UNITED STATES DEPARTMENT OF THE INTERIOR
J. A. Krug, Secretary

GEOLOGICAL SURVEY
W. E. Wrather, Director

Bulletin 953



# GEOLOGIC INVESTIGATIONS IN THE AMERICAN REPUBLICS 1945

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1949

# CONTENTS

[The letters in parentheses preceding the titles are those used to designate the papers for separate publication]



# ILLUSTRATIONS

## TABLES

UNITED STATES DEPARTMENT OF THE INTERIOR
J. A. Krug, Secretary

GEOLOGICAL SURVEY
W. E. Wrather, Director

**Bulletin 953-A**

# ANTIMONY DEPOSITS OF THE TEJOCOTES REGION STATE OF OAXACA, MEXICO

BY

DONALD E. WHITE AND REINALDO GUIZA, JR.

Prepared in cooperation with the
UNIVERSIDAD NACIONAL AUTONOMA DE MEXICO, INSTITUTO DE GEOLOGIA and SECRETARIA DE LA ECONOMIA NACIONAL DIRECCION GENERAL DE MINAS Y PETROLEO
under the auspices of the
INTERDEPARTMENTAL COMMITTEE ON SCIENTIFIC AND CULTURAL COOPERATION, DEPARTMENT OF STATE

Geologic Investigations in the American Republics, 1945

(Pages 1–26)

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON : 1947

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.
Price 75 cents

CONTENTS



ILLUSTRATIONS

# TABLES

# ANTIMONY DEPOSITS OF THE TEJOCOTES REGION

# STATE OF OAXACA, MEXICO

By Donald E. White and Reinaldo Guiza, Jr.

## ABSTRACT

The antimony mines of the Tejocotes region, Oaxaca, have produced more antimony in each year since 1938 than any other district in Mexico. From 1938 to 1943 the average annual production was 4,300 metric tons 1/of shipping ore containing 56 to 58 percent of antimony; since 1941, however, the average has been below this figure, despite vigorous efforts to increase production.

Until recently the deposits were worked from open cuts and shallow underground workings, entirely by hand methods. In August 1942 large-scale surface mining with Diesel shovels was introduced, but the experiment proved costly and production was not appreciably increased. The material that could be mined commercially with shovels was exhausted early in June 1943, and production has now become dependent upon underground mining almost to the exclusion of surface work. As mining is thus confronted with rising costs and increasing difficulties, the district is entering a very critical stage of its development.

The sedimentary rocks of the area are of Middle Jurassic age, and consist of three formations of limestone and three of shale, overlain by a formation of sandstone. These rocks have been complexly folded and faulted, and intruded by quartz porphyry and feldspar porphyry.

The antimony ore occurs in limestone in the following forms, each of which grades into the others: (1) More or less elongate or irregular bodies. (2) Similar masses embedded in clay that replaces limestone. (3) Veins in fractures. (4) Veinlets and disseminations. The ore bodies of types 1 and 2 are found near contacts of quartz porphyry, and in general they are oriented roughly parallel to the contacts. Each body contains, on the average, a few tons of shipping-grade ore, but a few bodies contain as much as 500 tons of ore. The ore bodies of types 3 and 4 are not so closely restricted to the porphyry contacts, and in general are oriented perpendicular to the contacts. At least two of the veins of type 3 have yielded as much as 300 tons of shipping-grade ore.

1/ All measurements are in the metric system, 1 metric ton=2,205 lbs.

The original antimony mineral in all of the deposits was the sulfide stibnite. Near the surface this mineral has been almost completely oxidized in place to antimony oxides that range in color from yellow to orange brown.

The formation of ore bodies has been favored by the following environments listed in order of importance:

1. Anticlinal cores consisting of the lower limestone overlain by the lower shale.
2. Eastern (generally the hanging-wall) contacts of irregular sill-like bodies of quartz porphyry in the limestone.
3. Irregular parts of the porphyry contacts.

In some places replacement of limestone by silica and by clay minerals are indications of ore. In several of the deposits, ore may have been concentrated at the surface by selective removal of limestone and clay during the erosion of the deposits.

Recommendations are given to guide the search for new ore bodies.

## INTRODUCTION

### Location and accessibility

The antimony mines described in this report are near Tejocotes, a town in the municipality of San Juan Mixtepec in the western part of the State of Oaxaca, at 97°55' west longitude and 17°17' north latitude (see fig. 1). Tejocotes is accessible by way of a dirt road, which runs westward from the pan-American highway at a point about 15 kilometers southeast of Tamasulapa and through San Juan Teposcolula and Tlaxiaco. The distance by road from the highway to Tejocotes is about 90 kilometers. During the rainy season, which lasts from June to September, the mine is most readily reached by taking an airplane to Tlaxiaco and a truck from there to Tejocotes.

Before July 1943, the ore was shipped by truck to Parián, which is about 70 kilometers east of Guadalupe by way of a road that passes through Nochistlán. Parián is on a narrow-gauge line of the Mexican National Railroad between Mexico City and the city of Oaxaca and is the nearest railhead. At present, however, the ore is being shipped from Huitzo, a railhead very near the pan-American highway, about 97 kilometers by road southeast of San Juan Teposcolula. Although the distance is considerably greater, the very poor road between Nochistlán and Parián is thereby avoided.

## CLAIMS AND OWNERSHIP

The active mines at Tejocotes are owned by the Compañía Minera de Oaxaca, S. A. Since 1937 all of the principal claims in the district (see pls. 1 and 2) have been included within the Yucunani group. The most important mines and claims are as follows: the Yucunani mine (see pls. 3-7), on the Yucunani, Ampliación de Yucunani, and Dolores claims; the Chivos mine (pl. 1), on the Nochebuena claim; the Cacho mine (pl. 1), on

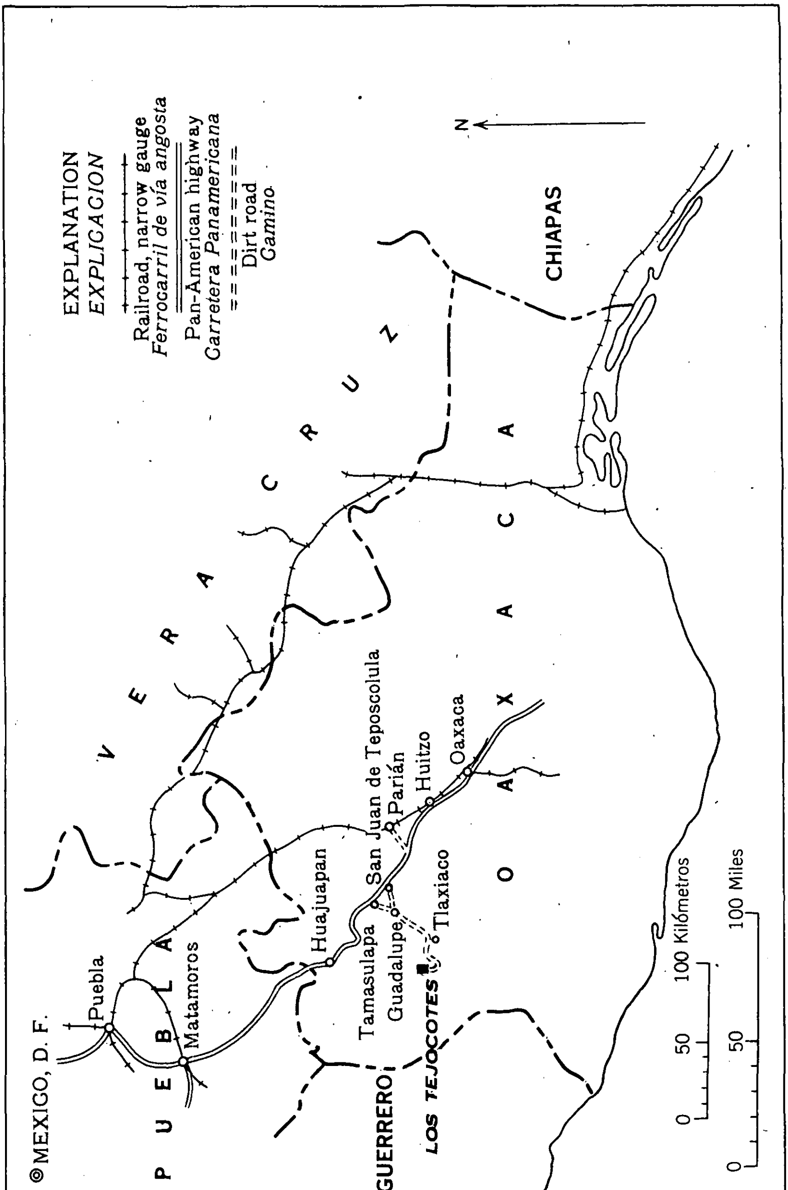


Figure 1. -- Map of the State of Oaxaca, Mexico, showing the location of the Tejocotes region

