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ANTIMONY DEPOSITS OF SOYATAL DISTRICT STATE OF QUERETARO, MEXICO

BY

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CONTENTS

ILLUSTRATIONS

TABLES

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By Donald E. White

ABSTRACT

The Soyatal district is in the north-central part of the State of Querétaro, about 190 kilometers north of México, D. F. Its deposits were discovered in 1905; they have been worked almost continuously ever since, except for a period beginning in 1918 and extending into 1934. The district is the third largest producer of antimony in Mexico, having produced, up to the end of 1943, about 74,000 tons of ore containing more than 25,000 tons of metallic antimony.

The sedimentary rocks of the district have been divided into three formations, distinguished for the time being merely as lower, middle, and upper. The lower formation, the base of which has not been seen, consists chiefly of limestone, with some shale and limestone conglomerate. The middle formation generally consists of about 30 meters of limestone containing numerous lenses of chert. It contains fossils that indicate Lower Cretaceous age. The upper formation has a maximum thickness of 115 meters within the district, but its total thickness is much greater. Its basal beds are in part conglomeratic, grading upward through impure limestone into shale. All the sedimentary rocks were folded and faulted, and in a few places they were intruded by dikes of basalt and altered andesite (?). Most of the folds strike northwest and are asymmetrical, some leaning to the northeast and some to the southwest. The folds are cut by faults, which are partly contemporaneous and partly later than the folds. The dikes were intruded after most of the faulting had ceased; they may be related to extrusive andesities that lie 3 or 4 kilometers northwest of the mines.

Antimony deposits were formed, probably by ascending hydrothermal solutions, and perhaps soon after the intrusion of the dikes. The localization of the deposits was influenced by the following factors, named in order of importance: (1) Faults and fractures served as the principal channels for the migrating solutions. (2) The lithologic sequence of limestone overlain by shale caused most of the ore to be deposited not far below the contact of the two. The shale served as a barrier to prevent further upward migration of much of the solutions, which were diverted from the fissures into the adjacent wall rocks. Most of the deposits are therefore in the lower part of the upper formation, though some are in the upper part of the middle formation. (3) The folds, especially the major anticlines, were particularly effective in controlling the migration of the ore-bearing solutions.

In the past the mines have depended largely on ore that could readily be hand-sorted to a shipping-grade product containing more than 30 percent of antimony. Since 1940, however, ore containing as little as 18 percent of antimony has been shipped.

As ore bodies are not developed and blocked out in advance of mining, being mined out immediately after their discovery, the district contains no "measured" reserves in the usual sense of the term. Although the reserves cannot be estimated accurately, rough estimates indicate that they should permit a moderate degree of mining activity for at least 10 years. Specific recommendations are made to guide future development.

INTRODUCTION

This is the fourth of a series of reports on the antimony deposits of Mexico, which have been investigated by the Geological Survey, United States Department of the Interior, and the Instituto de Geología of the Universidad Nacional Autónoma de México. This investigation formed part of a cooperative program under the sponsorship of the Interdepartmental Committee for Scientific and Cultural Cooperation, United States Department of State. At the time of this investigation, the cooperating Mexican agencies were the Instituto de Geología and the Secretaría de la Economía Nacional.

LOCATION AND ACCESSIBILITY

The antimony deposits of the Soyatal district are in the north-central part of the State of Querétaro, Mexico (see fig. 4), approximately at 99°42′ west longitude and 21°07′ north latitude. The district is about 190 kilometers by airline north of México, Distrito Federal, and about 120 kilometers by dirt road north of Bernal, which is on the Mexican National Railroad and is the nearest shipping point. The best road, which passes through Tequisquiapan, Cadereyta, and Peñon Blanco, is rough and stony in some places but has been much improved since 1942. It is now passable for most of the year, though traffic is occasionally interrupted during the rainy season, which generally lasts from June until September.

TOPOGRAPHIC SETTING AND CULTURE

The Soyatal district lies in the deeply dissected eastern border zone of the Mesa central of Mexico. Altitudes in this region range from about 300 meters, on the Río Extoraz, 8 kilometers south of the mines, to about 3,200 meters on Cerro Pingüicas, which is on the crest of a high range and a few kilometers north of the mines. Although altitudes within the antimony district have not been carefully determined, they probably range from about 1,750 meters, at the Cardón mine (see fig. 5), to more than 2,300 meters in the eastern part of the district.

Most of the mines are on the upper slopes of two high ridges and are therefore dry. Water is scarce and must be hauled for considerable distances. Water for the Santa María de Miera mine and camp (see fig. 5) is brought up in trucks from Motoxí, a settlement about 10 kilometers northwest of the mine, on a small tributary of the Río Extoraz. Water for the Santo Niño mines and the Carrasco mill is obtained from another small tributary of the Río Extoraz, several kilometers south of the mines. This scarcity of water is one of the greatest difficulties encountered in mining the antimony deposits. Mainly because of it, there is no permanent population at Soyatal,

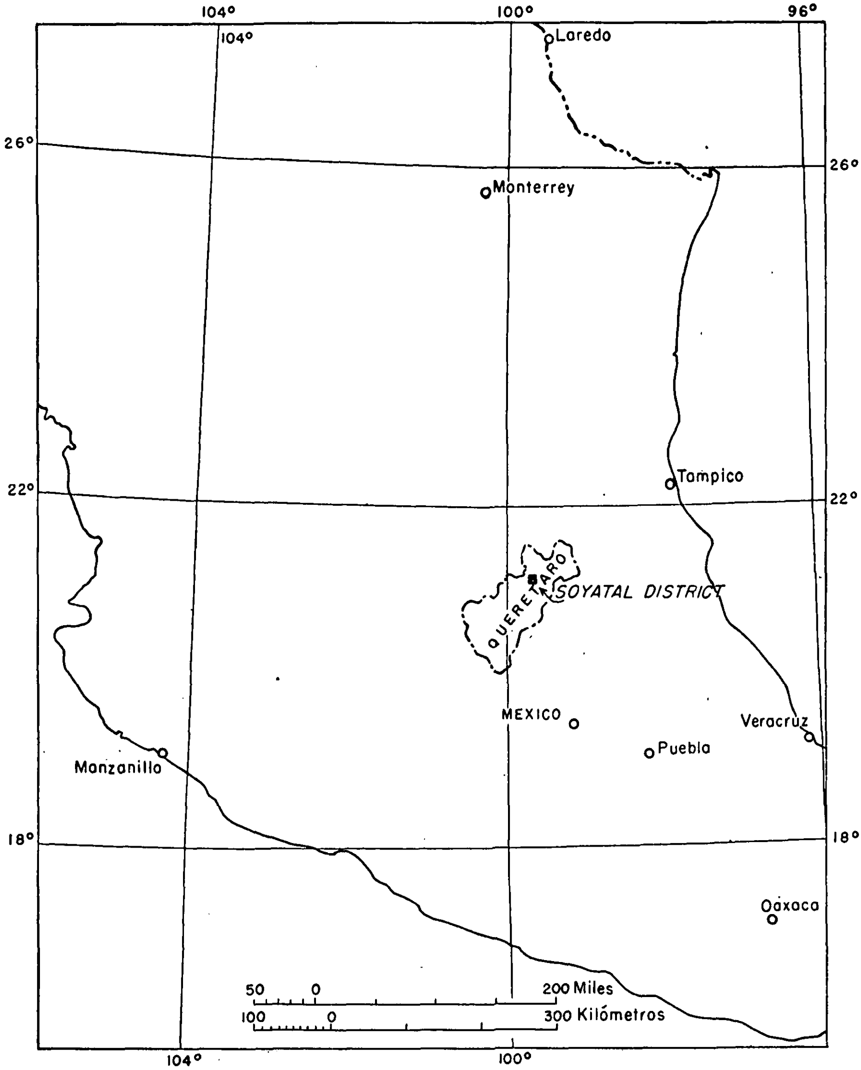

FIGURE 4.—Index map of central Mexico, showing location of the Soyatal antimony district.

and the mines are therefore dependent upon labor from a large surrounding area. All the miners leave the district when the mines are inactive; even when production is at a maximum they commonly insist upon taking long week ends to visit their homes.

Most of the area near the mines is barren of vegetation, though the higher ground was originally covered with moderate-sized trees, mostly piñon. Fortunately, the mine workings are stable and require little timbering. The timber used is generally obtained from Amoles, which is about 10 kilometers by airline northeast of the district.

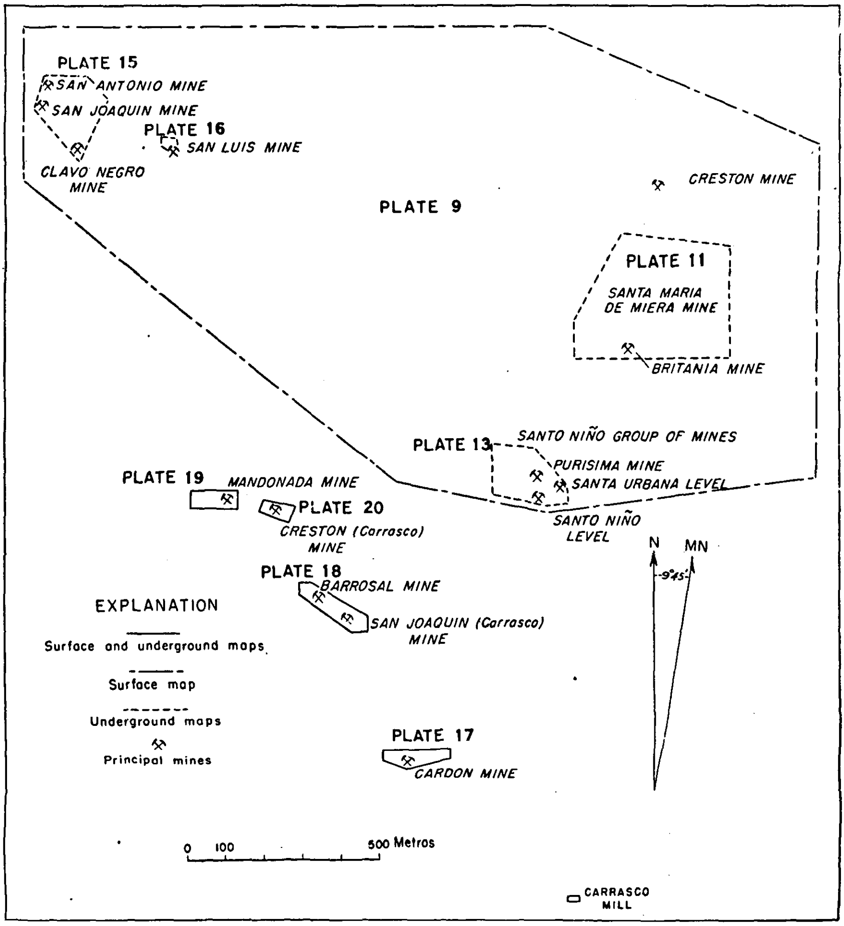

FIGURE 5.—Index map of the Soyatal antimony district, showing location of the mines and areas mapped in detail.

HISTORY, OWNERSHIP, AND PRODUCTION

The antimony industry of Mexico was started in 1898, when Mayer Elsasser, an assayer at the old silver district of Catorce in the State of San Luis Potosí, found antimony in specimens of ore from the central part of the Sierra de Catorce. He began to develop the deposits that were later known as the San José antimony mines,[1] shipping the ore to the Cookson interests of Newcastle-on-Tyne, England. In 1900 the Cooksons formed the Republican Mining & Metal Co., Ltd., with Elsasser as a stockholder and general manager. Several years later Elsasser identified antimony minerals in ore from the part of the State of Querétaro that is now known as the Soyatal dis-

[1] White, D. E., and González R., Jenaro, San José antimony mines near Wadley, State of San Luis Potosí, Mexico: U. S. Geol. Survey Bull. 946–E, 1946.

trict, and in 1905 he acquired the principal deposits for his company. The ore was carried by burro to Peñón Blanco on the Río Extoraz, and from there by wagon or burro for a distance of 100 kilometers over very poor roads to the railway station at Bernal. From Bernal it was shipped by rail to Wadley, San Luis Potosí, where, in 1904, the first antimony smelter in Mexico had been built to treat the ore from the San José mines.

During the years 1914 to 1916, communications in that part of the country were seriously disrupted by the Mexican Revolution. When the Soyatal mines were just beginning to recover their former prominence, in 1917, the price of antimony fell. In that year the Mexican Constitution was adopted, and because of the restrictions that the Constitution imposed on foreign companies, the Cía. Minera y Refinadora Mexicana, S. A., was organized. This company at once acquired all the mining interests in the Soyatal district that had been owned by the Republican Mining & Metal Co., Ltd.

From 1918 to 1934 the mines were almost completely inactive, because of the low prices for antimony then prevailing and because of the relative inaccessibility of the district. In addition, the mines were generally believed to be exhausted. The Santa María de Miera mine was, nevertheless, reopened in 1935, and within a few years it became one of the principal producers of antimony ore in Mexico. The other mines, however, had come under different ownerships about 1932 or a little later, when the Cía. Minera y Refinadora Mexicana, S. A., relinquished all its claims except the Santa María de Miera. That claim was reduced, moreover, to an area 400 meters long and 300 meters wide (12 hectares), which did not quite cover the principal workings of the mine.

The Puebla and the Jalapa claims, in the northern and central parts of the district, are now owned by Sr. Julio Pani of México, Distrito Federal, and Sr. García Robles of Querétaro, Querétaro. The Puebla claim includes the San Antonio, San Joaquín, Clavo Negro, San Mateo, San Luis, and Santo Domingo mines. The Jalapa claim, which surrounds the Santa María de Miera mine, includes the Santiago, El Puerto, El Crestón, Santa Cruz, and La Britania mines, together with the part of the Santa Catarina workings that is not included in the Santa María de Miera claim.

All the mines in the southern part of the district (see fig. 5) are included in the Tres Amigos, Chihuahua, and Marieta claims, now owned by Sr. Agustín Carrasco of Mexico, Distrito Federal. The distribution of the mines within the claims is not known.

The production from the Soyatal district is tabulated below, in table 1. No exact figures were available for the ore produced by Pani and Robles, but according to an estimate by Sr. Enrique Chirot, the mine manager, the average annual production from 1935 to 1943 was probably between 600 and 800 metric tons containing from 40 to 44 percent of antimony. Exact figures were unavailable also for the ore produced by Sr. Carrasco from 1935 to 1941, but an annual production of 800 metric tons of ore containing 40 percent of antimony is a reasonable estimate. The over-all production from the Soyatal district to the end of 1943 was about 74,000 metric tons of ore, containing 25,500 tons of metallic antimony.

Since 1942 about 60 percent of the annual production has consisted of newly mined, hand-sorted ore. Of the remainder about 15 percent consisted of screened fines, 15 percent of concentrates from hand-jigging the old dumps and stope fills, and 10 percent of low-grade, hand-sorted ore recovered from dumps and fills.

