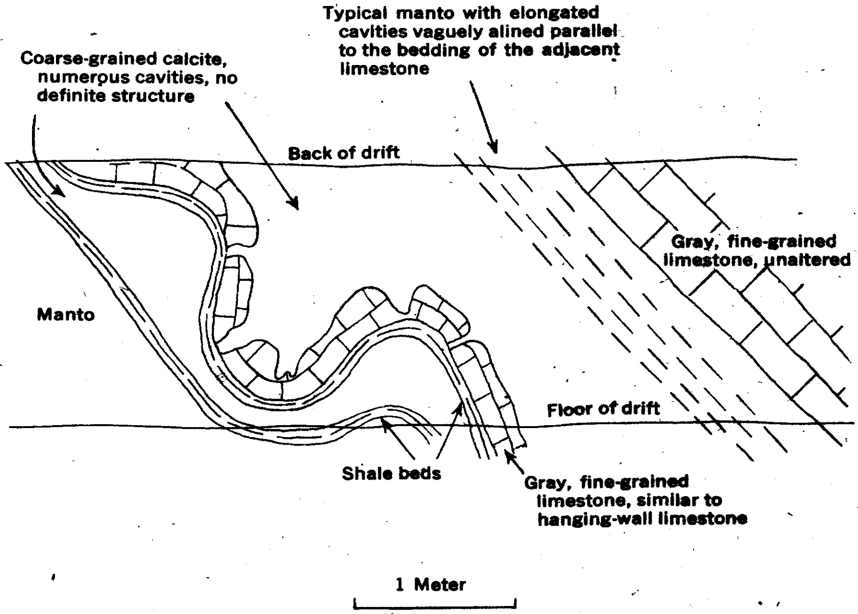

Figure 20.—Upper part of third manto, northwest part of San Felipe tunnel, Santa Emilia mine.

The area contains many faults, most of which belong to one major system, striking about N. 40° W. The individual faults dip steeply, some to the east and some to the west. The movement along the faults has in general been almost horizontal, the west sides having moved relatively southward, in many places bringing anticlines in fault contact with synclines. The faulting is believed to have been at least in part contemporaneous with the folding, and it may be for this reason that several faults with comparatively large displacements die out abruptly along the strike. The Colorado fault has a stratigraphic displacement of about 70 meters at a point northwest of Cerro de la Corona, but only 350 meters farther to the northwest the displacement is less than 3 meters. About 100 meters west of El Pastor a fault has an apparent horizontal displacement of 70 meters. Approximately 250 meters farther to the northwest it dies out, and individual beds are seen to cross the strike of the fault without displacement or noticeable brecciation. Moreover, individual folds on one side of a fault commonly cannot be matched with corresponding folds on the other side (see pls. 45 and 49), and this fact, like the sudden dying out of faults, is believed to be most satisfactorily explained as a result of contemporaneous faulting and folding. Some movement along the faults may have taken place, however, after the folding was completed.

ORE DEPOSITS

The principal antimony deposits lie within an area 2 kilometers long by 1 kilometer wide, extending north and south. The antimony ore minerals consist principally of the oxides cervantite, valentinite, and stibiconite, which are secondary after the sulfide stibnite. Only a small amount of stibnite is found, however. In the whole history of the mine, little more than 1 percent of the ore produced has been treated separately as a sulfide ore, although undoubtedly more than 1 percent of the antimony in the average ore is present as stibnite. Most of the ore bodies are in the four mantos, already described, in