the Nochebuena, Primera, and Cuarta claims; and the Reyes mine (see pls. 1 and 8), on the Reyes claim. The smaller producing deposits are as follows: the Aguila mine (pl. 1), on the Aguila and Ampliación del Aguila claims; the Providencia mine (pl. 1), on the Providencia claim; the Escondida mine (pl. 1), on the Escondida claim, and the Capulín mine (pl. 9) on the Capulín claim. Except for the Capulín mine, which is 1½ kilometers to the north, all the principal deposits are contained within an area 2 kilometers long from north to south and 1½ kilometers wide.

The only mine in the district that is not owned by the Cía. Minera de Oaxaca, S. A., is the Paz mine (pl. 9), which is owned by Aquiles Serdán of Mexico, D. F. This mine, which is about 150 meters southeast of the Capulín mine, has been idle for several years.

## FIELD WORK AND ACKNOWLEDMENTS

This report is the second of a projected series of detailed studies of the antimony deposits of Mexico, which are being investigated by the Geological Survey, Department of the Interior, and the Instituto de Geología of Mexico. The investigation forms a part of a cooperative program sponsored by the Interdepartmental Committee for Scientific and Cultural Cooperation, under the auspices of the Department of State. Donald E. White of the Geological Survey and Ingeniero Reinaldo Guiza, Jr., of the Institute de Geología spent nearly 2 months, from January 21 to March 17, 1943, in the field, accompanied by Ingeniero Georges Ordóñez, geologist of the Cía. Minera de Oaxaca, S. A. White revisited the district for a period of 4 days in late November, 1943. An area nearly 2½ kilometers long and 2 kilometers wide was mapped on a scale of 1:2,500, with a contour interval of 10 meters (pl. 1). A topographic map supplied by the company was used as a base, but it was extended on the borders by reconnaissance methods. All of the accessible underground workings had been mapped by the company geologist, Georges Ordóñez, and they were not remapped in detail. The authors, however, have modified and extended the maps in minor particulars, and have indicated what they regard as the probable trends of the contacts between adjacent workings.

The writers wish to express their gratitude for the cooperation and assistance given by the company officials, particularly Enrique Madero, General Fernando León Novoa, John F. Codie, and V. L. Kegler. Georges Ordóñez contributed greatly to the success of the field work. The authors are greatly indebted to him, also, for the use of the maps of the underground workings.

## HISTORY AND PRODUCTION

The deposits were first mined at some time toward the end of the sixteenth century. Enrique Madero has an interesting series of letters written in 1587 by an agent of the King of Spain to determine the causes for disturbances and uprisings in the district. The Spanish miners, who were mistreating the Indians, were finally driven out of the region. The mines were probably inactive from that time until 1915-16, when 1,000 tons of ore is said to have been produced. Later the deposits changed ownership many times, but were not mined because of the low prices for antimony, the inaccessibility of the region, and the very high cost of transportation. In 1935 General Fernando León Novoa interested Enrique and Ernesto Madero in the deposits, and the Compañía Minera del Sur was formed. The company owned the Chivos, Providencia, Reyes, and Escondida mines, and they leased the Yucunani mine from Emiliano Pineda and the Cacho mine from a lawyer named Moreno. In 1937 the Texas Mining & Smelting Co., through its affiliate, the Cía. Minera y Refinadora Mexicana, S. A., became a principal shareholder, and the Cía. Minera de Oaxaca, S. A., was formed. At the same time, the Yucunani and Cacho mines were bought and all of the principal claims were consolidated as the Yucunani group. The geology of the area was first studied and mapped by the company geologist, C. Rasmussen, during the summer of 1937.

The production from the Yucunani group of mines is given in the following table:

Table 1. Production from the Yucunani group of mines

| Year | Ore produced (metric tons) | Percent of Sb | Antimony produced (metric tons) |
|---|---|---|---|
| 1915-16 (?) | 1,000* | 57* | 570* |
| 1935 | 2,500* | 57* | 1,425* |
| 1936 | 3,000* | 57* | 1,710* |
| 1937 | 3,309 | 57* | 1,886* |
| 1938 | 3,630 | 57* | 2,069* |
| 1939 | 4,297 | 57* | 2,449* |
| 1940 | 5,120 | 57* | 2,918* |
| 1941 | 4,518 | 57* | 2,575* |
| 1942 | 4,030 | 56.6 | 2,283 |
| 1943 | 4,290* | 54.2 | 2,325* |
| Total | 35,694* | | 20,210* |

* Approximate

The production from the individual mines is not known. At various periods in the past the Reyes, Aguila, Chivos, and Escondida mines have been large producers, but the Yucunani and Cacho mines have been the most consistent. In the early part of 1943 these two and the Chivos mine were yielding most of the antimony ore.

## MINING METHODS

Until about 1942 the ore was mined entirely by hand methods. The individual high-grade bodies that were exposed at the surface were followed down until they were exhausted. The first underground work was done in 1939 or 1940, and by 1942 more than 2,000 meters of tunnels had been driven into the hillsides, under the ore bodies that had been mined on the surface. Except for the tunnels of the Yucunani mine, all of the work was disappointing; it revealed no important new ore bodies, and

732859 O - 47 - 2

the known ones did not persist far below the surface. Such a result, however, is not surprising, since this development was not guided by a knowledge of the ore occurrence. In the Yucunani mine, where the tunnels were driven mostly in zones regarded, from geologic evidence, as favorable, large quantities of ore were found. Underground exploration was abandoned in all of the mines except the Yucunani. Many of the surface pits, also, were gradually abandoned as the known ore bodies pinched out at depth, or as the banks of the pits became too high and steep to be maintained. During the rainy season the walls of the pits, which consist of boulders and fragments of limestone in a matrix of clay, are in almost constant movement downward; for every day spent on the working face, the miners commonly spend 3 or 4 days in removing the muck that has covered the face.

In August 1942 the company started to mine the Yucunani deposit by open-pit methods. Two Diesel shovels, each with a capacity of three-fourths of a cubic yard, had been purchased. For the greater part of the time, however, only one of the two shovels was in operation, because of breakdowns and the difficulty of getting repair parts. The ratio of waste to ore removed during the 10 months of shovel operation was 187:1, whereas previously, at the producing faces in the Yucunani mine, it had been only about 30:1. Because of the very high costs of operation and the large amount of dead work required to extract the ore, the use of the shovels was discontinued in June 1943. The company is now aware that the mining of great quantities of barren material in order to find most of the ore bodies is unnecessary.

As the easily located surface and near-surface bodies of ore have all been mined, a complete shift to underground methods is now inevitable. In July 1943, from 12 to 15 underground development faces were active and were progressing at a total rate of about 50 meters per week. A compressor and power drills were being used in 1945 at the Yucunani mine, but all of the other underground work was done by hand methods.