TABLE 1.—*Antimony production of the Soyatal district, 1905–43*

Year	Ore (metric tons)	Sb content	
		Percent	Metric tons
1905	[1] 3,000	(2)	[1] 1,050
1906	3,283	(2)	[1] 1,150
1907	4,589	(2)	[1] 1,605
1908	4,342	(2)	1,520
1909	4,686	(2)	[1] 1,640
1910	3,727	(2)	[1] 1,305
1911	3,542	(2)	[1] 1,240
1912	4,857	(2)	[1] 1,700
1913	4,876	(2)	[1] 1,710
1914	1,349	(2)	[1] 470
1915	127	(2)	[1] 44
1916	13	(2)	[1] 5
1917	1,616	(2)	[1] 565
1918	799	(2)	[1] 280
1919	610	(2)	[1] 210
1920	20	(2)	[1] 7
1921	1	(2)	----------
1922	----------	----------	----------
1923	----------	----------	----------
1924	----------	----------	----------
1925	----------	----------	----------
1926	----------	----------	----------
1927	----------	----------	----------
1928	35	(2)	[1] 12
1929	54	(2)	[1] 19
1930	----------	----------	----------
1931	----------	----------	----------
1932	----------	----------	----------
1933	----------	----------	----------
1934	----------	----------	----------
1935	[3] 870	(2)	[3] 305
1936	[3] 1,591	(2)	[3] 555
1937	[3] 1,698	(2)	[3] 595
1938	[3] 15	(2)	[3] 5
1939	[3] 1,020	(2)	[3] 355
1940	[3] 2,170	(2)	[3] 760
1941	[3] 1,832	28.5	[3] 522
1942	[4] 5,481	31.7	[4] 1,737
1943	[4] 6,828	27.3	[4] 1,864
	[1] 63,031	----------	[1] 21,230
Unrecorded production	[1] 11,000	[2] 40.0	[1] 4,400
Estimated over-all production	74,000	----------	25,630

[1] Approximate quantity.
[2] Approximate Sb content, 35 percent.
[3] Excluding production from mines owned by Carrasco and by Pani and Robles.
[4] Excluding production from mines owned by Pani and Robles.

METHODS OF MINING AND MILLING

The very extensive workings in the Soyatal district were excavated almost entirely by hand labor. The rock was drilled by hand; the ore as well as the waste was removed from the workings in sacks or baskets on men's backs until a few years ago, when ore cars and tracks were installed in a few of the more nearly horizontal workings. As a result, the workings were excavated almost entirely in ore, or in showings of ore, and are extremely irregular. These simple methods, however, were probably the most effective that were available under the circumstances. Labor was relatively cheap and unskilled, and the district was so difficult of access that ore cars, tracks, and machinery could not be brought into the mines except at heavy cost. Labor was for the most part hired by the day until about 1937, when the "gambusino" system was installed at the Santa María de Miera mine. Under this system the individual gambusino is relatively independent, being somewhat comparable to a small-scale lessee in the United States. He is permitted to work in the mine if he pays a royalty on the ore he produces. A capable minor commonly earns a good deal more under this system them he could at regular wages. The system results, however, in burying many workings under an accumulation of waste, for the gambusino removes only as much waste rock as he must to keep his haulage way open. He also refuses to carry on any new development that involves the mining of completely barren rock. Under this system the mining company, though relatively independent of labor laws and regulations, is burdened with high overhead costs entailed by having to remove most of the waste from the mines and carry on all new development work. This naturally places the company at a disadvantage in competition with outside buyers of ore.

The most recent period in the development of the mines began in 1940 or 1941, when the road from Bernal to Peñón Blanco, on the Río Extoraz, was extended to the San Antonio mine. Late in 1942 the road was continued to the north entrances of the Santa María de Miera mine. Up to that time the ore had been carried to Peñón Blanco by burro, and had to contain at least 30 percent of antimony; when the mines became directly accessible to trucks, however, it became profitable at the prices then prevailing to ship ore containing from 18 to 22 percent of antimony.

About 1941, a compressor and air drills were installed at the mines owned by Agustín Carrasco. In January 1943 a portable air compressor was installed at the Santa María de Miera mine. The east Tepozán tunnel was then driven with the new drilling equipment, and a considerable amount of ore that had been too hard and siliceous for hand methods was mined with air drills.

Milling operations were first introduced in the Soyatal district about 1940, also by Augustín Carrasco. The mill is a little more than 1 kilometer south of the Santo Niño workings and 512 meters below them. (See fig. 5.) The mill feed is transported from the mines and old dumps by means of an aerial tram, the head of which is 83 meters below the Santo Niño level. The milling methods employed involved the combined use of mechanical jigs and tables. In January 1944 the daily capacity of the Carrasco mill was about 25 metric tons of ore, which contained from 8 to 12 percent of antimony. According to Sr. Juan Heuter, General Manager of the Carrasco properties, the daily recovery when the mill was operating at maximum capacity was about 2½ tons of concentrates, which contained from 45 to 50 percent of antimony. The recovery of antimony in the concentrates, therefore, was approximately 50 percent of that contained in the mill feed. Until the contract expired on September 15, 1943, a large part of the mill feed had been bought from the Cía. Minera y Refinadora Mexicana, S. A. This material was obtained by reworking the old dumps of the Santa María de Miera mine.

A second mill, also using a combination of mechanical jigs and tables, was installed by the Cía. Minera y Refinadora Mexicano, S. A., at Motoxí, a small settlement about 15 kilometers northwest of the mines, on a tributary of the Río Extoraz. Operations were started in December 1942. During 1943 the company recovered 320 tons of table concentrates, containing 30 percent of antimony, and 210 tons of jig concentrates, containing 43 percent of antimony.

FIELD WORK

The district was visited during the period May 20 to 22, 1942, by Donald E. White, of the United States Geological Survey, and Jenaro González R., of the Instituto de Geología of Mexico. The field work upon which the present maps and report are based was done by White over a period of about 10 weeks, from late in October to early in February 1944.

The surface geology of most of the district (see pls. 9, and 10) was mapped on a topographic base supplied by the Cía. Minera y Refinadora Mexicana, S. A. This base map was modified, and 10-meter contours were interpolated, in the field. The resulting map, though probably adequate for most purposes, cannot be relied upon to give exact distances. Base maps for the Santa María de Miera mine (pls. 11 and 12) and the Santo Niño group of mines (pls. 13 and 14) were supplied by the respective owners, but they have been modified, particularly where the workings are very irregular. The geology was mapped in all the workings of these two groups of mines that had been surveyed up to February 1944, but unfortunately the author could not survey and map the remaining workings because of other urgent work.

All the other mine maps (see pls. 15 to 20) that accompany this report are based on tape and compass surveys. They probably are adequate for most purposes, but they should be checked by transit surveys where exact measurements of distances and altitudes may be necessary.

ACKNOWLEDGMENTS

The writer is grateful for the hospitality and cooperation extended by the many residents of Soyatal, especially to Mr. Jerome Hilbert and Sr. Ing. Enrique Prado of the Cía. Minera y Refinadora Mexicana, S. A., Sr. Juan Heuter of the Carrasco mines, and Sr. Enrique Chirot of the Pani and Robles mines. Mr. C. A. Stover, General Manager of the Cía. Minera y Refinadora Mexicana, S. A., Sr. Agustín Carrasco, and Sr. Julio Pani were exceedingly helpful in supplying the author with base maps and information concerning the history and production of the mines.

GEOLOGY

The bedrock of the area studied consists largely of a thick sequence of calcareous rocks, overlain by rocks that grade upward into shale, (See pls. 9 and 10.) The sedimentary rocks were folded and faulted, and in a few places they were intruded by dikes of basalt and andesite(?). At a later time, antimony minerals were deposited from solutions that were guided for the most part by the faults and folds. Throughout the district the ore was concentrated near the base of the shaly rocks, probably because of their relative impermeability as compared with the underlying rocks.

SEDIMENTARY ROCKS

Three sedimentary formations have been mapped in the area. As the present investigations were local in character, these formations are not given specific names but are distinguished merely as lower, middle, and upper.

LOWER FORMATION

The lower formation consists of an unknown thickness of limestone, chert, limestone conglomerate, shaly limestone, and a little calcareous shale. Only the upper part of the formation has been mapped. This part generally consists of 15 to 20 meters of unstratified limestone conglomerate, which contains irregular masses of chert and angular boulders of limestone as much as 1 meter in diameter. As the conglomerate is very massive and relatively resistant to erosion, it is the most prominent cliff-forming rock in the area.

The massive limestone conglomerate is generally in abrupt contact with the overlying middle formation, but 250 meters southwest of the Santiago mine, in the central part of the district, the massive limestone conglomerate is separated from the middle formation by

15 to 20 meters of limestone with little or no chert, interbedded with a small proportion of limestone conglomerate (see pl. 9). The lower formation may have been folded on a very moderate scale and partly removed by erosion, before the middle formation was deposited. The contact of the two formations is probably a disconformity in most places, but in some places it appears to be a low-angle unconformity.

The rocks below the limestone conglomerate have not been studied in detail. About 200 meters northeast of the Santo Niño mine there are exposures of limestone and chert, interbedded with gray limy shale and a few beds of red shale. Southwest of the Santo Niño mine, a considerable part of the lower formation consists of gray limestone and chert that are very similar in appearance to the dominant rocks of the middle formation. These rocks, however, are interstratified with others, such as red limy shale, limestone conglomerate, and limestone without chert, that do not occur in the middle formation.

The relationships of the beds east of the Raizal fault, in the eastern part of the area, are not clearly understood. These beds consist predominantly of interbedded limestone and calcareous shale, almost identical in appearance with rocks forming part of the upper formation. Downward and eastward, however, they grade into conglomerate beds resembling some of those in the lower formation. No rocks closely similar to those of the middle formation, or to the shale in the upper part of the upper formation, have been found east of the fault, and the beds there exposed are tentatively assigned to the lower formation.

MIDDLE FORMATION

The middle formation generally consists of about 30 meters of thin-bedded limestone characterized by numerous lenses of chert.[1a] The limestone is light gray on weathered surfaces, but dark gray to blue gray on fresh surfaces. Individual beds of limestone are 5 to 50 centimeters thick and are commonly separated by thin shaly partings, which are mostly red or reddish purple. Upon close examination each limestone bed is found to be laminated to a degree that is unusual in limestones. The lamination is generally parallel to the beds, but deviations due to local channeling may be found in a few places. These internal structures are believed to have been caused by an original accumulation of calcareous sediments consisting of clastic grains as much as 1 or 2 millimeters in diameter.

About 150 meters south of the Santo Domingo mine, in the southwestern part of the area (see pl. 9), the middle formation appears to be no more than 15 meters thick; 250 meters south of the Santa María

[1a] White, D. E., Diagenetic origin of chert lenses in limestone at Soyatal, State of Queretaro, Mexico: Am. Jour. Sci., vol. 245, pp. 49–55, 1947.

de Miera mine it is only about 20 meters thick. The local thinning of the formation may be due to faulting, to unequal deposition, or to erosion of the upper beds prior to the deposition of the upper formation. This erosion may have been one of the most important factors, since the upper contact appears to be a disconformity or an unconformity.

A few poorly preserved fossils, found in the upper beds of the middle formation, were examined by R. W. Imlay of the United States Geological Survey and were determined by him as *Crioceras?* sp., *Hamulina?* sp. and *Macroscaphites?* sp. Imlay comments:

> The fossils from the Soyatal area consist of fragmentary uncoiled ammonites, whose preservation does not permit a close age determination. Similar uncoiled ammonites are most common in beds ranging in age from latest Jurassic to late lower Cretaceous. Probably the most similar species known from Mexico are those described by Böse (1923, Inst. geol. Mexico Bol. 42, pls. 17–19), from the Cuesta del Cura limestone at the top of the Comanche series (upper part of Lower Cretaceous).

UPPER FORMATION

The upper formation contains the principal ore bodies of the district, and the lithologic character of the formation is of great importance because of the influence it has had in localizing the ore. The succession of rock types in the basal beds differs in detail from place to place. The beds in the lower 1 to 40 meters consist predominantly of limestone conglomerate and massive limestone, but include a few fine-grained limy sediments. The beds in the overlying 50 to 75 meters consist of alternating limestone and calcareous shale, with the proportion of shale beds increasing upward. A thick succession of higher beds consists predominantly of shale and interbedded sandstone, but as these rocks occur only outside the area mapped, they have not been studied in detail.

Most of the ore bodies in the district are found within 20 to 30 meters stratigraphically above or below the base of the upper formation; the beds containing these ore bodies were studied with special care. Detailed correlations of individual lithologic units cannot be made with certainty on the basis of present information, but they can be made in the future if more closely spaced sections are obtained. The succession of beds of the upper formation at different places across the northern part of the district (see pl. 9) is shown in figure 6.

In the northern and central parts of the district, the thickness of the basal conglomerate ranges from 1 to 5 meters. The conglomerate attains its maximum thickness, and also is coarsest, about 100 meters southwest of the Santiago mine. At several places west of this point, a bed of red shale was seen to lie directly upon the conglomerate, but it apparently is not continuous throughout the San Joaquín and San Antonio mines.

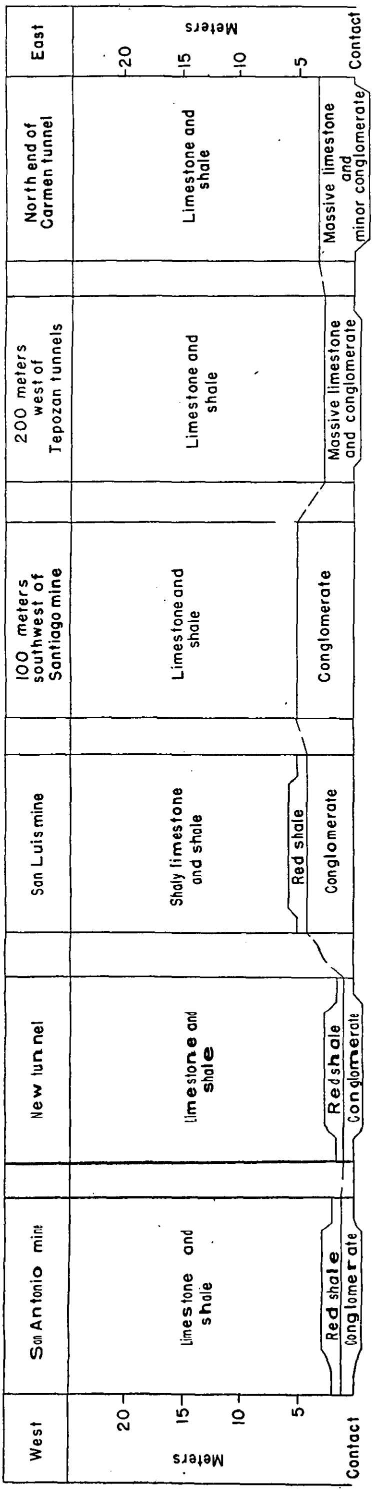

FIGURE 6.—Basal beds of the upper formation, from the northwestern to the northeastern part of the district.