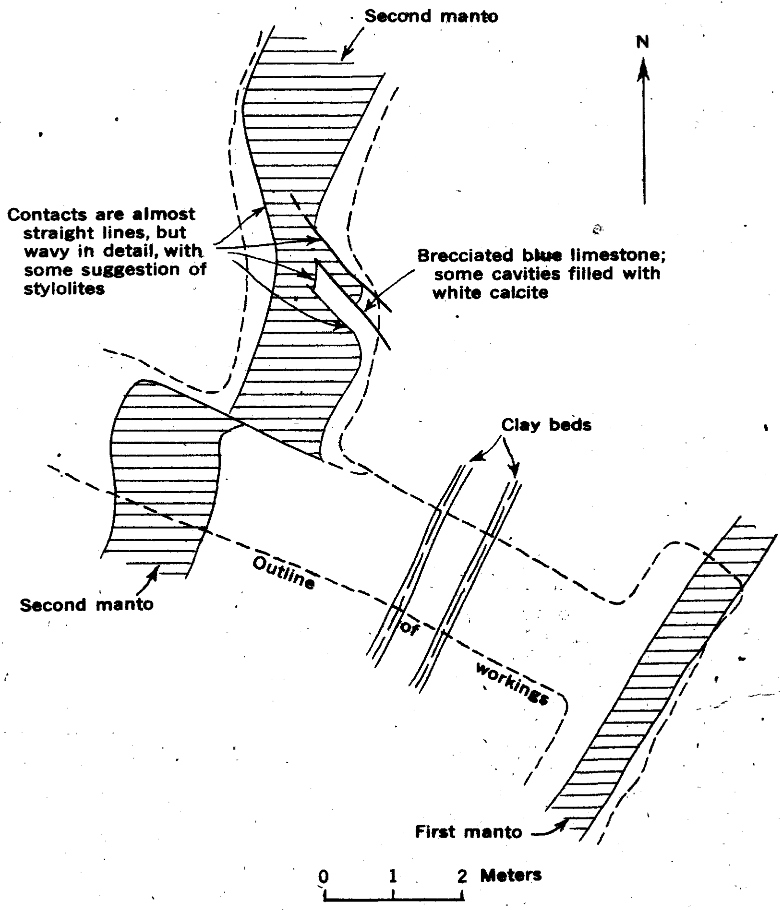

Figure 21.—Sketch of second manto, northeast part of General level, San José mine.

the upper part of the Santa Emilia formation. The structural conditions most favorable for the deposition of ore are found in the major faults, where one wall consists of shale of the

San José formation, and the other consists of the upper beds of the limestone of the Santa Emilia formation on the axis of an intersecting anticline (see pl. 49). The known localization of the ore bodies strongly supports the hypothesis that the antimony-bearing solutions for the most part came up the major faults and fractures until their progress was impeded by the relatively impermeable shale overlying the limestone. The solutions then migrated on up the faults on the limbs of the intersecting anticlines to the anticlinal axis. At these points further migration upward was possible only to a slight extent through the nearly impermeable shale. Most of the migration then took place in the mantos on the anticlinal axes with the direction of movement away from the faults. The upward rake to the southwest of nearly all the fold axes favored a general migration of the solutions to the southwest. In accordance with this hypothesis of migrating solutions and structural traps, an anticlinal axis of limestone on the northeast, faulted against shale to the southwest, is a favorable location for ore, but the continuation to the northeast of the downward-plunging axis is favorable only if other antimony-guiding faults or fractures lie farther to the northeast and were the source of at least a part of the mineralizing solutions. It should be pointed out that although the traps and anticlinal channels formed by combinations of folding and faulting are logical places to look for ore, some traps and channels may be barren if they were sealed off or if the mineralizing solutions were never guided to them.

Many small ore bodies unrelated to fold axes have been found at the intersections of the mantos with minor fractures and in the mantos near faults and fractures. In addition, some ore has been found on fractures outside of the mantos, particularly between the first manto and shale of the San José formation. In the San José mine, ore was also found below the San José level on the steeply dipping or overturned eastern limb of an anticline. A minor amount of ore has been found in the Corona formation as well as in the Santa Emilia formation below the mantos.

Much of the production from the district in the period following its discovery was derived from the Santa Emilia workings, on the northwest side of the Cañón de la República. Here the antimony ore was localized on the crest of a plunging anticline, and it was mined down the dip for at least 100 meters. Most of the ore came from the fourth, or lowest manto.

The largest early-discovered bonanza in the strongly mineralized region south of and surrounding the Cerro de la Corona was found near the Casa de la Compresora (see pl. 45), at the intersection of the first manto with the San Elías fault. Most of the activity of the past twenty years or more has been concentrated on the area underlying and near the Cerro de la Corona, between the San Elías fault and the Colorado fault. Early in the development of the region, the emphasis was placed on discovering ore bodies in the faults; later, the emphasis shifted to the mantos. Since about 1928, when the mine workings were accurately surveyed and the underground geology was first mapped, the importance of the intersections of the mantos with the faults has been fully appreciated. Many of the ore bodies on the intersections of the first and second mantos with the faults had indeed been discovered already, but after 1928 these intersections were explored consistently. The success of the application of geologic mapping and surveying to the San José mines is indicated by the figures on yearly production after 1928 as compared to previous production. Recently exploration has been directed toward the search for ore bodies at the intersections of the faults with the third and fourth mantos. Some ore had previously been found to be associated with these lower mantos, but in general they were considered relatively barren, particularly as compared with the first manto, which has been the most productive of all. The principal results of the present study, it is to be hoped, will be an appreciation of the importance of the anticlinal axes as well as of that of the contact of shale and limestone in guiding the migration of the solutions and the deposition of ore. These relationships may not have been fully appreciated in the past because the ore-bearing horizons have been eroded from the crests of the major anticlines, within the mine area (see pls. 45 and 49).

In the first manto the antimony oxides are widely distributed, commonly occurring far from the major faults. In places the ore bodies are associated with north- or northwest-striking fractures of little or no displacement, the antimony-depositing solutions having apparently migrated away from the major feeding fractures and faults. Most of the ore is in the central part of the manto, near the base of the siliceous zone and in the underlying white, recrystallized limestone (see fig. 18). In the low-grade ore bodies, the antimony is likely to be encountered in a band of high-grade oxide ore, 1 to 10 centimeters thick, on the contact of the siliceous zone with the underlying limestone. In the larger, higher-grade ore bodies, the siliceous zone is broken up and veined with calcite, and the greater part of the manto is characterized by open cavities and by irregular siliceous blocks enclosed in the limestone. Where the siliceous upper zone is thoroughly broken up, the antimony minerals are generally distributed throughout the manto, but where the siliceous zone is uniform and completely unbroken, antimony minerals are scarce or absent. The second, third, and fourth mantos rarely contain ore bodies except in close association with cross-cutting fractures or faults.