The workings in clay are extremely difficult to maintain and must be retimbered periodically, but the necessary timber is readily obtained from the nearby pine forests. The problem of mining the clay bodies which contain much of the ore is likewise difficult. The present method consists in driving drifts through the clay and mining immediately any bodies of ore that may be encountered. In some places where the clay is very plastic and flows readily, it is removed as fast as it appears on the level. No systematic attempt is made to mine all of each body of clay, though that is the only way in which all of the ore in clay could be recovered. The ore in veins or lenses in limestone and silicified limestone is followed until it is mined out; reserves are never blocked out in advance of mining.

## GEOLOGY

### Sedimentary rocks

The stratified rocks of the area (see pl. 1) include three shale formations alternating with three limestone formations, and the highest shale is overlain by a formation of sandstone. The sequence is briefly described below:

STRATIGRAPHY OF THE TEJOCOTES REGION

| Age | Formation | Thickness (meters) | Description |
|---|---|---|---|
| Middle (?) Jurassic | Sandstone | 75+ | Massive sandstone weathering light brown. Top removed. |
| | | | Contact rather abrupt |
| Middle Jurassic | Upper shale | 15 - 50 | Light-brown shale, generally characterized by round chert concretions 1 to 15 cm. in diameter. Many concretions contain molds of small clams and fragments of ammonites.* |
| | | | Contact abrupt and conformable (?) |
| Middle Jurassic | Upper limestone | 150 - 200 | Mostly massive blue-gray limestone, but shaly limestone occurs in middle of formation in northern part of district. Contains abundant oysters, and in upper part some brachiopods and a few ammonites.* Formation contains the Escondida, Capulín, and Paz ore deposits. |
| | | | Contact not exposed; may be an unconformity |
| Middle (?) Jurassic | Middle shale | 100 - ? | Black shale, commonly weathering to light gray, with a purple tinge on many fragments. Black concretions of limestone up to 20 cm. in diameter are common. Normal shale grades into schist in several places. Schist facies is light brown to gray in color, characterized by quartz lenses and stringers parallel to schistosity, which in turn is generally parallel to original bedding. |
| | | | Contact abrupt |
| Middle (?) Jurassic | Middle limestone | 140± | Ranges from well-bedded blue-gray limestone (similar to upper limestone) to light-gray, |

STRATIGRAPHY OF THE TEJOCOTES REGION (CON'T.)

| Age | Formation | Thickness (meters) | Description |
|---|---|---|---|
| | | | recrystallized limestone, with little or no bedding (similar to lower limestone). Contains abundant oysters. |
| | | | Contact generally abrupt |
| Middle (?) Jurassic | Lower shale | 125?± | Black carbonaceous and calcareous shale, weathering to yellow brown. Contains a few beds of limestone conglomerate. |
| | | | Contact abrupt |
| Middle (?) Jurassic | Lower limestone | 50 - ? | Massive, recrystallized, light-gray limestone, with little or no bedding. Base of formation not known. This formation contains all of the large antimony deposits. |

* Assigned by Ralph Imlay, after examination of the fossils submitted, to the basal Upper Jurassic.

## Igneous rocks

There are two kinds of igneous rock in the district, both intrusive and both porphyritic. A brown, fine- to medium-grained feldspar porphyry, possibly a trachyte, forms small dikes that have generally been intruded along pre-existing faults. Feldspar is the only mineral in the rock that can be identified with a hand lens. No antimony ore is associated with these dikes. More abundant is a light-brown or white porphyry with prominent phenocrysts of quartz and feldspar. This rock is probably a latite or a rhyolite, but for convenience it is called quartz porphyry. Broadly speaking, the bodies of quartz porphyry are parallel to the stratification. The quartz porphyry is of particular importance because most of the ore bodies occur in limestone near intrusive contacts with this porphyry.

The relative age of the two kinds of porphyry could not be determined during the course of the field mapping, but, according to Georges Ordóñez,2/ recent exploration south of the Yucunani mine revealed a small body of feldspar porphyry intruded into quartz porphyry. Both rocks were intruded after the main periods of faulting, although some minor faulting and fracturing occured after they were emplaced.

2/ Ordóñez, Georges, Personal communication.

## STRUCTURE

The structure of the area is complex, and difficult to decipher because of the absence of good outcrops in critical parts of the area, the absence of key beds, and the lithologic similarity of the limestone formations. The trend of the folds is in general about N. 35° W., but it ranges from N. 60° E. to N. 45° W. (see pl. 1). The folds are asymmetrical; in the eastern and southern parts of the area their axial planes dip to the east, but in the central and northwestern parts they dip to the west. The ore bodies of the Aguila, Yucunani, Providencia, and Reyes mines are believed to be related to a single anticline at least 2 kilometers long.

Along the crests of two anticlines that trend northward through the central part of the area there are several outcrops of the lower limestone. These were at first interpreted as representing lenses within the lower shale, because of their lenticular outlines on the surface, their lack of alinement with each other, and the apparent difference in thickness and lithology between the shale west of limestone outcrops and that to the east. When the field work was being done, the contacts were not exposed in the underground workings or on the surface except locally, west of the Providencia mine and southwest of the Reyes mine. The lower limestone is now regarded as forming the cores of the anticlines, for the following reasons: 1. During the summer of 1943, a number of surface pits and trenches were made in order to explore the contacts south of the Yucunani mine. The eastern contact was found to dip eastward at an average angle of 30°, whereas the western contact dipped eastward at an average angle of 85°. A similar situation was found in the new underground workings of the Yucunani mine, where the contacts were cut in five different places; there the average dip of the eastern contact is 35° E. and that of the western contact 60° E. The steeper western contact is believed to be on the overturned limb of an anticline. 2. The lithology of the two contacts is similar. 3. The shale at the north end of the Yucunani mine apparently arches over the limestone, although the contact is not well exposed. 4. The northern extensions of the Covacha and Yucunani II levels (see pls. 4 and 5) of the Yucunani mine prove that the contacts swing to the northeast toward the Providencia mine. 5. The grade of the ore apparently becomes lower with depth, and this change seems to be due to the stratigraphic and structural control afforded by anticlines rather than to a zoning of the ore in relation to the original topographic surface.

The structure and relations of the lower limestone have been considered in detail because of their very important bearing upon the localization of the ore.

Most of the faults in the area are premineral, but they apparently have had no influence upon the localization of most of the ore bodies. The largest faults, which strike northwest, were both preceded and followed by smaller faults that strike northeast. The fault north and northwest of the Escondida mine is a thrust fault along most of its course, but about 200 meters northwest of the Escondida mine it changes eastward from a thrust fault to a normal fault, bringing the schist of the thrust plate under the upper limestone.

The ore bodies of the Chivos and Providencia mines and those of the Covacha section of the Yucunani mine are largely controlled by small northwest-striking faults, which are later than the quartz porphyry.

## ORE DEPOSITS

Most of the antimony ore forms rounded or irregular bodies, some of which have yielded more than 500 tons of high-grade ore. The ore minerals are stibnite and several of the antimony oxides. The ore occurs near the crests of anticlines in massive or altered limestone of the lower limestone, on or near the hanging walls or eastern contacts of the quartz porphyry intrusions. A much smaller amount of ore is found in shaly limestone, shale, sandstone, and quartz porphyry. The field mapping has shown that the areas of massive limestone uncut by intrusive rocks contain little or no ore, and areas of massive limestone containing extensive intrusions of quartz porphyry generally have been mineralized with antimony minerals. The ore controls explaining these facts are considered in the order of the size of the structural features involved, which coincides with the order of their relative importance in localizing the ore.

Contacts of lower limestone with lower shale along crests of anticlines.—Evidence favoring the view that the lower limestone forms the cores of overturned anticlines has been summarized in the preceding section. Those places along the anticlinal crests at which the contact between the lower limestone and the lower shale is highest were probably the most favorable for the deposition of ore. It is in these places, also, that there has been the deepest erosion. For example, the anticline of the Yucunani mine plunges to the north and to the south from the central part of the mine area. To the northeast the same anticline flattens near the Providencia mine, then plunges again to the north, eventually rising abruptly near the Reyes mine.