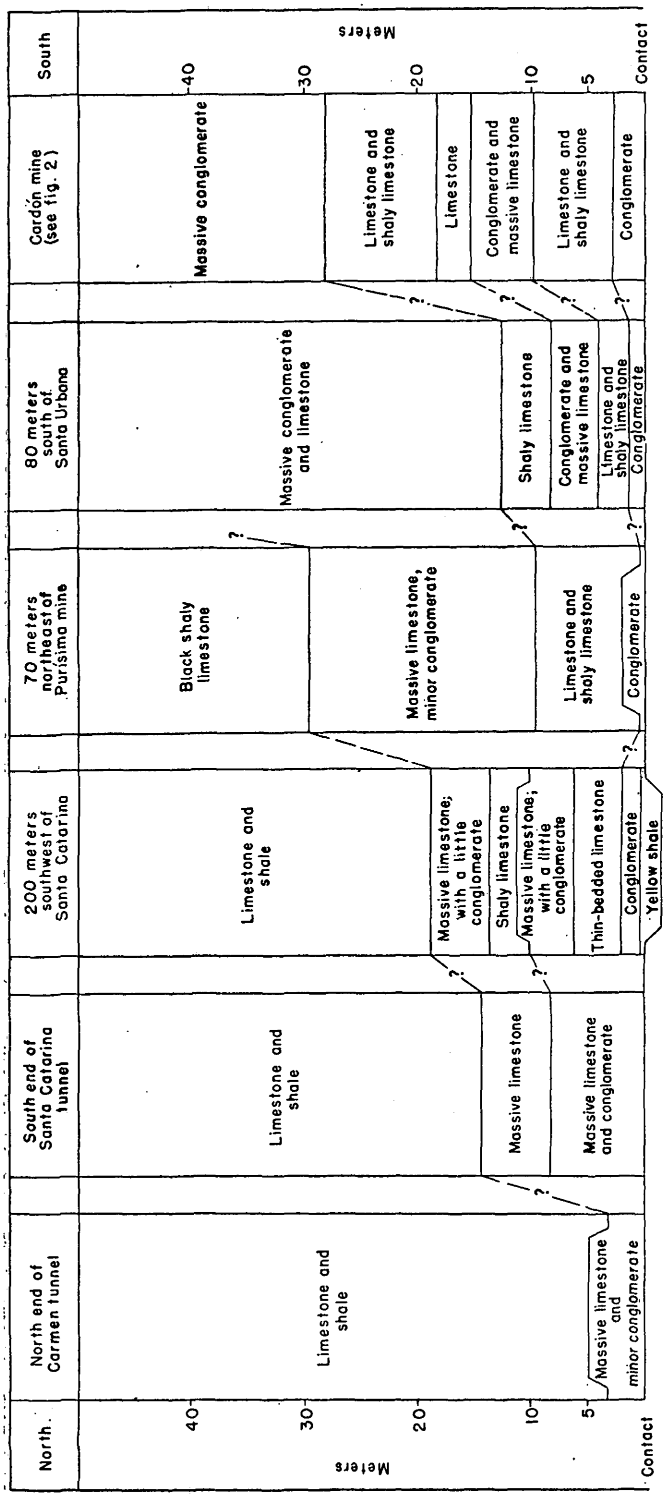

FIGURE 7.—Basal beds of the upper formation, from the northeastern to the southern part of the district.

The detailed succession of the basal beds at different places, from the northeastern part of the district southward, is shown in figure 7. (See also pl. 9 and fig 5.) The variety and complexity of the basal beds increase markedly from north to south. The massive limestone and limestone conglomerate are most abundant in the southern part of the district, where, also, the coarsest conglomerate was found. The sediments of the upper formation therefore probably came from the south.

The limestone conglomerate shows considerable variation in character within the district. Many beds consist of unsorted detrital fragments of limestone as much as 50 centimeters in diameter. The finer-grained beds generally consist of relatively well sorted particles of limestone cemented with calcite; other constituents are inconspicuous or absent. The coarser beds, on the other hand, are characterized by unsorted, angular masses of limestone and blocky, irregular bodies of chert. Some of the chert bodies have the rounded terminations that are typical of the chert lenses of the middle formation, but far more numerous are tabular fragments, which commonly lie transverse to the bedding. These have square or angular terminations, indicating that they may have been derived from the breaking up and rearranging of chert lenses from the underlying middle formation. Many other masses, however, are so irregualr in size and shape that they are believed to have been formed in their present positions.

IGNEOUS ROCKS

AMYGDALOIDAL BASALT

The area contains a few inconspicuous dikes and small irregular intrusive bodies. The only unaltered igneous rock found in the district forms an irregular mass that lies about 100 meters southwest of the Clavo Negro mine (western part of map, pl. 9). This mass consists of amygdaloidal basalt—a dark rock with small rounded cavities now filled with quartz and calcite. The rock contains phenocrysts of augite and calcic labradorite in a fine-grained groundmass of granular pyroxene mixed with lath-shaped crystals of sodic labradorite. It also contains small inclusions of quartz and fragments of a finer-grained basalt. The amygdaloidal texture is believed to indicate that the basaltic magma solidified at relatively shallow depth; it probably was intruded when the surface of the ground was no more than a few hundred meters higher than it is at present.

ANDESITE(?)

Three northwest-striking dikes were found in the central and southeastern parts of the district. (See pl. 9.) The rock in these dikes is so completely altered that its original nature could not be determined, but it was probably different from the basalt that has been described. Although none of the original minerals are preserved, the outlines of a few phenocrysts are recognizable.

The two dikes south of the Santa María de Miera mine occupy fractures that show little or no displacement, but the dike 500 meters west of the same mine came up along a preintrusion fault that shows a stratigraphic displacement of 10 to 15 meters.

Seven small masses of what are believed to be altered igneous rocks were found in the Santa María de Miera mine. (See pl. 11.) Apparently none of these intrusives crop out at the surface. The small dike in the northwestern part of the Raizal mine is in the Raizal fault zone, but it shows little or no brecciation and is therefore believed to have been intruded after the principal movement took place.

The complete alteration of the dikes was probably caused by hydrothermal solutions that intimately permeated the rocks. Although the altering solutions may have been related to the antimony-bearing solutions, the distribution of the ore bodies is not closely related to that of the dikes. Of possible significance, however, is the relative abundance of small dikes in the Santa María de Miera mine, which is in the most highly mineralized part of the district. No dikes were found in any of the other mine workings in the area.

The dikes are tentatively regarded as consisting of altered andesite. Several andesite dikes with a similar northwesterly trend were found a kilometer or more north of the mapped area, and erosion remnants of a thick series of andesitic lavas and pyroclastics occur on the mountains bordering the basin of the Río Extoraz, 2 or 3 kilometers northwest and west of the antimony mines. Although the base of the lavas in each erosion remnant appears to lie 1,900 to 2,000 meters above sea level, or about 150 to 300 meters below the principal mines, no lavas are found in the area of the mines or on the much higher mountains to the east. The lavas may have been faulted downward to their present position, along some line immediately west of the mines. On the other hand, the Soyatal district may formerly have lain on the eastern border of an erosion basin filled with lavas and pyroclastics; the volcanic rocks then possibly lapped up over the present bed rocks of the district and were later eroded. The altered, supposedly andesitic dikes in the district may have served as feeders for some of these extrusive rocks.

No direct evidence was found for assigning a definite age to the volcanic rocks in or near the Soyatal district, but they are probably outliers of the extensive areas of mid-Tertiary andesites found throughout central Mexico.

STRUCTURE

FOLDS

The structural pattern of the area consists of a complex system of folds cut by numerous faults. Most of the folds strike northwest; a few strike north or northeast. The folds are generally asymmetrical and a few are overturned. The direction of overturning is not the same throughout the district: the axial planes of the folds that are shown in plate 9 generally dip to the west or southwest, but the axial planes of the folds in the southern part of the district dip to the northeast. Although the geology of this southern part of the district was not everywhere studied in detail (fig. 5), it was observed that the beds on the southwest flanks of many of the anticlines were nearly vertical or even overturned. (See pls. 17, 19, and 20.)

Many of the major folds contain a large number of minor folds, which are commonly most abundant in and above the basal beds of the upper formation. (See pls. 11 to 14.) Most of these minor folds die out downward; they are not found in the massive beds of conglomerate in the lower formation.

The axes of many of the folds are in part horizontal, but more commonly they plunge at angles that range up to about 20°. The large anticline immediately northeast of the Santa Niño group of mines (pl. 9) contains a domical structure that has a maximum closure of about 60 meters. The base of the upper formation along the crest of the anticline ranges in altitude from 2,165 meters in the southeastern corner of the map to 2,225 meters at a point on the south flank of the Santa María ridge; this point is near the crest of the domical structure. About 750 meters to the northwest, the crest plunges to an altitude of 2,150 meters.

FAULTS

Most of the faults belong to two fairly distinct systems, although a few of them cannot be assigned with certainty to either.

The faults in the system that contain most of the large faults in the district strike northwestward and dip at moderate angles to the southwest. They are normal faults, their downthrow being on the southwest, and the stratigraphic displacement on them ranges from a few centimeters to many meters. On the Raizal fault, which is the largest of this system (see northeast parts of map, pls. 9 and 11), the displacement may be 150 meters or more. These northwest-striking faults are believed to have controlled the migration of the ore-bearing solutions almost everywhere in the district.

The northeast-striking faults may be in part contemporaneous with those that strike northwest, but most of them are later. These faults are more varied than the others in regard to dip and direction of movement. On many of them the horizontal component of movement may have been greater than the vertical component. Apparently no single fault of this system has a displacement of more than 40 meters, and on most of them the movement was not more than a few meters.

A few breccia zones are shown in plates 9, 11, and 13. In general these zones are ill-defined and are parallel to the bedding of the enclosing rocks. Their position, mostly in or near the axes of synclines, is evidence that they were formed contemporaneously with the folds. Breccia zones are apparently common adjacent to the more massive and competent beds of limestone and conglomerate near the base of the upper formation.

ORE DEPOSITS

RESTRICTED DISTRIBUTION OF THE ORE

The principal antimony deposits lie within an area about 2 kilometers long and 1 kilometer wide. (See pl. 9.) Other deposits have been mapped within a kilometer south of the principal area. (See fig. 5.) There are small unmapped workings a few hundred meters southwest of the Clavo Negro mine, and others 1 or 2 kilometers northwest of the San Antonio mine.

The restricted distribution of the antimony deposits is a product of three factors, which are, in order of importance: (1) fault fissures and other steep fractures, which afforded the principal channels for the migrating solutions; (2) the lithologic sequence of limestone overlain by shale. The shale prevented further upward migration of the solutions, which were diverted away from the principal faults into the adjacent wall rocks; (3) the influence of the folds, particularly of the major anticlines, which were of major importance in controlling the migration of the ore-bearing solutions.

INFLUENCE OF FAULTS AND FRACTURES

The distribution of the antimony ore is closely related to the distribution of the faults and fractures. The Santa María de Miera mine, the largest in the district, is near the northwest-striking Raizal fault (pl. 9), which is the greatest fault in the district; the stratigraphic displacement on this fault apparently is at most 150 meters. Many of the most extensive workings in the mine are within 50 meters of this fault (pl. 11) and workings are particularly abundant in its southwest, or hanging, wall. Most of the large stopes elsewhere in the mine are on or near northwest-striking faults of moderate displacement.

At many places in the mine, small northeast-striking fractures have served as local channels along which the ore-bearing solutions were diverted from the major faults. These fractures are particularly numerous immediately west of the Raizal fault. They are so closely spaced, however, and have so little persistence, that they were not mapped in detail. The only large ore-controlling fault of the northeast system in the Santa María de Miera mine is exposed in the Carmen stopes, in the north-central part of the mine.

In most of the other mines in the district the distribution of the ore is influenced by faults and fractures that belong to the same two systems, but the displacements on the faults rarely exceed 1 or 2 meters.

It may be because of the absence of strong and persistent faults that none of these other mines is as productive as the Santa María de Miera mine. But the amount of mineralization is not proportional to the throw of the fault; little or no ore is associated with certain faults in the central part of the district on which the stratigraphic displacement ranges from 5 to 20 meters (pl. 9). Apparently these faults, for some undetermined reason, were not utilized as channels by appreciable quantities of the ore-bearing solutions.

Poorly defined zones of breccia, which generally lie parallel to the bedding, are conspicuous in several of the mines. These zones are believed to be contemporaneous with the folds, for they are commonly found on or near the axes of synclines, where the compression that resulted from the folding was greatest. Some of them, moreover, are adjacent to the thickest and most massive beds of limestone and conglomerate, where the folding entailed an unusually large amount of adjustment. The breccia zones are well mineralized in some places and relatively barren in others.

INFLUENCE OF CHARACTER OF SEDIMENTARY ROCKS

Nearly all the ore deposits are near the contact between the middle and upper formations. (See pls. 1, 3 to 11.) Although showings of ore have been found in the lower formation and in the upper part of the upper formation, probably 90 or 95 percent of the total past production from the district has been obtained within a distance of 20 meters below or 30 meters above the base of the upper formation.

This remarkable concentration of the ore within so narrow a stratigraphic range must have been caused by differences in the lithologic character of the upper formation. In the middle and lower formations there are hundreds of meters of limestone and but little shale, whereas in the upper formation the proportion of shale is large, increasing upward. The lithologic succession is strikingly comparable to that in the San José antimony mines of the State of San Luis Potosí.[2] There a great thickness of nearly pure limestone is directly overlain by an almost impermeable shale. Nearly all the past production has come from limestone beds below the shale, within 35 meters of its base. No ore is found in the shale, and only very small showings occur in the limestone that overlies the shale. A similar restricted distribution of ore in limestone that is directly overlain by shale is found in the Tejocotes antimony district of western Oaxaca.[3]

In contrast to the shale formations in the San José mines and in the Tejocotes district, the basal beds of the upper formation in the

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[2] White, D. E., and González R., Jenaro, The San José antimony mines near Wadley, State of San Luis Potosí, Mexico: U. S. Geol. Survey Bull. 946–E, 1946.

[3] White, D. E., and Guiza, Reinaldo, Jr., The antimony deposits of the Tejocotes district, State of Oaxaca, Mexico: U. S. Geol. Survey Bull. 953–A, 1947.

Soyatal district are relatively permeable, and the upward decrease in permeability is gradual rather than abrupt. This difference, however, is less important than the fact that in the most productive districts of Mexico the antimony ore is in limestone overlain by shale. The opposite also is true: in nearly all the minor antimony districts in Mexico, the ore deposits occur in limestone that is not directly overlain by shale.

Despite this emphasis on what is believed to be a particularly favorable succession of rocks, it should not be forgotten that other factors are essential for the formation of antimony deposits; antimony-bearing solutions must once have been present, faults and fractures by which they could migrate must have been available, and chemical reactions that would bring about deposition of the antimony minerals must have been possible.