In part, the stibnite was originally deposited in open cavities and fractures and in the porous parts of the mantos, but replacement of limestone is also believed to be very important. Ordinarily, however, the relative importance of the two processes is very difficult if not impossible to determine.

The stibnite, now pseudomorphically replaced for the most part by antimony oxides, was originally coarse-grained. Some of the oxide pseudomorphs have the form of euhedral, coarse-bladed crystals of stibnite, but most of the ore is hard and of earthy appearance, with a cream, buff, or yellow color. Some of the ore is associated with chalcedonic silica, occurring as a filling of open cavities and in part as a replacement of limestone. Much of the ore of the first manto is associated with a mixture of chalcedonic silica and the quartz of the upper, siliceous part of the manto. Quartz and chalcedony probably constitute the greater part of the gangue, but calcite also is a very abundant gangue mineral and predominates in some of the ore. Cinnabar is not uncommon, generally occurring as a thin layer of "paint" on oxidized antimony ore, but even with selective mining it would be impossible to obtain a high-grade quicksilver ore.

Mine descriptions

Most of the antimony produced from the district has been mined in the area near and underlying the Cerro de la Corona, in the integrated workings known as the San José mine. Most of the early production in the district came from the Santa Emilia mine, which is further north, on the northwest side of the Cañón de la República; this mine, however, is inactive at present.

San José mine

The San José mine consists of extensive workings on five different levels (see pl. 47), which may be described as follows:

(1) The San José, or upper level, at an elevation of 2,453 meters, consists essentially of the San José tunnel, with more than 3 kilometers of drifts and crosscuts. The San José tunnel is connected at the south with the El Japón tunnel, which has approximately 300 meters of workings. The separate workings of the San Pablo tunnel in the southern part of the mine at an elevation of 2,455 meters consist of about 400 meters of workings.

(2) The San Juan level is below the San José level at an elevation of 2,440 meters, and it consists of more than 600 meters of workings, largely on the first manto. The upper San Elías tunnel in the northern part of the mine area is at an elevation of about 2,440 meters, and consists of approximately 90 meters of workings.

(3) The San Pedro level is 36 meters below the San José level, at an elevation of 2,417 meters, and consists of at least 2 kilometers of workings, largely on veins and mantos. The Nueva Esperanza tunnel, at an elevation of 2,426 meters in the southern part of the mine area, contains about 800 meters of workings. The end of a northern drift in the San Pablo tunnel is less than 100 meters from some of the workings on the San Pedro level. Included with this level is the middle San Elías tunnel with more than 200 meters of workings.

(4) The General-San Antonio level, 71 meters below the San José level and at an elevation of 2,382 meters, is the most extensive in the mine, comprising nearly 4 kilometers of drifts and crosscuts. The San Antonio tunnel was at one time under a different ownership from that of the General tunnel, but the two were connected when all of the property in the district was combined under one ownership and management.

(5) The Colorado level, north of the San Antonio workings, is 88 meters lower than the San José tunnel, at an elevation of 2,365 meters. In May 1942 the workings were accessible only near the entrance of the west tunnel. The total length of the drifts and crosscuts is not more than 3/4 of a kilometer, including the lower San Elías tunnel at about the same elevation. This tunnel was reopened in 1943.

The geologic structure revealed in the underground workings of the San José mine (pls. 47-48) can be generalized as follows: A synclinorium, generally consisting of two synclines separated by a small anticline, trends due north to N. 50° E., its average trend being about N. 17° E. The folds plunge 5° to 25° northeastward, more steeply in the northern part of the mine workings than in the southern part. The folds are asymmetrical, with the west limbs of the synclines dipping steeply to the east. In the Nueva Esperanza and San Pablo tunnels, the limestone dips almost vertically and in places is overturned, dipping steeply to the west. The folds are cut by northwest-striking faults, along the south sides of which the folds, when they can be matched up, have been shifted progressively to the southeast. The major faults are grouped into two systems, the San Elías and the Colorado, which are roughly parallel to each other and about 200 meters apart through the central part of the mine. Although on the surface the San Elías system, which is the one farther east, has been mapped as a single fault for much of its length, it is seen underground to consist in places of as many as four faults. This fault or fault zone ranges in dip from 70° W. in the San Elías tunnel to 80° E. in the southern part of the mine (see pl. 48). In the northeastern part of the workings of the General level the apparent horizontal displacement is about 50 meters (see pl. 47) but in other parts of the mine the folds on one side of the fault are so dissimilar that they cannot be matched and the displacement cannot be determined (see pl. 49).