Stratigraphic and structural "traps," consisting of anticlines containing limestone overlain by relatively impermeable shale, characterize not only the deposits of the Tejocotes region but also the two next largest antimony districts in Mexico.3/ In the San José mines, near Wadley in San Luis Potosí, antimony ore is found in limestone below an abrupt contact with black carbonaceous shale. It is much more abundant in the anticlines than in the synclines. In the Soyatal district of Querétaro, limestone grades upward into limy shale. There the ore deposits are distributed through a total stratigraphic thickness of 30 to 50 meters, adjacent to the contact. Relatively impermeable shale is believed to have impeded the upward progress of the ore-bearing solution, and to have caused slow lateral migration at and below the contacts.

---

3/ White, Donald E., and Gonzáles, Jenaro, the San José antimony mines near Wadley, State of San Luis Potosí, Mexico: U. S. Geol. Survey Bull. 946-E, 1946, and unpublished manuscripts.

In this district also ore is most abundant in the crests of anticlines, although the relation is not as definite as in the San José mines. In contrast to the deposits in these important districts, however, the many smaller Mexican deposits in limestone that have been examined by the senior author are not overlain by shale.

The only deposits in the Tejocotes region that are believed to be unrelated to anticlines or to limestone directly overlain by shale are those in the Escondida, Capulín, and Paz mines.

Eastern (generally the hanging wall) contacts of irregular, sill-like bodies of quartz porphyry in the limestone.—In the Yucunani, Chivos, Reyes, and Providencia mines, the ore bodies are on or near the eastern contacts of porphyry intrusions in limestone. These contacts generally form the hanging walls of the intrusions, but locally they form the footwalls. In both the Aguila and Escondida mines, the ore bodies were found immediately south of small porphyry intrusions, which may plunge to the south under the ore. The small Paz and Capulín mines, in the upper limestone (see pl. 9), are the only ones in the area that are not closely associated with porphyry intrusions. Ore bodies are generally absent in areas (1) where the porphyry intrusions are not in or near cores of anticlines; (2) where the intrusions are entirely within shale; (3) where shale forms the eastern contact of the intrusion.

The ore-bearing solutions and the quartz porphyry are believed to be genetically related. Although the solutions almost certainly did not originate from the porphyry now exposed on the surface, the solutions and the porphyry are believed to have come from a common source. The evidence includes (1) the close association of the ore and the quartz porphyry wherever the latter is in limestone near the cores of anticlines; (2) the absence of ore in the limestone cores of anticlines where quartz porphyry is also absent; (3) the complete lack of relationship between ore and the feldspar porphyry, even where the latter is in limestone; and (4) the general association of antimony ore with similar quartz porphyry throughout west-central Oaxaca,4/ as shown in the Chicahuaxtla, Yucunicoco, Cahuayaxi, Santo Domingo, and Juxtlahuaca districts. This last point constitutes very strong evidence that the ore is genetically related to the quartz porphyry, and that the close association of the two is not merely an indication of structural control by the porphyry.

Irregular parts of quartz porphyry contacts.—The most favorable parts of the porphyry contacts are believed to be those that are most irregular. In both the Yucunani and Reyes mines (see pls. 1, 4-6, and 8), the largest and best concentrations of ore have been found where the porphyry embays and cuts across the bedding of the limestone; little or no ore is found where the contact is straight for distances of more than 50 meters. Irregularities in the contacts may have been instrumental in channelling the ore-bearing solutions, and they may also have localized the fracturing which followed the intrusions but preceded the ore. A third possibility is that the intrusions were more irregular in the places where the limestone had already been extensively fractured. Such places would also be favored by the later antimony-bearing solutions.

---

4/ White, Donald E., unpublished reports in files of U. S. Geol. Survey.
Rasmussen, C. (former geologist of the Cía. Minera de Oaxaca, S. A.), unpublished reports.

The antimony ore commonly occurs as "boleos" consisting of rounded, elongate or irregular masses of antimony minerals and chalcedony, either in massive limestone or enclosed in bodies of compact reddish-brown clay contained within the massive limestone (see pl. 4-6, 8, and 9). The clay, according to C. S. Ross,5/ is largely an isomorphous mixture of montmorillonite and nontronite. The boundaries of the clay bodies are sharp in some places, but more commonly the clay grades into the massive limestone through a phase consisting of porous sandy material, which is made up of clay particles thoroughly mixed with white calcite grains about as large as those in the recrystallized limestone. The clay may be in part the residual product of the hydrothermal leaching of the limestone which occurred during and after the deposition of the antimony ore. Most of the clay, however, if not all, is believed to have been deposited from ore-bearing solutions. Although some bodies of clay contain large amounts of ore, others appear to be barren. The extent to which the limestone is replaced by the clay minerals is not, therefore, a reliable indication of how much ore the limestone contains. In the Yucunani mine, the clay bodies are for the most part adjacent to, or very near, the hanging-wall or eastern contact of the large body of porphyry, and are commonly elongated parallel to the contact (see pls. 4-6). In the other mines the clay bodies are not so closely restricted to the porphyry contacts, but the relationship is always reasonably clear.

Clay of a different origin is found on or near the surface in all of the areas underlain by limestone. This surficial clay is a residual product of the weathering of limestone and other rocks. It is very similar in appearance to the hydrothermal clay; in some of the surface workings the two cannot be distinguished. In general, however, the surficial clay is less compact; it commonly contains varied types of rock fragments and it is underlain by limestone, the upper surface of which is very irregular and sharply defined, without the gradation through partially leached calcite sand that is typical of the contact of the clay bodies of hydrothermal origin.

The elongate or irregular bodies of ore grade into ore bodies of another type, consisting of irregular veins of antimony minerals in massive limestone, generally associated with silicified limestone in which there is relatively little clay (see fig. 2). The veins on the Covacha level, at the north end of the Yucunani mine (see pl. 4 ), are largely of this type; these veins are roughly perpendicular to the contact and are most strongly mineralized at or near the contact.

Another type of ore consists of low-grade material containing veinlets and disseminations of antimony minerals in limestone.

Most of the mines contain more than one kind of ore, but the "boleo" type is dominant in the Yucunani, Cacho, Reyes, Aguila, Paz, and Escondida mines, while veins are more important in the Providencia, Chivos, and Capulín mines and the Covacha section of the Yucunani mine.

---

5/ Ross, C. S., Personal communication.

The antimony ore consists of stibnite mixed with brown, yellow, and more rarely white antimony oxides. Very large anhedral crystals of stibnite are commonly found, some being as much as 50 centimeters long, 10 centimeters wide, and 8 centimeters thick. Kermesite, the red oxysulfide of antimony ($Sb_2S_2O$), is

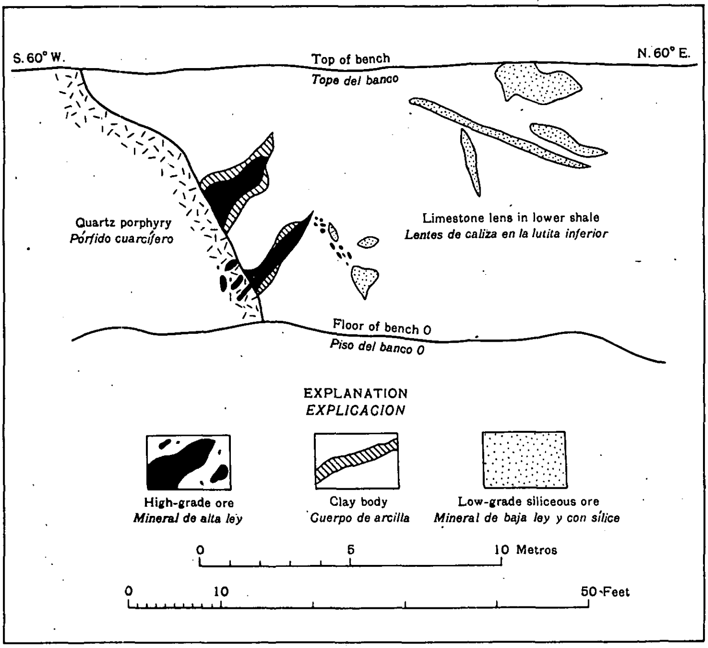


Figure 2. Sketch of the north face of Bench 0, Yucunani pit, 120 meters north of the portal of the Dolores I tunnel.

present but scarce. The hand-sorted ore is shipped under two classifications, oxide and sulfide, but the sulfide ore is relatively pure whereas the oxide ore contains almost as much sulfide as oxide. With increased depth of mining the average ratio of sulfide to oxide will of course tend to rise. This ratio, however, is also dependent upon the size of the ore body and upon its relation to the channels through which oxidizing solutions have migrated downward from the surface. The centers of most of the ore bodies consist predominantly of antimony sulfide, but their outer parts consist of oxides. Oxides also border the numerous fractures that cut the sulfide bodies. Chalcedony is rare in the central parts of the ore bodies, but on the borders it generally predominates over the antimony minerals. Supergene stibnite, a mineralogical curiosity, was identified in several specimens, where clusters or rosettes of tiny needles of stibnite were found on antimony oxide that had previously replaced the early stibnite.