INFLUENCE OF FOLDS

Many of the ore deposits in the district are found in the upper parts of the major anticlinal structures. That is particularly true of the deposits in the Santa María de Miera, San Antonio, San Joaquín (Carrasco), and Barrosal mines. These major anticlinal structures consist, in detail, of a number of minor folds, whose relation to the major folds is illustrated in the structure sections of the Santa María de Miera mine. (See pl. 12.) The Carmen and Catorce workings of this mine are near the crest of a major anticlinal structure, and they are in some of the most highly mineralized ground in the mine (pl. 11); whereas the ground southwest of the Carmen workings, in the trough of a major synclinal structure, is apparently part of the least mineralized. The Santo Niño group of mines, however, is in a major synclinal structure (pls. 11 and 12).

At many widely separated places in the district, the localization of the ore appears to be closely related to minor anticlines. This relation is exemplified in the largest of the Puertecito and Catorce stopes of the Santa María de Miera mine (pl. 11), and in several of the Dolores stopes of the Santo Niño group of mines (pl. 13): several of the stopes in the San Antonio mine lie immediately northeast of the crests of minor anticlines (pl. 15). Probably more than half the stopes in the district, however, are not directly related to any of the minor folds. Nevertheless, the relationship is common enough to be regarded as an important factor in planning future search for ore.

MINERALOGY OF THE ORE

ANTIMONY MINERALS

The mineralogy of the deposits is relatively simple. Stibnite (Sb_2S_3) is the principal primary or hypogene ore mineral, although in many of the ore bodies it has been almost entirely oxidized. The antimony oxides found in this district range in color from brown through orange and tan to buff or white, and are very fine grained. They form pseudomorphs after the original stibnite, and since they form no euhedral crystals, the different species can be distinquished only with the aid of quantitative chemical and X-ray analyses, neither of which, unfortunately, could be made at the time of this investigation.

Stibnite is abundant in many of the ore bodies that lie at a considerable depth below the surface. The ore that was being mined in 1943 and 1944 from the western Negra stopes of the Santa María de Miera mine and from the northwestern end of the Santa Urbana level of the Santo Niño group of mines consisted entirely of unoxidized stibnite ore. In most of the other stopes the oxides predominate, but a little stibnite is found in almost all of them. The over-all ratio of antimony oxides to stibnite is probably about 2 or 3 to 1.

The antimony minerals are found mostly in low-grade ore bodies replacing impure limestone and calcareous shale. Much of the mineralized and altered rock retains a bedded structure. The stibnite commonly forms radiating clusters of euhedral and subhedral crystals that cut across all the relict structures of the original beds.

About half the volume of the antimony minerals is concentrated in fractures that either lie roughly parallel to the bedding or cut it at high angles. The fracture filling is generally less than 1 centimeter thick, although much greater thicknesses are not unusual.

CINNABAR

The antimony minerals, which occasionally occur in rounded or oval masses as much as 30 centimeters in diameter, have been found in an unusual association with cinnabar in the near-surface San Andrés workings and reportedly at several other places in the Santa María de Miera mine. Relict structures in some of the masses suggest that the ore has not filled open cavities, but has replaced calcareous sediments. Each mass generally contains a core of fresh stibnite, surrounded by antimony oxides that form pseudomorphs after stibnite. Very fine grained cinnabar "paint" forms a thin coating on radial or concentric fractures found only in the outer part of the oxidized zone. The radial fractures apparently widen outward, but they terminate inward without cutting the sulfide core of each mass; they are probably related, therefore, to the oxidation of the stibnite. As the antimony oxides all have higher specific gravity than stibnite, the oxidation is probably accompanied by a slight decrease in volume.

The cinnabar paint ranges in color from brilliant red to dark-reddish purple. In some instances, at least, the darker color is found near the outer border of each mass. The differences in color as well as the distribution of the cinnabar show concentric banding parallel to the outer border. The greatest concentration of cinnabar generally occurs from 1 millimeter to 15 millimeters from the outer border of each rounded mass, but little or no cinnabar is found on the outer surfaces, and no cinnabar has been observed in the unoxidized cores.

The origin of this cinnabar presents an interesting problem. As the cinnabar is restricted to fractures in the antimony oxides, it either was introduced after the oxidation of the stibnite or was formed by the oxidation of some mercury-bearing sulfide mineral. In order to determine whether such a mineral was present, J. J. Fahey, of the United States Geological Survey, tested the sulfide cores of several rounded masses for mercury. The apparatus employed, which consists of an ultraviolet lamp and a fluorescent willemite screen, detects minute traces of mercury. The light is of such a wavelength as to be absorbed by any mercury vapor that may issue from a heated specimen, so characteristic shadow effects are produced on the screen. This technique revealed small amounts of mercury in all the samples of sulfide, even when special precautions were taken to prevent contamination. Finely ground powders of the sulfide were then examined under the microscope, where they were compared with powders known to contain cinnabar and livingstonite ($HgS.2Sb_2S_3$). Neither of these minerals was detected. Despite this negative evidence, the cinnabar is believed to originate either from the supergene oxidation of minute, undetectable particles of livingstonite or from mercury-bearing stibnite. The rounded masses of sulfide ore may originally have contained more mercury near the outer, now oxidized, borders than in the centers. The occurrence of the cinnabar suggests that it may have been concentrated by local migration and deposition as a colloid.

Cinnabar paint is also found rather commonly at a number of other places in the district, on pseudomorphs of antimony oxide after stibnite. The only cinnabar in the district that is believed to be hypogene was found in a small stope in the El Raizal workings of the Santa María de Miera mine. This cinnabar is almost pure, coarse-grained, and dark ruby red. It was abundant in one veinlet 30 centimeters long and about half a centimeter wide. None of this coarse-grained cinnabar is closely associated with the antimony minerals that occur in the same stope.

CHALCEDONY AND QUARTZ

Silica is the most common associate of the antimony minerals. A very little of it is in the form of medium- to coarse-grained quartz, which appears to be found only in the more massive concentrations of the antimony minerals. At least 99 percent of it consists of fine-grained chalcedony replacing limestone. The chalcedony is almost everywhere more widespread than the antimony minerals, which have been found, nevertheless, in small amount in unsilicified or partially silicified limestone.

CLAY MINERALS

Hydrothermal clay minerals are especially abundant in the Santa María de Miera mine. They are not, in general, closely associated with individual ore bodies but are found mostly in the associations described in the following three paragraphs.

Clay minerals occur in impure mixtures that are apparently residual concentrations resulting from the leaching of $CaCO_3$ from argillaceous limestone. The individual species of clay minerals occuring in this manner have not been identified. The association is commonly found in breccia zones that appear to be related to the axes of synclines. The final product after the leaching of $CaCO_3$ from the breccia consists of soft, porous masses that retain the shapes of the original fragments of breccia. The leaching probably was done by hydrothermal solutions, which may have been related to the antimony-bearing solutions.

Nearly pure masses of the clay mineral endellite, $Al_2Si_2O_5.(OH)_4.2H_20$, formed by hydrothermal replacement of limestone and possibly of chert, occur in some places. The material was identified by C. S. Ross and G. T. Faust, of the United States Geological Survey. This large-scale occurrence of endellite is of considerable interest, because it is only in recent years that this mineral has been identified as a distinct species.[4] Endellite is unstable in the atmosphere, where, by partial dehydration, it alters to the better known clay mineral halloysite, $Al_2Si_2O_5(OH)_4$. When newly exposed, endellite is gray, tan, or light blue, semi-translucent, and of opaline appearance. It is somewhat greasy to the touch and has a conchoidal fracture. Unlike most clay minerals, endellite does not adhere to the tongue until after it has been exposed for several days in a dry atmosphere and has become at least partly altered to halloysite. When thus altered, most of the material loses its translucency and becomes opaque and porcelainlike. Endellite is abundant in the East Tepozān tunnel, where it occurs adjacent to the Raizel fault and below the principal ore bodies. (See pl. 11.) About 50 percent of the walls of the tunnel southeast of N. 295–E. 275 consist of massive endellite that has directly replaced limestone. A sample collected at N. 285–E. 285 was analyzed in the chemical laboratory of the United States Geological Survey, with the results given in the table on p. 57. The symbol, N. 295–E. 275, desig-

[4] Alexander, L. T., Faust, G. T., and Hendricks, S. B., Relationship of the clay minerals halloysite and endellite: Am. Mineralogist, vol. 28, pp. 1–18, 1943.

nates a point at the intersection of two lines in the coördinate system on which all the mine maps are plotted. The point designated here is at the intersection of a line 295 meters north of the origin with a line 275 meters east of the origin.

Analysis of endellite from the east Tepozán tunnel, Santa María de Miera mine

[Analyst, W. W. Brannock]

SiO	42.68	K_2O	0.08
Al_2O_3	35.05	Na_2O	
FeO	.07	H_2O-	7.97
Fe_2O_3	.22	H_2O+	13.87
TiO_2	.02		
CaO	.50	Total	100.58
MgO	.12		

A small amount of the clay mineral allophane ($Al_2O_3.SiO_2.nH_2O$), associated with halloysite and endellite, was found in a cavity in limestone 55 meters south of the portal of the south Tepozán tunnel. The minerals were identified by C. S. Ross, of the United States Geological Survey.

ALUNITE

Alunite, $KAL_3(OH)_6(SO_4)_2$ occurs in considerable quantity at several places in the Santa María de Miera mine and is generally abundant wherever endellite and halloysite are found. The alunite, which is white to cream-colored, fine-grained, and of porcelainlike appearance, is not dissemminated through the clay minerals or the wall rocks; it is generally found in distinct rounded or oval masses as much as 20 centimeters in diameter or in irregular veins.

GYPSUM

Gypsum ($CaSO_4.2H_2O$) was found in small quantity at many places in the mines. Seams of fibrous gypsum are common in some of the basal beds of the upper formation. The mineral is particularly abundant in a black shaly limestone that occurs in several of the western Negra stopes of the Santa María de Miera mine and in the northwestern part of the Santa Urbana level of the Santo Niño group of mines. It is found also in the leached material derived from brecciated limestone. Euhedral crystals of gypsum (selenite variety) occur in cavities in the Purísima mine of the Santo Niño group.

VARISCITE

Veinlets of variscite ($Al_2O_3P_2O_5.H_2O$) were found in several of the stopes of the Santa María de Miera mine; several distinct veinlets as much as 1 meter long and 1 centimeter wide occur in the northwestern part of the main Puertecito stope near N.190–E.310. The mineral ranges in color from dark green to greenish white, but the white material, which occurs on the outer borders of the veinlets, may be a weathered or hydrated product of variscite. The identity of the mineral was verified by W. T. Schaller, of the United States Geological Survey. These veinlets are not directly associated with antimony minerals, although they cut antimony-bearing rocks.

CALCITE

Coarse-grained calcite is fairly common throughout the district. Much of it is white and is probably a product of the recrystallization of the limestone in which it occurs. In the Santo Niño groups of mines and the Clavo Negro mine, a little antimony ore is in recrystallized calcite that lies immediately below chert lenses of the middle formation. Large euhedral crystals of calcite occur with gysum in cavities in calcareous rocks. A few large, milky-white to apple-green crystals were found in the Purísima and Santa Urbana workings of the Santo Niño group of mines.

ORIGIN OF THE ANTIMONY DEPOSITS

The stibnite of the ore deposits is believed to have been deposited from antimony-bearing solutions that came up along faults and fractures from a considerable depth. The solutions may have come from the same source as the andesitic extrusive rocks and the altered dikes in and near the Soyatal district. They migrated upward until they reached the base of the upper formation, where, because of the decreasing permeability of the shaly rocks upward from the contact, they were diverted from the principal faults into the basal beds of the upper formation. The concentration of the ore deposits in or near the crests of the major anticlinal structures tends to support this view. The shaly rocks are not to be thought of as having formed completely impermeable dams or traps. The stibnite was probably deposited by solutions that contained only a small proportion of antimony, and that migrated onward after all or a part of their antimony content had been deposited, to be followed by solutions that carried a fresh supply of antimony. Eventually the solutions are believed to have arrived at the surface as hot springs.

Completely impermeable traps were probably unfavorable to ore deposition. The structural dome on the anticline immediately northeast of the Santo Niño group of mines had a structural closure of at least 60 meters before it was partly eroded away. (See pl. 9.) The crest of the dome was about 175 meters northeast of the portal of the Santo Niño level. As faults are completely absent in the area near its crest, the dome was so impermeable that it would have made an ideal oil-bearing structure, yet it contains no ore. The structures generally most favorable for ore deposition were major anticlines penetrated by fissures through which the depleted solutions could escape.

How the stibnite was precipitated is difficult to determine without knowing the composition of the ore-bearing solutions. The precipitation probably was not caused directly by reaction of the solutions with the wall rocks. Although the solutions appear to have migrated upward through hundreds of meters of limestone, very little stibnite was deposited until the solutions were diverted into the basal beds of the upper formation. It is conceivable that a reaction of the solutions with the shaly beds of the upper formation may have caused the precipitation of stibnite in the Soyatal district. This seems, however, improbable in view of the evidence from the San José mines of the State of San Luis Potosí.[5] In these mines, which are similar in many respects to those of the Soyatal district, the contact of limestone and shale is so abrupt, and the degree of impermeability of the shale so marked, that almost all the antimony ore is found in the limestone from 8 to 40 meters below the shale.

THE MINES

SAN ANTONIO MINE

The San Antonio mine (pl. 15) is the largest of the group owned by Julio Pani and García Robles. Its workings, which are mainly drifts and nearly horizontal stopes, have explored an area 160 meters long and 90 meters wide.

The mine is near the crest of a major anticline, in beds of limestone and shaly limestone. In contrast to the steep dips that prevail in most of the district, the dips are gentle and rarely exceed 20°. The ore is mostly on or immediately east of the crests of anticlines, and in many places it is adjacent to fractures or faults on which the displacement is only a few centimeters. These faults dip steeply and strike N. 20° W. to N. 45° E. In some places the fractures curve near the axes of folds (N. 290–E. 185, N. 250–E. 195, pl. 15), which may indicate that they were formed contemporaneously with the folds; some of the fold axes die out adjacent to the fractures. Some of the fractures are open, probably having been formed by the horizontal separation of the walls with little or no vertical displacement. The open spaces, however, were possibly formed by solution along joints. The walls of the fractures are commonly lined with calcite, but the fractures are rarely filled, and the open spaces range to as much as half a meter in width. Near N. 250–E. 185 there is a nearly vertical fracture at least 10 centimeters wide, but this fracture is confined to

[5] White, D. E., and González R., Jenaro, The San José antimony mines near Wadley, State of San Luis Potosí, Mexico: U. S. Geol. Survey Bull. 946–E, 1946.

a single bed, not being represented even by a crack in the beds above and below.