The Colorado system in the Colorado tunnel consists of one fault that splits to the southeast. These two parts generally dip steeply to the east, though in places they dip westward. The displacement on each part and on the system varies in extent from place to place. On the west branch near its south end, the displacement is apparently restricted to the upper part of the limestone of the Santa Emilia formation and shale of the San José formation, for no displacement of strata was found at the General level on the downward projection of the fault. At the surface, on the north side of the Cañón de la República, the displacement on the Colorado fault is small or negligible, but near the portal of the Colorado tunnel the stratigraphic displacement is 70 meters.

The San Elías and Colorado faults are connected by at least two faults that strike N. 50°-70° W. In contrast the fractures west of the Colorado fault strike N. 10°-25° E. The displacements on these fractures are probably small, but cannot be measured because of the absence of key-beds. In the southwestern part of the mine area, the fractures have the same strike as the bedding of the limestone, but they all dip steeply, regardless of the varying dips of the beds.

As already indicated, the antimony ore is largely restricted to four limestone beds, or mantos, in the upper part of the Santa Emilia formation, and to the faults and fractures. The intersections of the mantos with the faults are particularly favorable locations for ore bodies. The map of the underground workings (pl. 47) shows the faults, and in many places it shows the mantos. In order to avoid the confusion which would result from projecting the locations of all of the faults and all of the mantos from five levels to a common plane, the faults and mantos are ordinarily mapped only in or near the workings in which they are exposed. The fractures generally have vein fillings of calcite, with or without antimony minerals. The calcite veins are commonly as much as 1.2 meters wide and probably average about 0.6 meter. Although much of the vein filling contains only a little antimony, the best ore bodies in the mine are generally in the veins, at their intersections with the mantos. At many such intersections, however, particularly in the downthrown fault blocks, no ore has been found (see north end of area shown in pl. 49).

The upper, or first manto, it will be remembered, is from 1/2 to 1 1/2 meters thick, and comprises an upper siliceous part, from 10 centimeters to 1 meter thick, and a lower part consisting of white recrystallized limestone. In the syncline in the lower workings of the San José mine this limestone is commonly medium-grained and dense, but in the upper workings it is variable in texture and contains abundant cavities lined with crystals of calcite. The three lower mantos consist of white, light-gray or cream-colored, coarse-grained calcite with some disseminated chalcedonic silica, honeycombed with solution cavities commonly oriented parallel to the bedding. These mantos are, for the most part, between 1 and 4 meters in thickness, although at one place on the General level the fourth manto is at least 10 meters thick. All of the mantos are believed to have been recrystallized, but there has been extensive solution and redeposition of calcite, within limestone beds that originally may have been more porous than adjacent beds, or that may have contained gypsum which was dissolved and removed in solution. Because the thickness and character of the mantos have no apparent relation to the structures which controlled the deposition of the antimony ore, the recrystallization is believed to have occurred before the introduction of the antimony-bearing solutions.

Antimony minerals are particularly abundant in the first manto, but they are not uncommon in the lower mantos. The whole first manto in the eastern part of the mine, between the San Elías and Colorado faults and from the surface down to the San Pedro level, contains enough antimony oxide to be a milling ore, its antimony content ranging up to 10 percent. In this low-grade ore, the antimony oxides are commonly concentrated just below the upper, siliceous part of the manto. In some places where a manto has been brecciated, antimony ore occupies its entire thickness, such a condition being particularly common where the manto is cut by northwest-striking fractures. The fractures commonly have little or no measurable displacement, and the ore is generally restricted to the manto, although in some places ore is found on the continuation of the fractures into adjacent unaltered beds of limestone. Many of the stopes in the mantos have not been surveyed, but the accompanying map of a stope in the first manto above the San José level, in the eastern part of the mine (fig. 22), illustrates the irregular distribution of the ore, with a suggestion of control by fractures that strike northwest and north. The fractures that strike north apparently extend for even shorter distances into adjacent beds than those that strike northwest.

A number of large high-grade bodies of antimony ore have been found along the San Elías fault, in contact with the mantos in the upthrown block of limestone to the southwest (see pl. 49). The whole area of the San José mine was developed mainly as a result of the discovery in the early days of high-grade ore at the surface in the San Elias fault adjacent to the first manto, which crops out near the Casa de la Compresora. The ore was followed for some distance down on an average rake of 30° to the northwest, along the intersection of the fault with the manto. Apparently very little ore was found at this intersection on the San José level, but on and slightly below the San Juan level a large ore body was found and mined in 1936. This ore body is described as having been about 7 meters wide, 7 meters deep, and 35 meters long, and it is said to have yielded about 3,000 tons of ore, containing 1,000 tons of metallic antimony. The ore partly filled a large open cavern, which was lined with pseudomorphs of antimony oxide after euhedral crystals of stibnite. Some ore has been mined from the lower levels on the same structural intersection, but no other large ore body has been found.