The Yucunani mine has been developed to a maximum depth of 70 meters below the surface. Both the quantity and the richness of the ore have probably decreased somewhat with increasing depth. In this, as in all the mines, the greatest concentration of ore was found on or near the surface, a condition due in large part to the localization of the ore beneath the shale, in or near the crests of anticlines. Another cause, however, is believed to have been a process of residual concentration whereby the overlying rocks were eroded and the fine-grained and soluble products carried away, while the large, heavy, insoluble bodies of antimony ore remained near their original positions or moved only a short distance downhill.

In all of the mines except the Yucunani, attempts to discover new ore bodies in underground workings have been largely unsucessful. The crests of the anticlines, however, are completely unexplored in all the localities where the limestone plunges under shale, except for a short distance northeast of the Covacha veins, and the porphyry contacts have nowhere been systematically explored except in the Yucunani mine (see pls. 4-7), where a large amount of good ore was found. In the Cacho mine (see pl. 1) tunnels were driven below ore that had been found on the surface, and without finding any new ore; but none of these tunnels has explored or even reached the porphyry contacts which are believed to be the sources of a considerable part of the residual concentrations of ore. A contact was explored, however, for a few meters in the Reyes mine (see pl. 8), with disappointing results. Other possible locations for undiscovered ore have not been investigated.

## MINES

### Aguila mine

The Aguila mine is in the southwest corner of the mapped area (see pl. 1), in the lower limestone, which at the outcrop forms the core of an overturned anticline. According to General León Novoa, in 1935 the deposit yielded the first ore produced by the Cía. Minera del Sur, the predecessor of the Cía. Minera de Oaxaca. The ore body had a prominent outcrop standing 2 or 3 meters above the surrounding bedrock.

In 1943 the mine consisted essentially of an open pit 35 meters long, 25 meters wide, and 10 meters in maxium depth. A tunnel about 125 meters long and 20 meters below the level of the pit was driven from the southwest to intersect the ore at depth, but only a few stringers and specks of ore were found under the pit.

The only work that was being done at the mine in the early part of 1943 consisted of the deepening of a small hole near the center of the main pit. According to local reports, high-grade ore was being mined from old workings below the pit when the workings caved.

The material in the central part of the pit, which contained most of the antimony ore, consists largely of an intermixture of red-brown clay and blocks of limestone. No porphyry was found in the pit, but the south end of a sill-like body crops out only a few meters to the north, and another small body was found about 20 meters to the southeast. South of the mine the anticline in which the ore was found plunges to the south; north of the mine the crest of the fold is either horizontal or plunges gently to the north. The mine is therefore on or near a dome on the anticline.

Although the mine has probably yielded between 500 and 1,000 tons of shipping ore, its future does not seem very promising. A cross cut should, however, be driven northward from the central part of the Aguila tunnel, to intersect the sill-like body of porphyry and to explore its contact. The crest of the anticline may contain ore to the north and south of the outcrops of the lower limestone, but there is no clear evidence of mineralization in these places.

## Yucunani mine

The Yucunani mine, which is 600 meters north of the Aguila mine and in the core of the same anticline, has been the most productive in the district, and has the most extensive workings. In the latter part of March 1943 the main open pit (see pl. 1) was about 200 meters long, 45 to 80 meters wide, and 10 to 50 meters deep. During the period August 1942 to May 1943, the open pit was developed by means of a series of seven benches at 10-meter intervals, 2,790 to 2,850 meters in altitude.

The underground workings consist of the following levels:

| Level | Altitude (meters) | Meters of workings, November 1943 |
|---|---|---|
| Covacha | 2,813 | 250 |
| Yucunani I | 2,810 | 145 |
| Yucunani II | 2,800 | 625 |
| Intermediate | 2,790 | 100 |
| Dolores I | 2,780 | 640 |
| Dolores II | 2,740 | (caved) |

The Covacha level is the most recent major development in the mine, and has probably been the most productive level per unit of area. It was started late in 1942, as a result of finding ore in a raise from the Yucunani I level. The largest of the Covacha veins had previously been worked from the surface down almost to the present level, but for some reason further development from the surface was discontinued. During the summer of 1943 the Covacha level and the Yucunani I level were connected.

The Yucunani I level once consisted of extensive workings, from which a large amount of ore was produced; but before the geology was mapped in detail the ground that contained these workings had been almost wholly removed in the process of mining Bench I of the open pit. The workings of the Yucunani I level that are shown on plate 4 were reopened during the summer of 1943, after the mining in the open pit had been stopped.

In mining Bench 0 the Yucunani II level, which is at nearly the same altitude, has been destroyed up to a point 100 meters north of the entrance (see pl. 5).

The intermediate level (see pl. 3), at an altitude of 2,790 meters, has not been mapped, or even seen, by the authors, Late in 1942 a shaft, now filled, was sunk to a depth of 10 meters in the floor of Bench O. The workings that extend from the bottom of the shaft were driven to determine whether the antimony content of the area was sufficiently high to justify mining by the open-pit methods that had recently been put into operation. Open-pit mining on Bench OO, which is at the same altitude as the Intermediate level, was stopped before the workings on the level were reached.

The Dolores I level (pl. 6) contains the most extensive workings in the mine. None of these workings has been penetrated by the open pit, nor has any systematic exploration been carried on below this level. The Dolores II tunnel (see pl. 1), at an altitude of 2,740 meters, was started in order to cut the mineralized zone at a greater depth, but this tunnel caved and has not been reopened.

The Dolores III tunnel, south of the Yucunani workings and at an altitude of 2,785 meters, was started early in 1943 to explore a zone of clay between two parallel intrusions of quartz porphyry. A little ore was found, but in general the results were disappointing.

The geology shown in the underground workings (see pls. 4-7) illustrates four types of ore occurrence:

1. More or less rounded or irregular masses of ore in massive limestone, generally at or near quartz porphyry contact.—The masses of high-grade ore are commonly bordered by a mixture of antimony minerals and chalcedony, which in turn is bordered by a reddish-brown clay. The localization of the bodies of ore was probably influenced by fractures in the limestone, but partial alteration and solution of the limestone have largely removed the evidence as to control. This type of occurrence is best shown in the southern part of the Yucunani II level (see pl. 5). Another example is the large ore body in the southern part of the Covacha level (see pl. 4 and section D-D' of pl. 7), which is said to have been about 20 meters long and 6 meters wide and to have yielded more than 500 metric tons of high-grade ore. This body was mined almost vertically upward until it terminated abruptly against the lower shale about 15 meters above the level. It was also mined to a depth of 2 to 5 meters below the level, but at that depth it narrowed and became lower in grade. The vertical range of the ore thus appears to have been about 20 meters. The reasons for the localization of this ore body are not fully known, but the upward termination of the ore at the shale supports the view that the shale contact was an important control. The ore can hardly have followed a strong fault or a zone of prominent fractures, for neither was found on the lateral extensions of the ore body. The ore apparently replaced an ill-defined zone of brecciated limestone that may be related to the axis of the overturned anticline.