A large part of the ore thus far produced from this mine has come from beds lying from half a meter to 8 meters above the base of the upper formation. In some places two distinct mineralized horizons are found within this interval (N. 265–E. 270; N. 310–E. 205; N. 265–E. 225; N. 310–E. 150; N. 260–E. 190), but in other places the two horizons merge and are mined together (N. 310–E. 250; N. 300–E. 210; N. 280–E. 165). In this mine, the base of the upper formation consists of about 1 meter of limestone conglomerate, which is overlain by interbedded limestone and calcareous shale. The general proportion of shale to limestone increases upward, away from the contact. The stopes in the eastern part of the mine are largely in a bed of red shale that lies from 1 to 2 meters above the contact. Most of the ore is found below this bed, but in the easternmost part of the southeastern stope (N. 255–E. 290) two thin seams of ore were found along the upper and lower contacts of the shale. This bed of red shale was found also near N. 205–E. 190, where it overlies 1 meter of basal limestone conglomerate and 10 to 50 centimeters of ore. Apparently the red shale bed is not continuous, for it has not been identified in other parts of the mine.

About 20 meters west of the portal of the San Antonio mine, in an unmapped stope, a small body of high-grade ore was found 10 meters stratigraphically below the base of the upper formation. This stratigraphic horizon has not been prospected elsewhere in the district. Ore has been found, however, in the upper beds of the middle formation at several places. At N. 305–E. 185, ore was found 3 to 5 meters below the upper contact, below workings in the upper formation. This ore was most abundant adjacent to the prominent north-striking fractures. In the stope at N. 275–E. 165, much of the ore was found above the contact, but the mineralization continued down to about 1 meter below the contact. At N. 290–E. 190, much of the ore was adjacent to and below the contact.

The San Antonio mine appears to be one of the most promising of those owned by Pani and Robles. Most of the exploration done hitherto appears to have been based on the assumption that all the ore occurs at a single stratigraphic horizon, whereas ore bodies occur at many places in the mine as much as 10 meters below or 10 meters above the base of the upper formation. New ore is most likely to be found above and below the present workings at favorable stratigraphic horizons that have not yet been explored. The zone extending from 4 meters below to 8 meters above the contact probably contains the most favorable beds. The mine should be explored systematically by means of raises and winzes. The main ore horizons, also, should be explored along the crests of the anticlines and immediately northeast of them.

SAN JOAQUÍN MINE

The San Joaquín mine, owned by Pani and Robles, is immediately south of the San Antonio mine. (See pls. 9 and 15.) Its workings extend through an area some 90 meters long and 50 meters wide. Nearly all of them are at a single ore horizon, from 1 to 4 meters above the base of the upper formation. The principal exceptions are at N. 250–E. 215, where the ore horizon is probably several meters below the upper formation, only a little ore having been found in the overlying beds, which were reached from the San Antonio mine; and at N. 220–E. 180, where all the beds within a distance of 5 meters above the contact were found to contain ore. In all the stopes the ore is mostly adjacent to fractures and on or northeast of the crests of anticlines.

The best possibilities for undiscovered ore are believed to be above or below the present workings. In the San Antonio mine, ore has been found within a distance of 10 meters above and 10 meters below the base of the upper formation. In the San Joaquín mine, however, only the principal ore horizon has been developed.

CLAVO NEGRO MINE

The Clavo Negro mine, owned by Pani and Robles, is on the southeastern extension of the same folds that contain the San Joaquín mine. (See pl. 15.) All its workings, however, are in the limestone and chert of the middle formation, about 10 to 15 meters below the upper contact. All the ore thus far developed is at a single stratigraphic horizon and is adjacent to the feeding fractures.

The walls of the westernmost fracture in the mine (N. 125–E. 210) are generally separated by an open space from 10 to 80 centimeters wide and are lined with calcite a few centimeters thick. No antimony minerals are found on the falls of the fractures or in the calcite, but antimony oxides are found in small amount in the adjacent wall rock, between beds of limestone. In the westernmost stope of the mine, the antimony minerals are fairly abundant on the west side, where the east-dipping beds are inclined upward away from the fracture, but are uncommon on the east side, where the beds dip away from the fracture. This relation suggests that the antimony-bearing solutions were moving upward.

A considerable amount of low-grade ore was found in the stope near N. 125–E. 220. There the ore was localized by irregular fractures in the ore-bearing beds; the fractures appear to narrow or die out in the adjacent, less favorable beds. The antimony minerals are found mostly in limestone, adjacent to lenses of white calcite formed by local recrystallization of the limestone. The lenses are parallel to the bedding, and most of them lie immediately below chert lenses.

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Anticlinal axes have apparently had less effect on localization of ore in the Clavo Negro mine than they had in the San Antonio and San Joaquín mines.

In the district in general the most favorable stratigraphic horizon lies near the base of the upper formation. This horizon, however, has been eroded from above the southern 30 meters of the Clavo Negro workings, and when it is exposed at the surface it apparently is barren. It should be explored, nevertheless, above the north end of the present workings, adjacent to the prominent fractures.

NEW TUNNEL

A new tunnel (pl. 15) was being driven by Pani and Robles early in 1944, to connect with the eastern part of the San Antonio mine. It was meant mainly for ventilation; prospecting was a secondary objective.

The portal of this tunnel is at the base of the upper formation, near which most of the ore in the district occurs, but this horizon was not followed inward. Instead, the tunnel, which is nearly horizontal for most of its length, cuts across the inclined beds of the upper formation.

About 80 meters northeast of the portal, the favorable horizon was again intersected. At this place the basal bed of the upper formation consists of 1 meter of limestone conglomerate, which is overlain by two-thirds of a meter of bright-red shale. No ore was found, possibly because the nearest fissure that could have served as a feeder is at least 10 meters to the east. The extreme northern part of the tunnel was driven along a fault of small displacement, and is almost in the same beds that carry ore in the Clavo Negro mine.

A 10-meter raise on the fault at or near N. 215–E. 275 should intersect the favorable basal beds of the upper formation near the crest of the anticline shown in plate 15. A shallow winze might be sunk in the same vicinity.

SAN MATEO MINE

The San Mateo mine, owned by Pani and Robles, consists of a group of inactive, irregular workings that were formerly known as the San José, San Luis, and La Trinidad mines. The workings have not been fully mapped, but their approximate outlines are shown in the northwestern part of the map, plate 9.

The workings are largely in the basal beds of the upper formation, within 10 meters of the contact, and are on the northeast flank of the same major anticlinal structure that contains the San Antonio and San Joaquín mines. The beds dip, in general, from 10° to 40° to the north or northeast. The ore is apparently related to steeply dipping fractures that cut across the bedding, but these fractures have not been mapped in detail.

Undiscovered ore is most likely to be found about 30 meters northwest of the present workings, in the basal beds of the upper formation and adjacent to the fault shown in plate 9.

SAN LUIS MINE

The San Luis mine (pl. 16), owned by Pani and Robles, is east of the San Mateo mine and was formerly connected with it, but the connecting workings are now filled with rubble, washed in from a surface pit shown in plate 9. The mine has been inactive for several years. All the known ore bodies are in a breccia zone about 8 meters below the top of the middle formation.

About 15 or 20 meters north of the entrance to the workings is a little ore associated with thin lenses of white calcite. Each calcite lens has replaced limestone immediately below a lens of chert. The base of the upper formation there consists of 4 meters of limestone conglomerate, overlain successively by three-fourths of a meter of red shale and then by shaly limestone with partings of red shale. No ore has been found in these basal beds, possibly because brecciation was localized within the middle formation and did not extend into the lower part of the upper formation. The basal beds of the upper formation are cut by fractures that strike north or northwest and show little or no displacement. The easternmost of the north-striking fractures shows a curious relationship: the thickest bed of red shale shows no displacement on the fracture, but shaly material with an average width of 10 centimeters has been intruded downward into the limestone conglomerate for a distance of half a meter.

There may be some ore northwest of and above the present workings, on the strike of the beds. Ore might also be found north and east of the workings, adjacent to the fault that bounds the mine on the east, particularly if there is a minor anticline north of the workings and south of the major syncline shown in plate 9.

SANTO DOMINGO MINE

The Santo Domingo mine, also owned by Pani and Robles, is about 200 meters southeast of the San Luis mine. The workings are very irregular and have not been mapped in detail, but their approximate outlines are indicated in plate 9.

The ore deposits extend northwestward for about 70 meters along the contact of the middle and upper formations, which dip 35°–60° NE. At the surface, all the workings are above the contact, but near their maximum depth, which is about 30 meters, they extend from about 4 meters below to 8 meters above the contact. Most of the ore is adjacent to crossing-cutting fractures, which generally strike either northeast or northwest and dip to the west. In one place there are two sets of joints, one striking N. 60° E. and dipping 85° NW., the other striking N. 45° W. and dipping 35° SW. These joints are filled with relatively uniform veinlets of high-grade antimony oxide averaging about 1 centimeter in thickness.

Most of the ore in the mine has probably been found, but there may still be some ore southeast of the present workings, adjacent to the fault shown in plate 9. This fault has an apparent horizontal displacement of 10 meters. The ore may continue downward for a short distance, but exploration at greater depths would be difficult, and the fracturing, which is probably related to the adjacent syncline to the north, may not continue to the axis of the syncline.

LA PEÑA MINE

The La Peña mine, owned by Pani and Robles, is in the north-central part of the district, near the crest of a prominent anticline. (See pl. 9.) It has an adit 30 meters long; several stopes extend 5 to 10 meters above the floor of the adit. The ore is localized in the basal beds of the upper formation, along a normal fault that strikes N. 60° W., dips 45°–80° SW., and has a displacement of about 1 meter.

SANTIAGO MINE

The Santiago mine, owned by Pani and Robles, is on the opposite wall of the canyon from the La Peña mine. The deposits in these two mines have a similar relation to the adjacent anticline and to the contact of the middle and upper formations. The fault that apparently controls most of the ore in the Santiago mine strikes N. 60° E. and dips 45°–55° S. It may be the eastern continuation of the La Peña fault. The workings are caved within a short distance of the mine entrance, but their general outlines, taken from an old map of the district, are indicated in plate 9.

LA BLANCA MINE

The La Blanca mine, owned by Pani and Robles, is about 200 meters east of the Santiago mine. (See pl. 9.) The workings are largely filled with waste and were not studied in detail. The ore bodies are about 10 or 15 meters stratigraphically above the base of the upper formation and are apparently related to crosscutting fractures that were the channels for the ore solutions.

EL PUERTO MINE

The El Puerto mine, owned by Pani and Robles, is in the northeastern part of the district. (See pl. 9.) The workings explore an area about 100 meters long and 50 meters in maximum width. All these workings are open-cuts, but the largest stope, in the northern part of the mine, has attained a maximum depth of 15 or 20 meters. The stratigraphic position of the ore bodies is unusual; they are at least 75 meters above the base of the upper formation. The ore is localized in favorable beds of limestone; most of it is adjacent to crosscutting fractures that strike north to northeast, but some of that in the largest stope is as much as 15 meters from the nearest major fracture.

There may be undiscovered ore between the present workings and a major fault that lies 10 meters to the northeast, and other ore-bearing beds might perhaps be found below the present workings.

EL CRESTÓN

The El Crestón mine, owned by Pani and Robles, is 50 meters southeast of the El Puerto mine. Individual sections of the mine were formerly known as El Alacrán, La Tarántula, and La Víbora. Some of the lower workings are now concealed beneath the dumps of the upper workings.

The ore bodies are about 50 meters above the base of the upper formation, and are closely restricted to a zone of fractures lying immediately west of a normal fault of large displacement. The workings are relatively superficial; their maximum depth is no more than 10 meters, because the most favorable beds lie at a very shallow depth and dip almost parallel to the surface. The major fault to the east appears to be related to the ore-bearing fractures and to have controlled the mineralizing solutions.

During 1943 and 1944, the El Crestón mine was the most productive of those owned by Pani and Robles. The southern part of the mine was being worked as an open pit about 10 meters deep. Most of that part of the favorable ore horizon which lies adjacent to the major fault has already been explored. The principal hope for the future of the mine rests upon possible discovery of additional ore-bearing beds at a greater depth or in the wedge of rocks of the upper formation that lies east of the mine. The location of the mine is such that further prospecting could be done from tunnels driven into the hillside, adjacent to the major fault.

SANTA MARÍA DE MIERA MINE

GENERAL FEATURES

The workings of the Santa María de Miera mine (pl. 11) are contained within a single claim 400 meters by 300 meters in size. This mine, known in the past as the Tunnel group of mines, is the only one that has been retained by the Cía. Minera y Refinadora Mexicana, S. A., whose predecessors formerly owned and developed all the principal mines in the district. The eastern and western boundary lines of the present Santa María de Miera claim cut across many of the old underground workings. The adjacent claims are owned by Julio Pani and García Robles.

Probably more than half of the past production from the Soyatal district has come from the Santa María mine. The workings are very extensive and irregular, having been mined for 50 years without a systematic plan of development. During this period all the ore and waste was carried out of the mine on men's backs. The Carmen-Santa Catarina tunnel was the main haulageway, but its steep inclination was too great to permit the use of tracks and cars. (See section C–C′, pl. 12.) In the course of years the lower workings were gradually filled with waste and low-grade ore from the higher workings.

The latest phase of activity, and one of the most important, began in 1942 with the driving of the east Tepozán tunnel and continued in 1943 with the building of a tunnel in the middle Raizal workings. These tunnels were driven partly for exploration but mostly to drain the large filled stopes. The fill material now constitutes ore of low but commercial grade. Many new working faces have been uncovered as a result of this development.

The structural features exposed in the mine include numerous northwest-striking folds, cut by northwest-striking faults and contemporaneous or later northeast-striking faults. The minor folds shown in plate 11 are parts of two major anticlinal structures, separated by a major syncline (pl. 12). The ore bodies are found for the most part on or near the crests of the major anticlinal structures and lie within a distance of 10 meters below and 25 meters above the base of the upper formation. The ore is found in beds of impure limestone, which are generally more favorable than adjacent beds because they have been selectively brecciated, in part parallel to the stratification. The Raizal fault, which is a single fault in some places and a fault zone in others, is in the northeastern part of the mine and was the most important feeder for the ore solutions. (See pl. 11; sections A–A′ and B–B′, pl. 12.)

In many of the stopes the richest ore bodies are found on the crests of minor anticlines. Very commonly, however, ore is found also on the southwest flanks of the minor anticlines and in the adjacent synclines, where, because of the asymmetry of the folds and the direction of the pressure that caused the folding, the rocks are much brecciated.

The details of the geology will now be considered in relation to the principal divisions of the mine workings.

RAIZAL WORKINGS

All the Raizal workings, in the northeastern part of the Santa María de Miera mine, are closely related to the Raizal fault. On the west or hanging-wall side of this fault the rocks have been strongly mineralized at three or more stratigraphic horizons. Beds at the lowest horizon, which is from 3 to 5 meters below the upper formation, contained a considerable amount of ore in a stope near N. 270–E. 360, but they have not been prospected in adjacent areas. More extensive workings nearby are in the basal beds of the upper formation and in other beds from 5 to 8 meters above the base. As the outlines of some of these workings overlap and are very complex, they are simplified in plate 11.