Until very recent years the first and second mantos were considered to be the most important, little or no attention being given to the third and fourth. Now, however, much of the ore that is being produced comes from, or is associated with, the lower mantos. At the time the field work was being done in 1942, the largest productive ore body in the mine was on the San Juan level, at the intersection of the San Elías fault

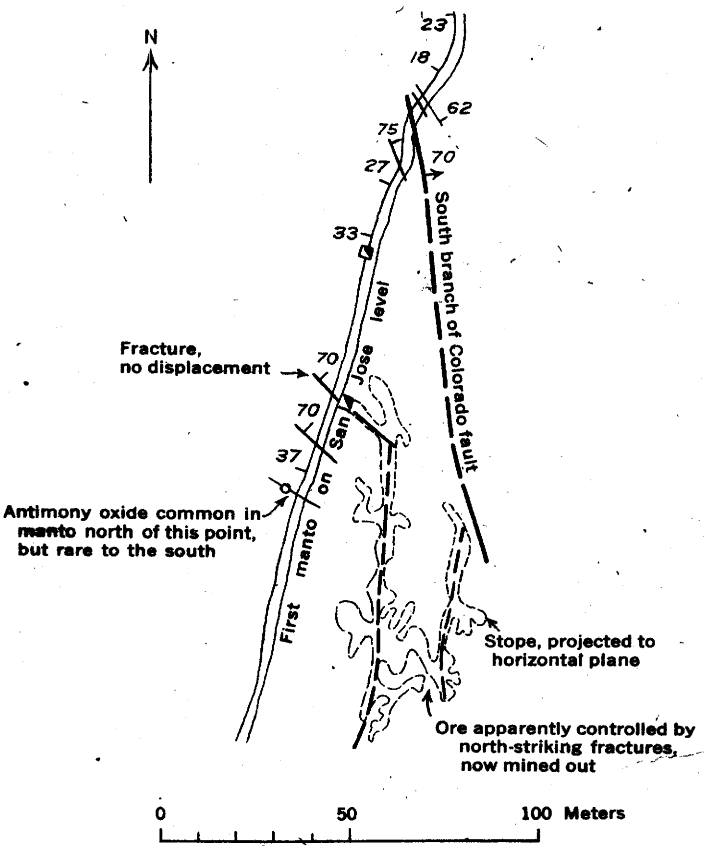

Figure 22.—Map of stope on first manto, San José level, San José mine.

probably with the third manto. Up to June 30, 1942, when 500 tons of ore containing more than 40 percent antimony had been mined from this place, the limits of the ore body had not yet been determined. Some ore was also being produced at that time from workings above the San José level, about 150 meters southeast of the portal of the tunnel, at or near the intersection of the first manto with a fault of small displacement striking N. 15° E. Wherever the necessary structural conditions prevail, ore bodies have been found on the General-San Antonio level, the lowest workings in the main part of the mine. On the average, this level has not been as productive as the upper ones because the workings are either below the mantos or they explore the mantos in down-warped or relatively down-faulted parts of the limestone. However, rich ore bodies have been found in at least two parts of the level where the structure is favorable. Ore was found in 1943 in the northeastern part of the level in the first manto on the crest of an anticline east of the eastern branch of the San Elías fault (see pl. 48, section F-F', and pl. 49). The ore continues down the plunge of the anticline for at least 40 meters east of the fault. However, the most productive area on the General-San Antonio level was about 250 meters east of the portal of the San Antonio tunnel, in and near the first manto on the crest of an anticline southwest of one of the faults connecting the Colorado and the San Elías faults. Ore was also found on the northern, downthrown and downward-plunging side of the fault below the level at a point 175 meters below the surface. This ore is believed to have been deposited by solutions migrating up the anticlinal axis from the San Elias fault. The intersection of this fault and the axis has not been explored but is a very good possibility for undiscovered ore.

The relative localization of ore in the higher parts of the mine is believed to be a result of the control of stratigraphy as well as structure in the deposition of ore rather than a direct result of the original depth.

Irregular bodies or masses of soft, reddish-brown clay have been found in or near the major faults (see pl. 47 and section F-F' of pl. 48). The clay is apparently barren of ore and is not closely related to the deposition of antimony. The origin of these masses is not clearly understood, but they may have been derived by the filling of solution cavities by clay from the overlying shale of the San José formation. This hypothesis is supported by the fact that all of the known bodies of clay are within 40 meters of the nearest contact of the limestone with the shale.

Santa Emilia mine

The "Santa Emilia mine" is a general term for all of the workings on the northwest side of the Cañón de la República. Nearly all of these workings are within 275 meters of the Colorado fault. Much of the antimony ore produced from the district in the early days came from the Santa Emilia mine, largely from the mantos west of the fault. Although the ore bodies are largely worked out, a little ore is still being mined by "gambusinos," who are leasers or independent miners.

In the vicinity of the Santa Emilia mine the upper, or first manto consists at most places of only 40 centimeters of siliceous rock, corresponding to the upper part alone of this manto as found elsewhere. No recrystallized white calcite is found with the siliceous zone west of the fault, and only a little of it east of the fault in the underground workings. The siliceous rock in the Santa Emilia mine area is generally unbrecciated and dense and has yielded little or no antimony ore.

The second manto, which consists of 2 meters of white or tan, porous, recrystallized calcite, contains much of the antimony ore. An extra manto not found in the San José mine lies between what are commonly known as the second and third mantos.