2. Irregular masses of high-grade ore, grading into type No. 1 and entirely surrounded by and embedded in masses of reddish-brown clay.—Some clay is associated with nearly all of the large ore bodies of type 1. Not all of the clay, however, contains ore (see pls. 4 and 5). The largest known body of clay, in the southern part of the Dolores I level, contains only a little ore. In several of the most productive parts of the mine, however, the ore was of this type. The body of clay shown in the southern part of plate 4 is an example. A large

quantity of ore contained in this body is said to have been mined from the Yucunani I level. The ground was so heavy and and the distribution of ore in the clay so haphazard that much ore remained to be mined from the open pit. The relations indicated in plate 4 are necessarily diagrammatic, because no record was made of the boundaries of the clay body or of the ore. The same body of clay contained abundant ore in its southern part on the Yucunani II level (pl. 5). On the Dolores I level (pl. 6), however, the clay on the downward extension of the same body contained only a little ore.

All the known ore bodies of types 1 and 2 whose direction of elongation is known lie elongated parallel to either the quartz porphyry contacts or to the anticlinal axes. No ore bodies of either type have been found more than 40 meters from the nearest quartz porphyry; type 2 shows a particularly close relationship to the porphyry contacts, all known ore bodies of this type being within 15 meters of a contact.

3. Antimony veins in fractures in the limestone.—Ore bodies of this type, though commonly irregular are in general more tabular in shape than those of types 1 and 2. The ore is usually lower in grade and associated with more of the silicified limestone and less of the clay. Complete gradations may be found, however, between any two types. The Covacha veins, near the north end of the Yucunani II tunnel (see pl. 4), range in strike from northwest to northeast. The smaller veins generally dip at moderate angles to the north, but the major west-striking system on the Covacha level dips steeply to the south. The veins have not been explored on the Dolores I level. On the Yucunani II level they were not very productive, but more than 1,000 tons of shipping ore has been produced from ground 5 meters or more above this level. The main west-striking system on the Covacha level was mined for a length of 60 meters and an average width of about 50 centimeters. The vein was apparently richest and widest near the porphyry contact, to which it is approximately perpendicular. On the surface (see pl. 1) the vein strikes N. 75° W., and dips 45° N. Old workings follow the vein down from the surface almost to the Covacha level.

4. Antimony veinlets and disseminations.—This type of ore grades into type 3. The veinlets, which are shown diagrammatically in plates 4 to 6, are either too irregular or too small to map individually. The ore is of low grade and cannot be mined except where it is associated with richer bodies of ore.

Individual masses of the various kinds of ore range in weight from a few kilograms to more than 500 metric tons. Some of the ore contains as much as 65 percent of antimony. The ore is hand-sorted to a shipping-grade product containing at least 56 percent of antimony, the lower-grade material being thrown away or dumped in piles which may be milled or jigged in the future. As in most antimony mines, the percentage of material that can be hand sorted to shipping grade is of much greater importance than the average grade of the ore. At the Tejocotes mines, the operators keep a running account of the ratio of waste to shipping ore, but the average grade of the ore has never been determined by sampling. The grade can be roughly estimated, however, by assuming that half of the antimony content of the ore is recovered in the high-grade shipping ore containing 7 percent of antimony on the average. On this assumption the average over-all grade of material mined from the Yucunani pit, where the over-all ratio of waste to ore was 187:1, is estimated to be about 0.6 percent of antimony. The ratio of waste to ore varies with the method of mining and the depth below the surface. In the early days, when the ore was mined from bodies exposed at the surface, the ratio was comparatively low, perhaps 5 tons of waste to 1 of ore. In the years 1937 to 1941, when the main mineralized zones were being mined by hand, the company officials at the Yucunani mine found that about 30 tons of waste and low-grade ore was mined for every ton of shipping-grade ore that was recovered. In the other mines this ratio varied between 50:1 and 70:1. Since the assays reported from the antimony mines apply in general only to shipping ores, it is seldom realized that the average grade of ore in the ground is as low as these ratios indicate. In the Diesel-shovel mining of the Yucunani deposits, where large areas of barren material were removed, the ratios were particularly high, as is shown in the following table:

Table 2. Benches of the Yucunani pit

| Bench | Altitude (meters) | Material removed 1/ (metric tons) | Shipping ore 2/ (metric tons) | Ratio of waste to ore |
|---|---|---|---|---|
| 5 | 2,850 | 3/ | 3/ | |
| 4 | 2,840 | 3/ | 3/ | |
| 3 | 2,830 | 46,506 | 23.8 | 1,960 |
| 2 | 2,820 | 40,086 | 90.8 | 442 |
| 1 | 2,810 | 128,362 | 965.0 | 133 |
| 0 | 2,800 | 115,400 | 761.2 | 151 |
| 00 | 2,790 | 15,129 | 2.9 | 5,244 |
| Total | | 345,483 | 1,843.7 | Average 187 |

1/ The quantity of material removed was determined by assuming that the material in each scoop of one of the Diesel shovels (3/4 cubic yard capacity) weighed 1 metric ton.

2/ The shipping ore contains, on the average, 57 percent of antimony.

3/ Figures not available; mostly waste, with little or no ore.

The figures on the ratio of waste to ore are known to be far from exact. They are given, however, because this is the only place in Mexico or the United States where deposits producing antimony are mined by machines from an open pit. In evaluating the data, the following facts are to be considered: (1) Benches 2 to 5, and to a lesser extent 0 and 1, consisted of material that had already been penetrated by earlier workings. The ratios for these benches are high because most of the ore had already been removed. (2) The lower benches caught large quantities of barren material that slid down from altitudes as high as 2,855 meters. The ratio of barren slide material to ore in place was probably highest on Bench 0, from which, moreover, an unusually large quantity of quartz porphyry was removed in order to mine a good area to the north. (3) The ratio for Bench 00 is completely misleading, because only a small unfavorable area at the south end of the bench had been mined when the Diesel-shovel operations were abandoned.

In the underground workings, the ratio has generally been between 25 and 50 tons of waste to 1 ton of shipping ore, although at times when development work was very active the ratio has risen to 100:1. The estimated over-all percentages of metallic antimony corresponding to ratios of 25:1, 50:1, and 100:1, respectively are about 4, 2, and 1, if we take into account the probable losses in waste. Accurate records for the various levels have not been kept. Plates 4 to 6 afford evidence, however, that the average grade of the ore is decreasing with depth. Although some very good ore was found in the Dolores I level (pl. 6), the ore bodies are apparently smaller and more widely spaced than on the Yucunani II level above it (pl. 5). Similarly, some ore has been produced from the Covacha veins near the north end of the Yucunani II level, but the same veins have been much more productive on the Covacha levels, which is the next one above (pl. 4).

Although a decrease downward in the average grade of the ore appears to be established, the rate of decrease cannot be determined from any available data. The fact must not be overlooked, moreover, that bodies of high-grade ore have been found as much as 80 meters below the surface. Other ore bodies may therefore be found at similar or even somewhat greater depths wherever the structure is sufficiently favorable.

The total production from the mine is not known, but is estimated to be at least half of the total production from the district, or about 20,000 tons of shipping ore.

The potentialities of the mine continue to be better than those of any other property in the district. Although the ore in the other mines is not yet known to continue at depth, the Yucunani mine has been explored through a total vertical range of 80 meters, with ore found in paying qualtity throughout this range. It is believed that new ore bodies are most likely to be found northeast of the Covacha workings, near the surface. There the limestone is believed to lie immediately below the lower shale, along the crest of an overturned anticline. This crest should be explored, systematically and continuously, between the Yucunani and Providencia mines and north of the Providencia mine.

## Providencia mine

The Providencia mine, about 150 meters northeast of the Yucunani mine (see pl. 1), consists of a few irregular surface workings and some shallow underground workings not more than 10 meters deep.