Some ore has been found east of the Raizal fault, in beds of limestone and limy shale that are probably part of the lower formation (section B–B′, pl. 12). Although at most places in the district these beds contain no ore, they should be thoroughly prospected wherever they are adjacent to the Raizal fault.

The small mass of altered porphyry found near N. 275–E. 360 was not seen in any of the nearby workings. Although the porphyry is in the Raizal fault zone, it shows but little brecciation. It probably was intruded after the main period of faulting and later altered by the mineralizing solutions.

IGLESIA WORKINGS

The Iglesia workings, southeast of the Raizal workings, consist of several large stopes that are mostly in the footwall of the Raizal fault, in beds probably belonging to the lower formation. The relation of the stopes to the Raizal fault and the middle formation is indicated at the eastern end of section B–B′, plate 12. The largest stope is about 40 meters long and 15 meters wide; its depth is not known but is probably at least 10 meters.

The ore is localized to some extent along the axes of two anticlines, which pass near N. 215–E. 410 and N. 230–E. 415, respectively. The ore solutions probably migrated up from the Raizal fault, through the more permeable and brecciated limestone beds, until they were partially diverted at the anticlinal axes.

Some ore remains on the walls of the stope near N. 225–E. 415, in small folds that have not been mapped. Other showings of ore were found in the extensive workings northeast of N. 225–E. 420.

POLVORÍN WORKINGS

The Polvorín workings are irregular "gopherings" that lie south and southeast of the Iglesia workings. Their relative altitude is not known, as the elevation figures for the survey stations were not available at the time the field work was done. Most of the workings are southwest of what is probably the southern continuation of the Raizal fault, and nearly all are in a single group of beds. The distance of these beds above the base of the upper formation is not known. The workings east of the fault may be in the lower formation.

The Polvorín workings are small and their ore is of low grade. It is quite possible, however, that some of the beds nearby are more highly mineralized than those exposed in these workings. The most favorable location is believed to be adjacent to the fault and below the present workings.

CATORCE WORKINGS

In the Catorce workings, which were the most active part of the mine during 1943 and 1944, the principal stopes are on the axis of an anticline that is nearly parallel to the Raizal fault (see N. 205–E. 360). The rock along the axes of the adjacent synclines is not so strongly mineralized and has commonly been left as pillars.

The beds that were chiefly being worked in January 1944 lie from 44 to 50 meters higher than the portal of the San Andrés tunnel and at an estimated distances of 10 or 15 meters above the base of the upper formation. The stopes were being enlarged both laterally and upward; while the higher beds were being mined, the floors of the stopes were being raised by the accumulation of waste material.

The ore is generally of low grade, containing on the average about 10 or 15 percent of antimony. Although the leanest material is discarded, the hand-sorted product rarely contains more than 30 percent of antimony, because of the thorough intermixture of ore and gangue. The country rocks are impure limestone and calcareous shale, in beds that range from 1 to 20 centimeters in thickness. These beds were brecciated and cut by two systems of fractures, one of which strikes northwest, roughly parallel to the fold axes and the Raizal fault, and the other, which had a greater influence on ore deposition, nearly at right angles to the first. Fissures belonging to the latter system apparently served as feeders along which the ore solutions were diverted from the Raizal fault. Many individual fractures, a centimeter or more in thickness, are filled with antimony oxides. Most of the antimony minerals, however, are in narrower fractures or in irregular veinlets parallel or nearly parallel to the bedding. These veinlets consist largely of stibnite and silica, which have replaced individual beds. A very little of the silica is in the form of medium- to coarse-grained quartz, but the quartz is found only in the more massive concentrations of the antimony minerals; at least 99 percent of the silica is fine-grained chalcedony replacing limestone. Silica is everywhere more widely distributed than the antimony minerals.

There is clear evidence that stibnite has replaced wall rock. Traces of the bedding of the limestone are commonly visible almost throughout the mineralized and altered rock. The stibnite commonly forms radiating clusters of euhedral crystals, which cut across all the relict structures. The diameters of these crystals range from one-fourth millimeter to 3 millimeters and average about two-thirds millimeter;

their maximum length cannot readily be determined but is known to exceed 2 centimeters.

The stibnite has been almost entirely replaced by yellow and buff-colored oxides of antimony. In some ore the cores of the larger crystals and masses of antimony minerals still consist of stibnite, surrounded by the antimony oxides. In the Catorce workings as a whole, stibnite probably does not constitute more than from 1 to 5 percent of the antimony-bearing minerals.

The extent of the old Catorce workings now filled with waste is unknown. The beds below the accessible workings are believed to be very favorable for ore, but they may already have been explored. They could nevertheless be developed or reopened by driving a stub crosscut from the middle Raizal tunnel.

WORKINGS WEST OF CATORCE WORKINGS

The stopes west of the Catorce workings, near N. 255–E. 340, are at two stratigraphic horizons, about 2 meters and 6 meters, respectively, above the base of the upper formation. The beds in this locality dip gently to the southwest, but the stopes terminate where the dip increases, and near N. 260–E. 315 the beds plunge down into a syncline. The syncline localized a large amount of ore, which has been mined from the ground nearby. Most of the beds were mineralized 4 to 8 meters above the base of the upper formation. These beds were brecciated, in part parallel to the bedding, and were mineralized probably by ore solutions migrating from the faults that bound the stope on the northeast and northwest.

A higher stratigraphic horizon that is mineralized at many places in the mine is apparently barren in the northern part of this synclinal area. The barren crosscut near N. 270–E. 315 is 7 meters above the main stope. The raise near N. 265–E. 310 extends at least 5 to 10 meters above the main stope. It is now inaccessible, but it appears to have been barren.

Near N. 230–E. 340, on the southern continuation of the syncline, two stratigraphic horizons have been mined. Although the upper one was the more productive at that place, it has not been much explored in the surrounding area. To the south, only the lower horizon in the basal beds of the upper formation has been productive.

Some additional search might be made for ore above the basal beds of the upper formation in these workings west of Catorce, particularly near N. 255–E. 325 and N. 210–E. 340.

WORKINGS SOUTH OF CATORCE WORKINGS

Most of the workings in the section south of the Catorce workings are in the basal beds of the upper formation, within 8 meters of the contact. The two principal exceptions are: (1) At N. 200–E. 370, where a horizon from 4 to 6 meters above the principal ore-bearing horizon has been worked; there the two zones are generally, though not always, separated by barren rock. (2) Most of the workings between N. 215–E. 375 and N. 230–E. 360 are on or below the contact of the middle and upper formations; there the higher ore-bearing beds have not been explored.

A large part of the ore south of the Catorce workings was localized in or near the axes of anticlines, and many of the pillars between the large stopes are in or near the axes of synclines.

WORKINGS WEST OF POLVORÍN WORKINGS

The stopes near N. 175–E. 375 are largely in beds that lie from 8 to 15 meters above the base of the upper formation. In general, the beds dip to the southwest, and they are somewhat crumpled and fractured, on a small scale, parallel to the bedding.

The area near N. 140–E. 370 consists of a breccia with ill-defined borders. The general trend of the breccia zone, which is shown in plate 11, indicates that the breccia is related to the associated syncline, and that the two structures probably were formed at the same time. The breccia consisted originally of limestone and calcareous shale, but the $CaCO_3$ has been so nearly leached out, that the breccia now consists of loose, porous material, in which relict structures and the shape of the original fragments are visible. The present constituents are mainly quartz sand, one or more of the clay minerals, and rather abundant veinlets or seams of gypsum. Most of the clay is probably residual from the original impure limestone and shale, but some may have been added by the altering solutions, which may have been related to the antimony-bearing solutions. The leached and altered rocks contain little or no ore, but a considerable amount of ore has been found in the adjacent rocks.

SANTA CATARINA WORKINGS

The Santa Catarina workings, in the southeastern part of the Santa María de Miera mine, are very extensive, but only a small part of these workings had been surveyed when the field work was discontinued. The largest stopes, which are east and northeast of the workings shown in plate 11, are unmapped. The ore in these stopes was controlled largely by the southwestern extension of the Raizal fault and by other faults nearly parallel to it. The influence of these faults, which served as feeders for the ore solutions, is to be seen in the workings shown in plate 11. A large amount of ore has been mined within a distance of 15 meters from the principal fault (see N. 115–E. 440), but at 20 meters west of the fault little or no ore was found.

Most of the ore fund in the Santa Catarina workings is in bedded limestone and limy shale, immediately above 10 or 15 meters of massive limestone and limestone conglomerate at the base of the upper formation. A little red shale is visible in some of the workings above the ore-bearing beds.

There may be undiscovered ore above the mapped workings. Some of the ground to the east and northeast also may be favorable, but its potentialities cannot be determined until all the workings are surveyed and their geology mapped.

SAN MIGUELITO WORKINGS

The San Miguelito workings, near N. 100–E. 375, are relatively small, and serve principally as underground connections between the Santa Catarina workings, to the east, and the La Negra workings to the west. The principal stopes are at two stratigraphic horizons, 12 and 15 meters, respectively, above the base of the upper formation. The basal beds are not ore-bearing in this locality, possibly because they consist largely of massive limestone.

SAN ANDRÉS WORKINGS

The San Andrés workings, in the southern part of the Santa María de Miera mine, have for the most part been unproductive. (See pl. 11.) They are under the open pit shown in plate 9, and about 10 meters below its floor. Most of the ore in the open pit is low-grade material replacing limestone and limy shale, but it consists in part of high-grade ore forming rounded masses as much as 30 centimeters in diameter. The center of each mass consists generally of almost pure stibnite, which is surrounded by a thick shell of antimony oxides. Cinnabar paint is found in fractures in the antimony oxides, mostly in the outer parts of the oxide zones, although no cinnabar has been found in the stibnite. This cinnabar may have been formed by the breaking down of a small proportion of livingstonite mixed with the stibnite. (See pp. 54–55.)

The ore mined from the open pit was found in a breccia zone on the south limb of a syncline. The breccia is roughtly parallel to the bedding, at a stratigraphic horizon about 15 meters above the base of the upper formation. It appears to be more compact downward toward the synclinal axis and probably was formed contemporaneously with the folding. The basal beds in this locality consist largely of massive, competent limestone that apparently was not favorable for mineralization.

SANTA ANA WORKINGS

The Santa Ana workings, in the southwestern part of the Santa María de Miera mine, consist of irregular stopes that were worked down from the surface, or that connect with raises from the San Andrés tunnel. The eastern stopes are in brecciated beds of shale and limestone, from 10 to 20 meters above the base of the upper formation. The largest stopes in these workings are on the southeast limb of a syncline, at an average distance of 30 meters from the axis and at a maximum depth of 15 meters below the surface. The same brecciated beds were explored in workings northwest of these near-surface stopes, adjacent to and in the axis, but were there found to be nearly barren of ore.

In the western stopes of the San Andrés tunnel, near N. 85–E. 150, ore was found in other beds of brecciated limestone from 5 to 10 meters above the base of the upper formation. The breccia zone that controlled the ore seems clearly related to the axis of the syncline. The breccia shows considerable alteration, which consists largely of the leaching of $CaCO_3$ from the impure calcareous sediments. Some gypsum is found in the residual sand and clay.

LA NEGRA WORKINGS

The La Negra workings, in the south-central and west-central parts of the Santa María de Miera mine, received their name from the black carbonaceous, limy shale that contains the ore in the western stopes. The south-central stopes of these workings are sometimes called the La Prieta workings.

The stratigraphic position of the rocks in the La Negra workings is not clear. The black carbonaceous beds are believed to be at least 15 or 20 meters above the base of the upper formation, but their exact position is unknown, because the contact is not exposed at any point within a distance of 100 meters. The La Negra workings are for the most part near the center of a major synclinal structure. (See sections A–A′ and B–B′, pl. 12.) In this part of the mine, as well as in the Santa Ana workings to the southwest, there are northeast-striking folds, transverse to the major regional folds.

The westernmost stopes have not been surveyed, but they probably extend at least 50 meters west of the mapped workings and possibly beyond the western boundary of the Santa María de Miera claim. In the stopes near N. 190–E. 285, which were being mined with air drills during most of the field season, the ore is found in irregular zones of black silicified breccia, which have poorly defined boundaries and are apparently related to the fold axes.

The eastern Negra workings have been surveyed only in part. Their most extensive unmapped portion is near N. 180–E. 310 and N. 165–E. 270. The stopes near N. 155–E. 340 are extremely irregular in detail, and only simplified outlines of them are shown in plate 11. In these stopes there are generally two distinct horizons of mineralization, but in some places these horizons merge and mineralization is continuous through a thickness of as much as 8 meters. A similar condition is found in the large stopes near N. 135–E. 315. The largest and most productive stopes are in beds that are probably 10 or 15 meters above the base of the upper formation. The basal beds of the formation, which there consist of limestone conglomerate and massive limestone, have been explored near N. 160–E. 300 and N. 130–E. 350 and in the lowest workings in the mine, near N. 125–E. 298. None of these workings were very productive. The workings near N. 150–E. 315 are shown in section B–B′ in plate 12. The uppermost workings explore slightly mineralized beds about 30 meters above the base of the upper formation. At the few places in the Santa María de Miera mine where these beds have been explored they are generally unproductive.

Because of downwarped rocks and the lack of large ore-controlling faults, the general area in which these workings lie appears less favorable than the Carmen-Raizal area to the north and northeast. It has been much less thoroughly explored than the Carmen-Raizal area, however, and may still contain undiscovered ore deposits.

If any further prospecting is to be done in this area, two alternative possibilities must be kept in mind. The major syncline may be—and the author is inclined to believe that it probably is—relatively barren and unfavorable for ore. On the other hand, it is possible that this syncline, though hitherto considered unfavorable, may contain bodies of ore that have remained undiscovered because they lie below the main haulage levels. This possibility is attractive enough to warrant a limited amount of exploration.

PUERTECITO WORKINGS

The Puertecito workings, in the central part of the Santa María de Miera mine area, contain one of the largest stopes in the mine. This stope, located near N. 180–E. 325, is more than 35 meters long and 15 meters wide, and in many places it is at least 5 meters deep, though much of it is filled with waste. It is farther below the surface than any other major working in the Santa María de Miera mine, being 60 or 70 meters below the crest of the main Santa María ridge.

Most of the ore in this stope was found in and southwest of the axis of an anticline, from 10 to 15 meters above the base of the upper formation. The thickness of the mineralized zone is greatest near the axis of the anticline, decreasing southwestward as the dip of the beds increases. Probably the ore solutions were diverted into the favorable beds from the fault that was found in the unsurveyed workings southwest of the Puertecito stope, near N.180–E.310.

The ore in the northwestern Puertecito stopes shows an unusually clear relationship to the axis of two anticlines. Most of the rock in the intervening syncline was left to form pillars, although it is mineralized in some places.