Neither this extra manto nor the normal third manto has yielded any substantial quantity of antimony. The fourth manto, which consists of 3 to 4 meters of porous, recrystallized calcite, has yielded more antimony ore in the Santa Emilia mine area than any of the other mantos.

West of the Colorado fault, most of the production has come from the second and the fourth mantos near the crest of the asymmetrical anticline and from the fourth manto near the trough of the adjacent syncline. In detail, however, the ore in the mantos is related to crosscutting fractures, as it commonly is in the San José mine.

The San Felipe tunnel (pl. 50) is the only part of the Santa Emilia mine that has been mapped in detail, and is the only level that has been systematically prospected and developed. The dominant structure in the tunnel is the Colorado fault, but two systems of faults are found. The earlier of these, which includes the Colorado fault, strikes about N. 35° W. and dips steeply to the east or west. The other strikes due north to N. 10° W. and dips from 50° E. to 70° W. The axis of the anticline west of the Colorado fault that is mentioned in the previous paragraph was explored in the San Felipe tunnel at its intersection with the Colorado fault. However, none of the mantos was explored at this intersection. The fourth manto, which was very productive at higher elevations, could be explored readily on the crest of the anticline on the tunnel level by extending the southernmost drift on this manto for no more than 15 meters to the north. A winze on the Colorado fault should also be sunk to explore the manto on the crest of the anticline at the fault.

No large bodies of antimony ore were found in the San Felipe tunnel, although good ore was mined above the level at the intersections of mantos with faults or fractures. Probably the best ore found on the tunnel level was in the Colorado fault zone where it intersects the second manto.

Miscellaneous deposits

The El Pastor mine contains the only producing antimony deposits in the area that are not owned by subsidiary companies of Texas Mining & Smelting Co. The principal deposits are on a western offshoot of the Colorado fault, just southeast of the little village of El Pastor and about 1 kilometer southeast of the portal of the San José tunnel (see pl. 45).

The workings are small, and the two or three gambusinos mining the deposits obtain only a few tons of ore a month. The ore is obtained from a vein filling the fault, adjacent to the first and second mantos, on the gently dipping western limb of an anticline.

Indications of antimony have been found at many places on both sides of the Arroyo de las Pilas, 1 1/2 kilometers east of the portal of the San José tunnel. The showings are small and consist largely of low-grade siliceous ore from which much of the antimony has been leached by surface solutions. The best prospect in this region is one-third of a kilometer northeast of Cerro Redondo, on the eastern limb of a tightly folded syncline. Its ore is high-grade, but the deposit is apparently small. The region is not very favorable, because of the absence of large faults or fractures like those in the San José mines.

The small workings near the head of the Barranca de la Pilas southeast of Cerro Redondo are in small faults and fractures, and are unrelated to the mantos that control the ore throughout the rest of the area.

Minas de Antimonio, Matanzas

The Matanzas mines, owned by a local cooperative society of miners, are about 5 kilometers northeast of the San José mines, on the west flank of the Sierra de Catorce near its crest. They lie in a group of three adjacent claims on a westward-trending, westward-sloping ridge. San Francisco de Arriba is on the crest of the ridge, San Francisco de Abajo is on the south slope, and Socavón del Cuervo on the north slope. The Matanzas mines are not in the area included in plate 45, but they are described in this report because of their similarities to the San José mines. The structure, and in even greater degree the stratigraphy, of the Minas de Antimonio are similar to those of the San José mines. Although these two groups of mines are over 5 kilometers apart, the first manto has the same stratigraphic position and similar lithologic characteristics in both. The Matanzas ore deposits are on the steeply dipping eastern limb of an anticline, which strikes almost due north. The bedding dips 35° E. in the San Francisco de Arriba workings, on the crest of the ridge, and steepens on the flanks of the ridge to a maximum of 75° E. The best ore has been found on the crest of the ridge, above, within, and below the first manto. The ore, which is related to northwest-striking fractures, is all in limestone but is not as closely restricted to the manto as in the San José mine. The Pabellón workings across the canyon to the south were not visited, but they were seen to be on the crest of the southward continuation of the same anticline.

A northwest-trending fault with a fairly large displacement cuts the Santa Emilia formation on the north end of the Socavón del Cuervo claim, and this fault may have been the source of a part of the antimony-bearing solutions. The only igneous rocks that were seen in the Wadley-Matanzas region are about half a kilometer northwest of the Minas de Antimonio. Several irregular dikes of green porphyritic andesite and of red, altered andesite cut limestone beds near the base of the Santa Emilia formation.

The weekly production of the mines in 1942 was only 2 1/2 to 4 tons of ore, containing 15 to 48 percent of antimony. This ore was obtained by reworking the old dumps and stope fills, and no active underground mining was being carried on. The area has good possibilities for continuing production.