The mine is on the northeastern continuation of the same anticline that contains the Yucunani mine. The lower limestone is exposed in this area only because of the deep erosion along the bottom of the gully. It is probable that erosion has removed not more than 5 meters of the upper portion of the lower limestone.

Much of the ore has been found in irregular pockets of clay in the massive limestone. The only active mining now in progress, however, consists of underground exploration of a mineralized fault in the northeastern part of the deposit. The fault strikes N. 40° to 50° W., and dips steeply eastward in some places and westward in others. A short tunnel follows the northwestern extension of the fault, where it displaces the overturned upper contact of the limestone, which has a reverse dip of 50° SE. At the surface almost directly overhead, the same contact is not overturned and dips 40° NW.

## Reyes mine

The Reyes mine is about 500 meters north of the Providencia mine, and is believed to be on the northern continuation of the same anticline. Its workings, contained in an area 350 meters long and as much as 150 meters wide, are in the lower limestone, which is exposed along the crest of the overturned anticline. The two largest openings are the southern pit, which is 150 meters long, as much as 40 meters wide, and 15 meters deep, and the northern pit, which is about 75 meters in diameter and 20 meters in maximum depth. The area also contains about 10 smaller pits of various sizes and about 400 meters of underground workings entered through 4 adits. Only the two southern tunnels, totaling 250 meters in length, were accessible in the later part of 1943.

Most of the ore was found in the southern pit, excavated in reddish-brown clay which has largely replaced the original massive limestone. Except at the southeast end, the pit is entirely surrounded by quartz porphyry. According to local reports, porphyry also originally overlay the clay and ore in the central and northern parts of the pit, and it probably localized the ore.

The northern pit is in altered limestone and clay on and near the eastern contact of the same large body of quartz porphyry. Here the porphyry contact dips to the west; the ore was therefore on the footwall of the porphyry, in contrast to the usual relation in the district. The ore was probably related, also, to the axis of the anticline; the upper contact of the lower limestone, however, must originally have been nearly 100 meters above the present floor of the pit. A long tunnel was driven from the pit to the porphyry, and the contact was then followed for 150 meters to the south, but no ore was found.

The Reyes IV tunnel (see pl. 8), at the south end of the mine, was started early in 1943. In November, after 230 meters of workings had been driven, the tunnel was discontinued. Enough ore was developed in the southern half of the workings to pay for the costs, but the northern workings, 10 to 20 meters below the floor of the surface pit, were almost completely barren. The geologic map (pl. 8) reveals, however, that 70 out of the 90 meters of the northern half of the workings is in quartz porphyry. Further exploration in the limestone and clay northwest and northeast of the present workings is recommended.

In general the southern part of the mine is the most favorable; because there the contacts of the porphyry intrusion are very irregular, a condition that apparently favors the localization of ore. South of the present workings, however, the possibilities for undiscovered ore are not particularly good, because the overturned anticline plunges very steeply to the south.

## Cacho mine

The Cacho mine, the second largest in the district, is in the central part of the main area shown in plate 1, in lower limestone that is believed to form the core of an anticline overturned to the east. It is very difficult, however, to interpret the structure, because the limestone is massive, unstratified, and almost completely recrystallized. The area of limestone is probably bounded by faults on three sides.

The scattered workings of the mine are distributed irregularly through a zone 375 meters long and as much as 300 meters wide. The largest opening, the main Cacho pit in the center of the mine area, is 100 meters in diameter and has a maximum depth of nearly 25 meters below the original surface. The workings include at least 25 other pits of various sizes and shapes, which are shown on plate 1. The mine contains more than 800 meters of underground workings in 11 tunnels, but only about 100 meters in the six shortest tunnels was accessible in early 1943. A little ore was being mined from two of these tunnels, but the rest are for the most part barren. Nearly all of them are far from the anticlinal crest and the porphyry contacts, which are believed to control the ore.

No details of the mineralization were found in the surface workings. The material in the main Cacho pit consists of clay mixed with blocks and fragments of massive limestone, some fragments of quartz porphyry, and a little high-grade antimony ore. Nearly all of the material being removed from the floor of the pit has slumped down from the walls; only a small amount is actually in place when mined.

The location of the pits suggests that much, but probably not all, of the ore was derived from zones near the porphyry contacts. The main Cacho pit is very near the assumed location of the axis of an overturned anticline. The floor of the pit is probably at least 75 meters below the original upper limit of the lower limestone. The ore taken from this pit, therefore, was either deposited at a considerable distance below the base of the lower shale where it crosses the crest of the anticline, or had been formed along the porphyry contact to the west and had migrated downhill as a result of erosion. The second hypothesis seems to afford the simpler explanation for the abrupt termination of the ore at depth. If this explanation is correct, more ore should be found in place near the contacts of the quartz porphyry. These contacts have not been intersected or explored systematically underground, although similar contacts are known to influence the localization of the ore in the Yucunani mine.

The mine has probably yielded between 5,000 and 10,000 tons of shipping ore. Its potentialities are believed to be fairly good, but its future is largely dependent upon the results of the proposed exploration of the porphyry contacts.

## Chivos mine

The Chivos mine (see pl. 1) is in the southwest corner of a large mineralized area, most of which is called the Cacho mine. The Chivos mine consists almost entirely of surface workings, with a maximum depth of 15 meters, irregularly distributed through an area about 60 meters in diameter, in the lower limestone. A tunnel, now inaccessible, was driven under this area to explore the deposit at depth, but it did not reach the most favorable locality. The workings are mostly on or near the assumed location of the axis of an anticline, and are probably less than 50 meters below the original upper limit of the lower limestone.

Most of the ore has been produced from the southernmost part of the mine, where a large irregular vein in brecciated and replaced limestone strikes N. 65° W. and is nearly vertical. The vein has been mined for a length of more than 20 meters and a depth of 15 meters. The width of the ore attains a maximun of 3 meters and averages 1½ meters. The vein is northeast of and very near to a dike of quartz porphyry that strikes in the same general direction. The vein terminates at the north against a lobe of the porphyry and at the south against a premineral fault striking N. 50°-70° E., and dipping 65° SE. The northwest-striking fractures which controlled the vein are believed to be related to the premineral fault. In the eastern part of the mine, small irregular bodies of ore occur in the limestone that forms the footwall of this fault, but no ore was found in the limy shale that forms the hanging wall.

A large part of the ore containing about 40 percent of antimony is so intimately mixed with its gangue of silicified limestone that it cannot be hand sorted to a high-grade shipping product. Clay is rare in the main vein, but common in the small workings to the north.

The total production from the mine is not known but is estimated to be between 1,000 and 3,000 tons of shipping ore. In March 1943, about 10 to 20 tons of ore were being produced weekly from the main vein.

The potentialities of the mine are good. The northeast-striking fault and particularly the nortwest-striking vein should be systematically explored at depth. In the area south of the present workings and the quartz porphyry dike, the lower limestone is below the surface, covered by lower shale. The limestone core of the anticline may there contain a large amount of ore.

## Escondida mine

The principal workings of the Escondida mine, which is 500 meters east of the Cacho mine (see pl. 1), consist of a compound pit about 40 meters in diameter and 10 meters deep, and the Escondida tunnel, which was driven recently. The deposit is in the upper limestone and, in contrast to all of the other mines in the district, is near the axis of a syncline.

About 1939 a large amount of high-grade ore, associated with bodies of clay, was found in the main pit, near the southern contact of a small intrusion of quartz porphyry. After the main ore body was mined out, the pit was continued horizontally into the hillside to the south. A tunnel was then driven 75 meters farther to the south at a maximum depth of 8 meters below the surface. Apparently the purpose of this exploration was to search for downward continuations of minor showings of ore on the surface. The better possibility of finding ore on the downward continuation of the contact of porphyry and limestone has not been investigated. The Escondida II tunnel, started in March 1943, 75 meters northeast of the main pit, was driven in order to explore the possibilities at depth. The tunnel is completely barren of ore, but there may be some ore north of the face of the tunnel, adjacent to the contact of quartz porphyry. The potentialities of the mine do not appear to be very good.