The fault that bounds the main Puertecito stope on the northeast, near N. 135–E. 335, has a local displacement of at least 10 meters, but its length apparently does not exceed 50 meters. Some ore was found northeast of the fault in the basal beds of the upper formation, but it was less abundant there than in the stratigraphically higher beds that were mined in the main Puertecito stope. These higher beds should be explored northeast of the fault.

CARMEN WORKINGS

The Carmen workings are concentrated for the most part on the northwestern extension of the same major anticlinal structure that contains the Raizal, Catorce, and Puertecito workings. In the Carmen workings, however, the major structure is narrower, and the number of individual minor folds is less. The folds trend N. 60°–85° W., in contrast to the general trend of N. 45° W. in the eastern workings of the mine. In the central part of the Carmen workings, the axes of the folds are nearly horizontal and have localized a large amount of ore. In the western stopes the folds are less mineralized and plunge gently to the west; in the south Tepozán tunnel the same folds are barren and plunge 5° to 20° W. The concentration of ore may therefore be related, at least in part, to the inclination of the fold axes.

The largest fault in the Carmen section strikes about N. 55° E. and dips steeply to the northwest. The downthrow is on the northwest, and the stratigraphic displacement in the central part of the workings is about 6 meters. To the northeast the fault apparently splits and may die out. It has not been positively identified in the east Tepozán tunnel, although it may be in one of the zones of alteration and replacement that are crossed by this tunnel. The fault certainly dies out a short distance to the west, however, for it does not appear in the south Tepozán tunnel.

In the central Carmen workings, the northwest side of the fault has been explored at two stratigraphic horizons. The lower horizon is probably from 2 to 6 meters above the base of the upper formation, and the upper horizon is 10 to 15 meters above it. Most of the workings southeast of the fault are in the lower horizon and near the base of the upper formation. The upper horizon may be barren adjacent to the fault, but that is far from certain, for it has not been explored at any place within 10 meters of the fault. A raise near coordinates N. 260–E. 290 is therefore recommended. A raise at N. 285–E. 290, to reach the upper horizon northwest of the fault, is also recommended.

The northwest-striking fault in the southwestern part of the Carmen workings appears to have a stratigraphic displacement of 2 to 4 meters, with downthrow on the southwest. A small amount of ore was found in the adjacent workings, but on the whole the results of the development work in this area have been disappointing. A few of the workings are in limestone conglomerate near the base of the upper formation, but most of them are probably in beds immediately above the conglomerate. A search ought to be made for a higher, undiscovered ore horizon. A raise at N. 260–E. 245 is recommended.

The raise from the east Tepozán crosscut at N.280–E. 245 was driven to drain the waste from the large overlying stopes. The largest stope, directly above the raise, lies 3 to 8 meters above the base of the upper formation. The raise revealed no ore in the middle formation and only small bodies of ore in the basal beds of the upper formation. These were accompanied by silicified limestone, by limestone partially replaced by a clay mineral that appears to be halloysite and by small rounded masses of alunite.

TEPOZÁN TUNNELS

The south Tepozán tunnel serves principally as a connection through the main ridge that contains the Santa María de Miera mine. No ore is exposed in this tunnel, and there seem to be three reasons for its absence. First, the tunnel is west of the principal faults that guided the ore solutions. Secondly, the tunnel for most of its length penetrates beds that are considerably above the principal ore-bearing horizons. Finally, the basal beds, where they are intersected near the portal of the tunnel, lie in the crests of abruptly plunging anticlines; there is evidence that, other things being equal, ore is less likely to accumulate in a steeply plunging fold than in a fold with a nearly horizontal axis.

The east Tepozán tunnel, which was driven principally to drain the accumulated waste from the old overlying stopes, is largely in the middle formation, at a considerable distance below the upper contact. Small showings of ore were found in a fracture near N. 310–E. 260, and old buried workings near the southeast end of the tunnel (N. 205–E. 390) contain some ore about 5 meters above the level of the tunnel.

Downward extensions of the Raizal fault and other parallel faults are revealed at a number of places in the central and eastern parts of the tunnel. Although no ore was found in the fault zones, alteration probably caused by the ore-bearing solutions is very pronounced throughout the workings, except for a length of about 70 meters adjacent to the portal. The limestone has been almost completely replaced by the rare clay mineral endellite, and to a lesser extent by alunite.

MISCELLANEOUS WORKINGS

The small Membrillo workings, east of the Carmen tunnel, explore an ore horizon that is probably at least 20 meters above the base of the upper formation. Apparently the beds are mineralized only northwest of the northeast-striking fault that has been described in connection with the Carmen workings (N. 275–E. 310).

The surface workings near N. 300–E. 225 connect with one of the large Carmen stopes. They explore slightly mineralized beds that are probably about 10 meters above the base of the upper formation. The small open-cut near N. 265–E. 220 is in beds 25 or 30 meters above the same contact.

Three surface trenches were made some years ago in the northern part of the Santa María de Miera mine. Only one of these has been located accurately enough to be shown in plate 9. Although the original project of sampling the whole ridge was never fully carried out, almost every sample from the trenches is said to have contained some antimony, despite the fact that the beds from which the samples came are from 20 to 40 meters above the principal ore horizons. Unfortunately no record of the assays is available.

LA BRITANIA MINE

All the workings represented in plate 11 that lie west of the Santa María de Miera claims are owned by Pani and Robles and are considered as part of the Britania mine. The claim line was not surveyed by the author, but is said to be on or near the coordinate E. 150.

Antimony ore has been found in small amount adjacent to the fault in the western part of the workings shown in plate 11 near N. 95–E. 60. Most of these western workings, however, lie 5 meters or more below the upper formation. The fault should therefore be followed to the northeast, where it cuts beds near the base of the upper formation; the drift should be extended at least 30 meters in this direction, to N. 110–E. 100.

The workings near the surface were not readily accessible. They are believed to be in beds a few meters above the base of the upper formation, but they apparently yielded little or no ore.

SANTO NIÑO GROUP OF MINES

The Santo Niño group of mines (pl. 13), owned by Augustín Carrasco, consists of many irregular workings lying about 600 meters southwest of the Santa María de Miera mine. These workings have explored rather thoroughly an area 200 meters long and about 100 meters wide. They are in a major syncline, and most of the ore is in crumpled and brecciated zones in the upper formation, although some of that in the western part of the mine is in the middle formation. When considered in detail, however, the structural control is found to differ considerably in different parts of the group.

PURÍSIMA MINE

The workings of the Purísima mine, in the north-central part of the area, lie from 27 to 38 meters above the Santa Urbana level. (See pl. 13.) They have explored a poorly defined, steeply dipping zone of breccia, about 30 or 40 meters stratigraphically above the base of the upper formation. This breccia zone is roughly cigar-shaped; it is generally less than 10 meters in vertical extent and in breadth (pl. 14), but its length is at least 120 meters. It lies near the axis of the major synclinal structure that contains all the mines of the Santo Niño group. The peculiar localization of the breccia is due to crumpling and small-scale drag-folding, such as is commonly found near the core of a tightly folded syncline. A part of the breccia contains open spaces, which are commonly lined with gypsum and coarsely crystallized yellow-green to white calcite. The antimony minerals apparently did not favor the large open cavities, as they are most abundant where the breccia was only moderately open. The outer boundaries of the ore bodies are indefinite, but they appear to have been roughly determined by a tightening of the breccia zones.

Much of the ore is of low grade, and the low-grade ore is apparently associated with considerable leaching of $CaCO_3$ from the wall rocks, which originally consisted of calcareous shale and impure limestone. The leaching was presumably done by the ore-bearing solutions. As in other parts of the district, the better ore is generally found where silicification was the dominant process.

SANTA URBANA LEVEL

The Santa Urbana level, in the northeastern part of the Santo Niño mine, is at a lower altitude than any of the other principal workings and is used as the reference level for all the other workings in the mine. The ore is contained for the most part in a zone of silicified breccia, which is parallel or nearly parallel to the bedding of limestone and black calcareous shale; it probably is from 10 to 30 meters above the base of the upper formation. The breccia zone is on the northeast limb of the major synclinal structure containing the Santa Niño group of mines. It apparently dies out both downward and upward, for it does not cut the lower contact of the upper formation southeast of the entrance to the workings (pl. 9), nor is it found in the crosscut from the Purísima mine (p. 13, and section A–A′, p. 14).

The ore zone has been explored for a length of 200 meters and through a vertical range of about 25 or 30 meters. The workings, at their northwestern limit, are about 70 or 80 meters below the surface. In this part of the level the ore bodies are nearly horizontal and are cigar-shaped like those of the Purísima mine; elsewhere, however, the level follows an ore body that is tabular in shape and more like a vein than any other major ore body in the district.

There may be undiscovered cigar-shaped ore bodies northwest of the present workings on the strike of the ore bodies there exposed.

DOLORES MINE

The workings of the Dolores mine, in the west-central part of the area, are the highest of a complex series of overlapping workings (pl. 13), from 39 to 54 meters above the Santa Urbana level. The mine explores mineralized beds of calcareous shale and impure limestone from 10 to 25 meters above the base of the upper formation. The rocks are commonly brecciated parallel to the bedding, and they are cut by steeply dipping fractures and faults, which may have guided the ore-bearing solutions. The largest ore body was controlled in part by a minor anticline (N. 220–E. 160), which has a dragfold relationship to the major syncline. It pinches out to the east, where the beds steepen into the principal synclinal structure. The minor anticline continues downward a short distance, to merge with an east-dipping "roll", and it apparently controlled some of the ore in the lower workings of the Santo Niño group of mines (pl. 14).

Future exploration in the Dolores mine should be concentrated northwest of the principal workings, on the extension of the anticline and the ore-bearing syncline adjoining it on the southwest. There may be some ore south and southeast of the present workings, but in that direction there is not much ground between the workings and the surface. There is room for a horizontal cigar-shaped ore body in the unexplored ground down the dip of the ore-bearing beds, between the Dolores and Purísima workings (section A–A′, pl. 14).

SANTO NIÑO LEVEL

The workings of the Santo Niño level lie from 26 to 30 meters above the Santa Urbana level. The mineralized beds are from 1 to 8 meters above the base of the upper formation, at a stratigraphic horizon where much ore occurs in other parts of the district. Large concentrations of ore were found in a series of small folds that have a dragfold relationship to the major synclinal structure of the area. Several of these minor folds die out to the northwest; in that direction the ore bodies become narrow, and some of them pinch out.

Future exploration on the Santo Niño level should be directed toward possible discovery of new ore bodies up the dip of the beds, between the present workings and the surface. Cigar-shaped ore bodies related to minor folds may have there remained undiscovered because they are not exposed at the surface.

REFUGIO AND PROVIDENCIA MINES

The workings of the Refugio and Providencia mines, in the southwestern part of the area (pl. 13), lie from 15 to 32 meters above the Santa Urbana tunnel. Most of them are in beds of limestone and chert about 10 or 15 meters below the base of the upper formation (pl. 14), but the large stope southwest of the Santo Niño workings (N. 170–E. 185) is only from 2 to 5 meters below the base. The localization of the ore has been partly determined by slight brecciation along the bedding; these brecciated beds are mineralized, whereas lithologically similar but unbrecciated beds adjacent to them are not mineralized. The ore is generally found adjacent to crosscutting fractures. One of these, a fracture striking northeast and showing little or no displacement, is exposed near the entrance to the Providencia mine and has been traced for 30 meters. A similar fracture controlled a part of the ore that was found near the entrance to the Refugio mine.

SANTA ELENA WORKINGS

The Santa Elena workings are a downward continuation of those in the Refugio and Providencia mines, lying from 8 to 15 meters above the Santa Urbana tunnel. They are for the most part in beds about 10 or 15 meters below the base of the upper formation.

The Santa Elena stopes, near N. 160–E. 140 and N. 190–E. 160, contain ore that was localized by faults of northwesterly strike and small displacement. Some of the ore is associated with lenses of white recrystallized calcite that has replaced limestone; each lens occurs immediately below a lens of chert. An excellent example of this type of occurrence was found in the lower Santa Elena workings, near N. 215–E. 155.

Undiscovered ore seems most likely to be found southeast of the present workings, below the large stopes of the Santo Niño level. The Santa Elena workings might therefore be extended at least 50 meters to the southeast.

LEVEL 3 WORKINGS

The Level 3 workings, which are very irregular, lie from 20 to 25 meters above the Santa Urbana tunnel and connect the underlying Santa Elena workings with the overlying Santo Niño level. The ore bodies are in part parallel and in part transverse to the bedding. (See section B–B′, pl. 14.) The breccia that controlled the ore is poorly defined and is apparently related to drag folds formed contemporaneously with the main synclinal structure.

MISCELLANEOUS WORKINGS

The Santo Niño group of mines includes several small workings from which little or no ore has been produced.

The Polvorín tunnel is southeast of the Santo Niño level and 10 meters lower. It was started at the base of the upper formation and appears to have been driven in search of downward continuations of the Santo Niño ore bodies. The inner workings were not accessible in the early part of 1944, but apparently no ore had been found.

A small amount of ore was discovered in the San Bartolo mine, 45 meters southeast of the Polvorín tunnel and 25 meters lower, near the contact of the lower and middle formations, in the basal beds of the middle formation.

The La Cancha mine is in the western part of the area. (See pl. 13.) The workings are relatively small, but they uncover some ore near fractures in the upper beds of the middle formation.

In the Mina Vieja workings, which are largely caved and have been idle for many years, a small amount of ore was found on the upward extension of the mineralized fracture zone mined in the Santa Urbana workings, but this fracture zone dies out a short distance northwest of the portal.

An unnamed tunnel lies 35 meters southeast of the Mina Vieja workings. Its portal is on the outcrop of the Santa Urbana fracture zone, but the main workings extend for 50 meters to the southwest. They explored the trough of the syncline that contains the Santo Niño group of mines, but found it barren. In this locality the syncline is a simple structure, without the accompanying minor folds that have in part controlled the ore to the northwest.

SANTA CRUZ MINE

The Santa Cruz mine, owned by Pani and Robles, is northwest of the Santo Niño group of mines. The workings have not been mapped in detail, but they are known to extend to a depth of at least 15 meters. Their approximate horizontal outlines are shown in plate 9.

Most of the ore is found in a mineralized fault of small displacement, and in crumpled beds along the axial plane of a major syncline. The structural control is similar in many ways to that in the Purísima mine to the southeast, which is at about the same altitude and near the axis of the same syncline. The ore-bearing zone may therefore continue through the ridge that separates the two mines.

CARDÓN MINE

The Cardón mine (pl. 17), owned by Agustín Carrasco, is south of the principal mines in the district (fig. 5) and is the lowest of the mines that were examined. Its workings lie within an area 180 meters long and 40 meters wide, at estimated altitudes of from 1,750 to 1,850 meters, or about 400 meters below the portal of the Santo Niño mine.