RESERVES

The reserves in the San José mines, as in practically all antimony mines in the world, are difficult to estimate for the following reasons: (1) The individual deposits are so extremely irregular in size, shape, and grade that the amount of ore in a deposit is not known until it has been mined out. (2) The ore bodies are not sampled and assayed systematically because only the high-grade ore is recovered. The average grade of a deposit is, therefore, of much less practical importance than the proportion and grade of the material that can be separated and recovered in the form of high-grade ore and hand-sorted concentrates. (3) Ore bodies are mined out immediately after their discovery, and are not developed and blocked out in advance of mining. The San José mines, therefore, contain no "measured" ore reserves in the usual sense.

If the mining of low-grade ore becomes feasible in the future, large tonnages can be blocked out in the mantos and in the veins. In addition, dumps resulting from more than 50 years of mining are readily available. All of this material is too low in grade to be classified as ore at the present time, because no low-cost milling methods have yet been developed for the efficient recovery of the antimony oxides.

PRESENT AND FUTURE PRODUCTION

The future of the San José mines depends to a large extent upon the development of a milling process by means of which antimony can be efficiently extracted from low-grade oxide ores. The mines have been operated in the past for the high-grade deposits—those that contain ore that can be sorted to an antimony content of at least 30 percent. High-grade ore bodies, however, are now more difficult to find than in the past, and the rate of discovery of new ore bodies was perhaps never so low at any other period of active search in the mine's history as it is at the present time. If the mines continue to operate under the present conditions, something like the present annual production of about 4,500 tons of ore, containing 1,500 tons of metallic antimony, can probably be maintained for several years. If the efficient and profitable concentration of low-grade antimony oxide ore were to become possible, production could be increased, and the life of the mines would be lengthened greatly. The actual production would depend upon the scale of the milling operations, and these, if wet methods of concentration were used, would be limited primarily by the available water supply. No large, dependable water supply has yet been developed. The nearest source for such a supply is most likely to be found near the Tolba de Abajo, at the junction of the Cañón de la República and the Barranca del Japón.

RECOMMENDATIONS

I

Recommendations for individual ore bodies where a comparatively small amount of development may result in the finding of "quick" ore, are as follows, approximately in the order of their potentialities:

1. The lower three mantos at their intersections with the San Elías fault below the large ore body mined from the first manto in 1936 (see pl. 48, section G-G', and pl. 49). The company maps indicate the presence of two raises in this general area from the San Pedro level, but these workings were not accessible in 1942 or 1943. All three mantos should be explored adjacent to the fault for a distance of about 90 meters south of structure section G-G'.

2. The intersection of the fourth manto and the San Elías fault below the rich ore body mined in 1942 from what was believed to be the third manto on the San Juan level (see pl. 48, section H-H', and pl. 49). The fourth manto could be explored either by sinking a winze from the San Juan level or by extending the San Pedro level 100 meters south of the location mentioned in 1, and raising to the fourth manto.

3. The second manto on the crest of the anticline 250 meters east of the portal of the San Antonio tunnel. When rich ore bodies were mined from the first manto, the miners also found ore 2 meters below in a recrystallized bed that they incorrectly believed was the second manto. If the true second manto is found to be ore-bearing, the third and fourth mantos should then be explored in this region.

4. The first manto in the same location as that mentioned in 3 above. The old stopes should be cleaned out, and the manto should be mined systematically up the crest of the anticline to the southwest.

5. The limestone between the first manto and the shale on the San Elías fault from above the San Pedro level to the surface (see pl. 49). The limestone above the first manto is thoroughly fractured and shattered and contains ore in sufficient quantity to be mined, but in general it was left in preference to the rich ore found in the first manto.

6. The intersection of the Colorado fault with the mantos in the small anticline southwest of the fault and east of the entrance of the San Antonio level. The anticline is shown on plate 45 and plate 48, section E-E'. The mantos have been worked to a slight extent in this area, but the size of the small dumps indicates that these old workings are superficial. The workings should be cleaned out and the mantos systematically explored.

7. The crest of the anticline east of the San Pablo tunnel (see pl. 47 and pl. 48, section J-J'). Apparently a considerable amount of ore was taken from old near-surface workings on the mantos along the crest of this plunging anticline (see pl. 45). Upon the author's recommendations in 1942 an old crosscut tunnel near the north end of the Nueva Esperanza was extended toward the anticline. At this depth, however, the anticline and the syncline to the east are insignificant features and are dominated by the major syncline on the west (see pl. 48, section I-I'). Farther to the south the anticline is much more prominent (see pl. 48, section J-J') and is cut by an ore-bearing fault. An extension of the San Pablo tunnel to the northeast for a distance of about 60 meters is recommended to explore the first manto on the anticlinal axis. If this manto is ore-bearing, the others should be explored.

8. The second and third mantos in the anticline on the east side of a branch of the San Elías fault, in the northeastern part of the General-San Antonio level (see pl. 48, section F-F', and pl. 49). The second manto containing only a minor amount of ore has been intersected on the crest of the anticline in a raise 15 meters from the fault. The intersection at the fault, however, is much more favorable because of the northeasterly plunge of the anticline.