The workings are on the crest and southwest flank of a major anticlinal structure. As in nearly all the mines in the district, the ore bodies lie near the base of the upper formation. The stratigraphic succession of the beds exposed in the mine is as follows:

Section through Cardón mine

		Meters
7.	Massive limestone conglomerate. Some ore on lower contact	4+
6.	Thin-bedded limestone and shaly limestone	10
5.	Well-bedded limestone	2
4.	Massive limestone and limestone conglomerate with little or no bedding; a little chert in places. Contains ore, mostly near top and bottom	5
3.	Thin-bedded carbonaceous limestone, black when fresh; a few seams of interbedded shale	6–10
2.	Massive limestone conglomerate containing irregular masses of chert	1–4
1.	Middle formation, consisting of thin-bedded limestone with numerous lenses of chert. Contains ore near top.	

The lowest workings, in the western part of the mine, consist of about 140 meters of crosscuts and drifts. Ore was found only near the base of the 5-meter zone of massive limestone and limestone conglomerate, in a fracture that is generally parallel to the bedding. The fracture strikes N. 60°–85° W. and dips 45°–65° SW. Almost all the ore was found in the middle part of the main drift, near N. 150–E. 150, where the strike of the main fracture is more westerly than it is on the average. The localization of the ore is believed to have been due, in the main, to this change in strike, but it may have been controlled in part by cross fractures.

The stope near N. 115–E. 190 is on the upper contact of the 10-meter zone of thin-bedded limestone. A small amount of ore was found there, associated with lenses of calcite as much as 40 centimeters long. The richest ore, however, was not in the calcite but in the adjacent limestone.

The workings that extend eastward and westward from N. 135–E. 225 are along or near the upper contact of the 5-meter zone of massive limestone and limestone conglomerate. In these workings the ore is found in fractures that are generally parallel to the bedding, but farther to the north the fractures are more irregular and cut across the bedding.

The stopes near N. 150–E. 210 are in or near the basal conglomerate of the upper formation. Apparently no ore was found below the level, but the stopes were mined from that level to the surface. The large stope near N. 145–E. 225 was started approximately at this level, in the basal conglomerate. It passes upward into higher beds, but how much these beds are mineralized is not known.

The northern and northeastern workings have explored a system of fractures that are largely parallel to the bedding and near the base of the upper formation. In the easternmost workings, however, near the crest of the anticline, the same fracture system cuts across the bedding.

The lower tunnel should be continued for a few meters north of the present face (N. 160–E. 170) to explore the beds near the base of the upper formation.

SAN JOAQUÍN (CARRASCO) MINE

A San Joaquín mine in the northwestern part of the district, owned by Pani and Robles, has already been described. A mine of the same name, owned by Agustín Carrasco, lies about 600 meters southwest of the Santo Niño mine and about 300 meters lower.

The bedrocks in this mine consist of limestone and chert of the middle formation, overlain by about 5 meters of conglomerate of the upper formation containing limestone fragments and a few irregular lenses and masses of chert. The conglomerate is overlain in turn by calcareous shale and interbedded limestone. The mine is on the crest of a sharply flexed anticlinal structure made up of several minor anticlines and synclines. The fold axes are nearly horizontal, and trend about N. 50° W., making an acute angle with the hillside.

Ore is found in the mine at three straitigraphic horizons. The southeastern workings, near N. 115–E. 275, are the only ones shown in plate 18 that were being actively mined in the early part of 1944. They are in limestone and chert of the middle formation, about 12 meters below the top. The workings extend 20 meters into the hillside, in or near the axis of the major anticline. The ore has been localized in part by steeply dipping fractures nearly parallel to the anticlinal axis.

A few meters northwest of the southeastern workings, near N. 130–E. 260, a second stratigraphic horizon in the middle formation has been mined. There the workings lie about 5 meters below the base of the upper formation and are in the axis of the major anticline. They extend 18 meters into the hillside.

The most extensive workings of the San Joaquín mine lie from 15 to 20 meters above the southeastern workings, between N. 140–E. 260 and N. 160–E. 200. They extend 65 meters into the hillside, at an acute angle to the surface; their northwest end lies about 20 meters below the surface. They are on the crest of the main anticlinal structure, at the contact of the middle and upper formations. The ore deposits are related to the axes of minor folds and to crosscutting fractures.

The ore horizons should be explored northwest of the present workings by driving adits into the side of the hill, in a direction normal to the trend of the present workings and at such altitudes that the adits will intersect the ore horizons in the crest of the main anticlinal structure.

BARROSAL MINE

The Barrosal mine is the northwestern continuation of the San Joaquín (Carrasco) mine and is also owned by Agustín Carrasco. (See pl. 18.) The geology of the two mines is similar, except that the Barrosal workings are restricted to a fourth or upper ore horizon of the area, in the upper part of the conglomerate member of the upper formation. The overlying calcareous shale contains little or no ore; the lower ore horizons have not been explored below the present workings.

The anticlinal structure of the San Joaquín and Barrosal workings continues to the northwest through a southwest-trending ridge. Ore was found at these horizons where they crop out again on the northwest slope of this ridge, at a distance of about 100 meters from the western workings of the Barrosal mine; the ore probably extends through the ridge.

The three ore horizons of the San Joaquín mine lie from 5 to 20 meters below the Barrosal workings, in which they have not been prospected. They could readily be explored by driving adits into the hillside, similar to the adit recommended for the San Joaquín mine.

LA MANDONADA MINE

The location of the La Mandonada mine is shown in figure 5. The workings (pl. 19) consist of an inclined shaft at an altitude of about 1,915 meters, and an adit 95 meters to the west and 70 meters lower. The shaft, which was about 10 meters by 6 meters in average dimensions, is said to have been sunk in high-grade ore to the bottom, 100 meters below the surface. The adit was driven to intersect the shaft at a depth of about 60 meters. The location of the proposed intersection was apparently never determined, however, and the adit failed to reach its objective.

The mine workings are in the basal beds of the upper formation. The succession of the beds exposed is as follows:

Section of the beds exposed at La Mandonada Mine

	Meters
4. Limestone conglomerate (ufc) interbedded with massive limestone	10+
3. Thin-bedded limeston (uft); thickness of individual beds generally less than 25 cm., but near portal of the Mandonada tunnel, unit contains a bed of fine-grained limestone conglomerate 75 cm. thick	4–7
2. Massive limestone (ufm); consists largely of recrystallized limestone without bedding, but upper and lower parts are commonly in beds up to 50 cm. thick	8–12
1. Middle formation (mf); consists of thin-bedded limestone enclosing abundant lenses of chert	35±

The ore was localized in the massive limestone (ufm), at its intersection with a zone of steeply dipping fractures that die out in the adjacent thin-bedded limestones. The ore body has a rectangular cross-section and pitches 75° SW., parallel to the beds. If it is true that the shaft was all in ore, this mine is an unusual example of vertical continuity in a body of antimony ore.

At the level of the Mandonada tunnel, the ore zone is believed to be about 30 meters S. 65° E. from the east end of the tunnel, but because of a possible downward change in dip of the beds, the tunnel should be driven along the upper or southern contact of the massive limestone until the zone of crosscutting fractures is intersected.

EL CRESTÓN (CARRASCO) MINE

The name Crestón, like San Joaquín, has been applied in this district to two mines. One of these, which lies in the northeastern part of the district and is owned by Pani and Robles, has already been described. (See p. 65.) The other lies about 150 meters east of the La Mandonada mine and is owned by Augustín Carrasco. (See pl. 20.) Its workings, though not extensive, are of interest because they are in beds of the middle formation that are nearly vertical and in part overturned. The rocks are typical of this formation, consisting of thin beds of gray limestone as much as 30 centimeters thick, with numerous lenses of chert. They strike N. 40°–70° W. and dip 85° SW. to 60° NE. The ore in the western workings, which are open-cuts, was localized in a zone of weak fractures that strike nearly normal to the bedding. The eastern workings consist of four short tunnels with a maximum length of about 40 meters. The ore bodies in these workings lie parallel to the bedding and are localized by two systems of fractures, one parallel and the other normal to the bedding. Both systems may have formed while the rocks were being folded. The localization of the ore has apparently been influenced, also, by slight changes in the strike and dip of the beds.

RESERVES

In the Soyatal mines, as in practically all antimony mines, it is difficult to estimate the reserves, for the following reasons. (1) The individual deposits are so extremely irregular in size, shape, and grade that the amount of ore in any one of them is unknown until the ore has been mined. (2) As only the relatively high grade shipping ore is recovered, the ore bodies are not systematically sampled and assayed. The average grade of a deposit is regarded as of much less practical importance than the proportion of material that can be separated and recovered in the form of ore and concentrates that assay at least 20 percent of antimony, preferably 40 to 50 percent. (3) As ore bodies are not developed and blocked out in advance of mining but are mined out immediately after their discovery, the mines contain no "measured" ore reserves in the usual sense of the term. (4) The future of the district depends to a large extent upon the discovery of new ore bodies in favorable rocks, near the base of the upper formation, that have been selectively brecciated and mineralized. In any mine where only one mineralized zone has been followed, at least one more and possibly as many as three may remain to be explored. This would not be the case if the most favorable areas were connected with each other by leads, all of which had been discovered and consistently followed by the miners. This may have happened in a few mines, and in those mines the results of further exploration are likely to be disappointing.

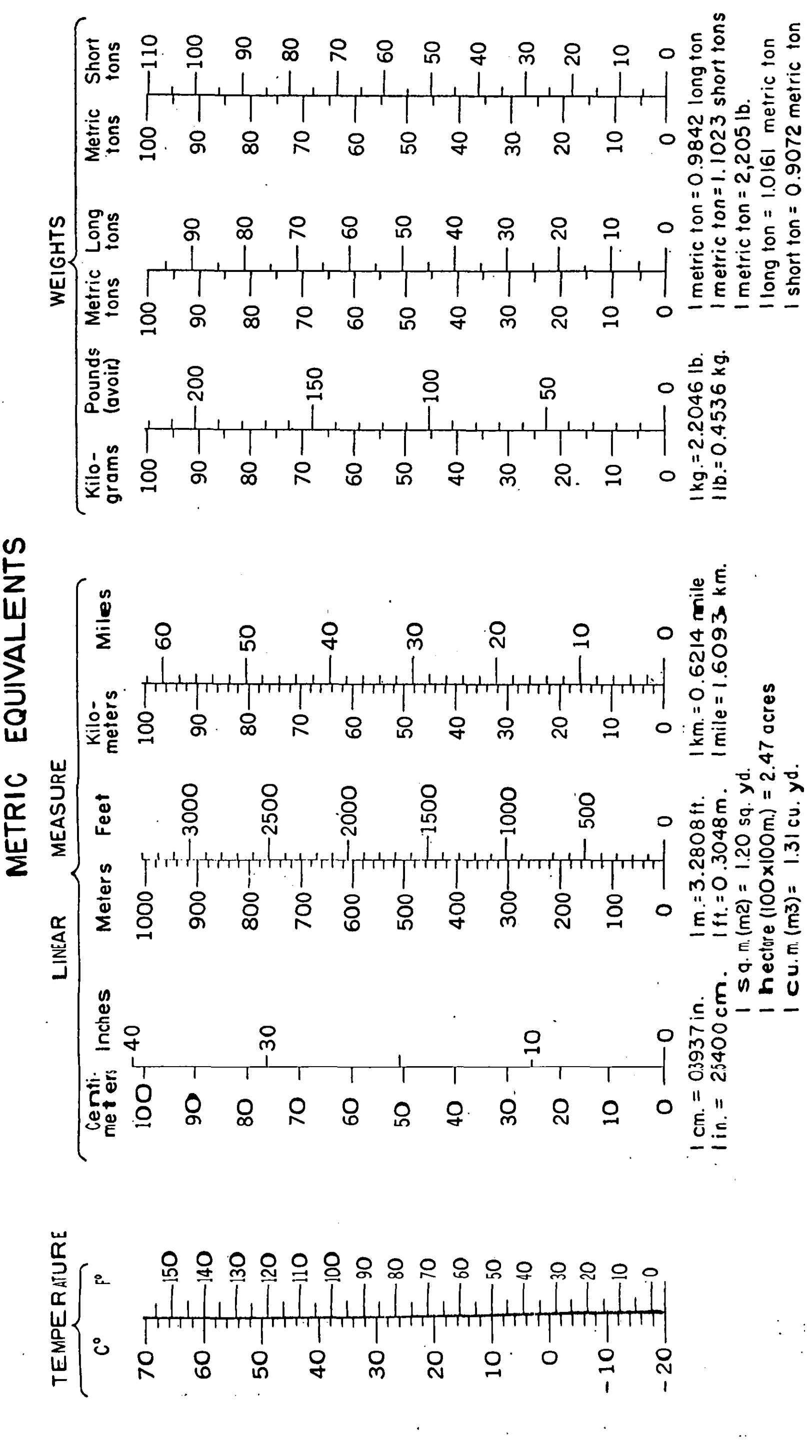
Many parts of the Santa María de Miera mine and the Santo Niño group of mines are already honeycombed with irregular stopes. If a large amount of ore is discovered in those mines in the future, some of it may not be recoverable, for, as the draining of waste from certain stopes has already resulted in caving and caused some workings to be abandoned, additional excavations may bring about caving on a larger scale. Accidents could of course result from such caving, but they could be avoided if due precautions were taken.

The total reserves are thus unknown and cannot be estimated accurately, but they probably would suffice to maintain a moderate degree of activity in the district for at least 10 years. The mines may even contain enough ore to equal the total past production.

RECOMMENDATIONS

New ore bodies can probably be discovered by exploring the most favorable undeveloped ground, which in general is most likely to be found above or below the present workings. In most localities only one ore horizon has been followed, and seldom have more than two of the favorable horizons been explored in any one mine. Mineralized beds may occur, however, at as many as four horizons within a distance of 20 meters stratigraphically below, or 40 meters above the base of the upper formation.

The best general rules for future exploration are these: where the present workings are on or below the base of the upper formation, raises should be driven on the principal faults and fractures into higher beds. Where the present workings are considerably above the base of the upper formation, winzes should be sunk on such faults or fractures into lower beds. Other things being equal, ground in or near the axis of an anticline is believed to be more favorable than ground near the axis of a syncline.


METRIC EQUIVALENTS
LINEAR MEASURE
Centi-meters
Inches
Meters
Feet
Kilo-meters
Miles
1 cm. = 0.3937 in.
1 in. = 2.5400 cm.
1 m. = 3.2808 ft.
1 ft. = 0.3048 m.
1 km. = 0.6214 mile
1 mile = 1.6093 km.
1 sq. m. (m2) = 1.20 sq. yd.
1 hectare (100x100m.) = 2.47 acres
1 cu. m. (m3) = 1.31 cu. yd.
WEIGHTS
Kilo-grams
Pounds (avoir.)
Metric tons
Long tons
Metric tons
Short tons
1 kg. = 2.2046 lb.
1 lb. = 0.4536 kg.
1 metric ton = 0.9842 long ton
1 metric ton = 1.1023 short tons
1 metric ton = 2,205 lb.
1 long ton = 1.0161 metric ton
1 short ton = 0.9072 metric ton
TEMPERATURE
C°
F°

INDEX

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