9. The continued mining of the recently discovered ore in the first manto down the plunging crest of the same anticline

mentioned in 8. The finding of ore at least 40 meters from the San Elías fault in this downward-plunging anticlinal axis supports the possibility of the existence of mineralized fractures and faults east of the San Elías fault.

10. The extension of the lower San Elías tunnel to the southeast until all of the mantos on the overturned limb of the anticline east of the fault have been intersected (see north end of pl. 49). Probably not more than 50 feet of drifting will be necessary. The intersection of each manto with the fault should be explored above the level by means of raises. The top of the raise between the lower and middle San Elías tunnels is in the third manto where a fairly large amount of ore was found.

11. The fourth manto in the San Felipe tunnel on the crest of the anticline west of the Colorado fault (see pl. 50). The southwestern drift on this manto could be extended to the north for a distance of about 15 meters to strike the plunging crest of the anticline. A winze on the Colorado fault should also be sunk to intersect the manto on the crest of the anticline.

12. The segment of the small anticline west of the San Elías fault on the General level and about 50 meters south of structure section F-F', plate 48 (see pls. 47 and 49). The anticlinal segment apparently plunges to the southwest in contrast to the major folds in the region. The first manto should be explored on the crest of the anticline throughout the distance of 30 meters that separates the two bounding faults.

II

The following recommendations relate to long-term projects, each involving a considerable expense as well as some degree of uncertainty as to the results. Each may be an important factor, however, in prolonging the life of the mine.

1. All possible cooperation should be given by interested parties to the Texas Mining & Smelting Co. and its affiliated companies in an effort to develop efficient, low-cost methods for recovering antimony from low-grade oxide ores.

2. In the probability that the large-scale treatment of low-grade ores will require abundant water, the exploration for an adequate supply should be encourged. The best possibility near the mines is believed to be in the bottom of the Cañón de la República near the Tolba de Abajo on the western edge of the mapped area (see pl. 45). An adequate supply of surface water is reported to exist on the east side of the Sierra de Catorce but its use would involve high costs in transporting the ore for milling.

3. All of the stopes should be surveyed and the geology mapped in detail. Many of the stopes have been surveyed but only those that were being actively mined in 1942-43 were visited by the authors. The others were not mapped because of insufficient time. Detailed mapping of the stopes will inevitably result in some modifications of the authors' present concept of the geology, and will focus attention on the favorable locations that have not yet been explored. In addition, the smaller ore deposits controlled by minor fractures have not received sufficient attention during this work. Careful geologic mapping of the zones of these fractures may indicate places that should be explored.

4. All of the workings west of the Colorado fault and from the San José level to the surface should be cleaned out and reexamined to determine favorable locations for ore. This area may well have been neglected in recent years in the belief that all of the near-surface ore was removed by the early miners. Sections F-F' to I-I' of plate 48 all indicate favorable locations, although most of this ore may already have been removed.

5. The San Pedro level should be extended for a distance of at least 200 meters southeast of the point suggested in 2 of the preceding section (see pl. 49). The core of the overturned anticline is a possible location for ore, as well as the overturned mantos in the southeastern limb. The overturned first manto is ore-bearing at the surface for a distance of 20 meters from the San Elías fault.

6. The Lower San Elías level can be extended beyond the point suggested in 9 of the previous section (see pl. 49). The tunnel will be in heavy ground, with shale forming one or both walls. The existence of an intersection of the fault with an anticlinal axis to the west and about 280 meters from the portal of the tunnel seems very probable. The mantos at this point may be slightly below the elevation of the tunnel. The existence of an anticline east of the fault and 320 to 370 meters from the portal of the tunnel (see pl. 49) is somewhat more doubtful. However, if the whole region east of the fault is a large syncline, the limestone of the Corona formation should be found at the surface because the shale of the San José formation is not more than 120 meters thick. The absence of limestone of the Corona formation is therefore the basis for inferring the presence of an anticline separating two synclines. The search for this anticline may be carried on more readily from the northeastern part of the General level in preference to the San Elías tunnel, but the lower elevation of the latter is a desirable feature.

7. If 9 of the preceding section is carried out and ore is found for a considerable distance east of the San Elías fault, the faults and mantos in this eastern region may be mineralized. All of the area east of the San Elías fault has always been considered to be barren.

8. The first manto at many places east of the San Elías fault and south of Cerro de Jobi (see pl. 45) contains casts of stibnite in chalcedonic silica. This material is very low in grade, because nearly all of the antimony has been leached from the ore. Bodies of much higher grade may exist below the surface to the northwest, where these mantos, dipping northwestward, intersect the San Elías fault (see pl. 49). This area could be explored either by (1) extending the San Pedro level beyond the point suggested in 5; (2) extending the San Juan level southeast of its present location (the elevation may be too high); (3) sinking a shaft from the surface on the San Elías fault.

9. For the most part, the mantos have been eroded from the crests of the anticlines in the region of El Pastor. However, the intersection of one anticlinal axis with the San Elías fault remains, and is shown on the southeastern end of plate 49. It is favorable, however, only if the mantos on the opposite side of the fault lie at a lower elevation.

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