## Capulín mine

The Capulín mine (see pl. 9) is about 1,500 meters north of the Reyes mine and has been mapped separately from the main mineralized area. In its geologic relations the deposit worked in this mine is unlike most of the others in the district: the ore is not related to anticlines and the nearest known quartz porphyry is 150 meters from any of the workings. The country rock is the upper limestone. The workings, which are small, lie within an area 150 meters in diameter. Small pockets of ore in clay have been taken from five pits, the largest of which is 20 meters long, 8 meters wide, and 4 meters deep. Most of the ore has been mined from two short tunnels near the center of the mine area. Both tunnels intersect a vein that strikes N. 20° W., and dips 70° E. The northern or upper tunnel yielded about 15 tons of ore from a lens on the footwall of the vein, at its intersection with another small vein striking due west and dipping 75° S. The lens was 30 centimeters wide and 4 meters long; its vertical limits had not been determined in March 1943. Where the main vein was exposed in the lower tunnel, it was largely barren and was characterized by open spaces dissolved out of the limestone country rock. In places the openings were partly filled with travertine, some of it 30 centimeters thick.

The total past production from the mine is probably between 50 and 100 tons of shipping ore. The outlook for the mine is not very promising, in view of the weakness of the veins and the absence of conditions that have elsewhere proved favorable, such as anticlinal structure associated with intrusive prophyry.

## Paz mine

The Paz mine (see pl. 9) owned by Aquiles Serdán of Mexico, D. F., is the only property in the district that is not owned by the Cía. Minera de Oaxaca. Its principal deposit lies about 150 meters southeast of the Capulín mine. The workings consist of a large open pit about 60 meters in diameter and up to 15 meters deep, together with four caved tunnels having a total length of about 100 meters.

All the workings are in the upper limestone. The main pit, which has yielded nearly all of the ore, is on the hanging wall of a steep thrust fault striking N. 30° -50° W., and dipping 45° SW. The ore is largely in reddish-brown clay that has replaced limestone. No ore is found in the upper shale that forms the footwall of the fault. The ore may have been localized to some extent by a schist facies of the middle shale, which at one time overlay the mineralized area along a thrust fault, larger than the one mentioned above, that crops out on the surface about 50 meters east of the mine. This fault is the northern continuation of the one mapped in the northeastern part of the main Tejocotes region (see pl. 1).

The mine has not been worked for several years. It was active from about 1935 to 1940, and its total production, to judge from the size of the pit and the amount of rejected low-grade ore, was probably between 500 and 2,000 tons of shipping ore. Little or no ore seems to have been produced from the tunnels south of the main pit.

The potentialities of the mine are uncertain, but there may be some ore on the downward continuation of the principal mineralized zone. This zone could be explored by means of short tunnels driven under the pit from the east.

## RESERVES

To estimate the reserves of the Tejocotes mines is particularly difficult for the following reasons: (1) As is usual in antimony mines, reserves are not blocked out in advance of mining; the ore bodies differ greatly and unpredictably in size, and when discovered they are mined immediately. (2) The readily discovered ore bodies have already been found. Others, including some that are of high grade, probably remain to be discovered in the limestone cores of plunging anticlines that have not been adequately explored. The results of any future exploration cannot be predicted with any approach to accuracy. (3) The average grade of the ore apparently decreases with depth, but reliable data on the rate of decrease are not available.

## OUTLOOK FOR THE DISTRICT

The Tejocotes mines may have fairly large reserves of high-grade antimony ore. The mines have been the largest producers in Mexico since 1938, and they should hold that position for at least a year or two longer. During the past 4 years, however, the annual production has slowly decreased from a peak of 2,918 tons of metal in 1940 to 2,325 tons in 1943. Diesel shovels were used in the surface mining of the Yucunani deposits from August 1942 to June 1943, in the hope that the rate of production could be increased; but it was barely maintained at about its previous level. The basic reason for the decline of production is that the near-surface bodies have been discovered and mined out and new ore bodies have become harder to find. If production is to be maintained, it must be by the discovery of new ore bodies below the surface. In the future, therefore, the antimony ore will have to be mined for the most part by underground methods. As a result, the cost of production will probably tend to rise; this tendency, however, can perhaps be offset by mining efficiently and by recovering antimony from the low-grade ores that have been thrown away in the past.

Transporation costs are high: in terms of United States currency in 1943 the trucking rate from the mines to the nearest railhead at Parián, Oaxaca, is about $11.30 per ton, and the freight rate to Laredo, Tex., is about $4.10 per ton. In addition, the export and production taxes on the ore average about $16.50 per ton. The sum of these charges, approximately $32.00 per ton, is almost one-third of the value of the ore at Laredo.

The ore deposits can probably be worked for many years if the probable decrease in grade with depth is found to be gradual rather than abrupt and if new ore is found by exploring the crests of anticlines near the known deposits. Unless one of these conditions is fulfilled, production cannot be expected to continue for more than a few years.

## RECOMMENDATIONS

Production could be increased most readily by immediately introducing methods for the recovery of antimony from the low-grade siliceous ore that has been thrown away in the past. Most of this ore has not been separated from the waste, although several thousand tons have been collected into small piles scattered throughout the district. In the antimony districts of central Mexico, such as those at Wadley in San Luis Potosí and Soyatal in Querétaro, old dumps containing not more than 5 percent of antimony are screened and the sized products are hand-jigged to a high-grade concentrate. The siliceous ore of the Tejocotes mines probably contains from 10 to 15 percent of antimony, but the material is coarse-grained and has to be crushed and screened for treatment. Hand jigs could readily be installed at Tejocotes, where they are being tried experimentally at the present time. A small mechanical crusher should replace the present method of breaking up the ore by hand with hammers. If some means of mechanical separation were adapted, the nearest source of an adequate supply of water would be San Juan Mixtepec, 8 kilometers distant.

The mining of the clay presents difficult engineering problems, yet all of the clay in the ore-bearing bodies must be mined if all of the contained antimony ore is to be recovered, This probably could be done efficiently, however, under the guidance of an expert mining engineer who had had experience with similar difficulties.

Production probably can be maintained for several years by thorough exploration, which must be guided by a knowledge of the relations of the antimony ore to the anticlines, to the contacts of limestone and shale, and to the quartz porphyry intrusions. These relations have been recognized to some extent in the Yucunani mine, but only in recent months, under the expert guidance of the company geologist, Georges Ordóñez, have they been recognized in the other deposits. The possibilities for ore at depth are good in the Yucunani, Cacho, and Reyes mines, where the eastern or hanging-wall contacts of the porphyry intrusions should be extensively and systematically explored. Particular attention should be paid to the more irregular parts of the contacts. The occurrence of clay and of silicified limestone are favorable indications of ore in some places. The most favorable locations for ore are believed to be in the vicinity of known deposits, in the cores of anticlines. It is specifically recommended that exploration be done in the following localities, listed in approximate order of promise:

1. Northeast of the Covacha workings (pl. 1), near the surface, in the crest of the anticline in the lower limestone where it is overlain by lower shale. All of the area between the Yucunani mine and the Providencia mine should be explored.

2. North of the Providencia mine (pl. 1), under the lower shale and on the continuation of the anticline referred to above.

3. The limestone core of the anticline extending south of the Chivos mine (pl. 1). The area near the quartz prophyry due south and southwest of the present workings is the most favorable. The location of the axis of the anticline is not known

with any degree of certainty because of the absence of outcrops in this area.

4. The eastern contacts of all the porphyry intrusions in the Cacho mine. In the past a large amount of ore has been mined from the open pits. This surface ore may be a product of the residual concentration of ore that moved downhill from sources near porphyry contacts. If that is true, the exploration under or near the pits failed to reveal ore because these contacts on which the ore was originally formed were not intersected. These contacts should be explored extensively at depth.

5. The whole Yucunani mine from a low level such as that of the Dolores II tunnel, which was started but never completed. The depth to which the deposits persist should be determined as soon as possible, as a basis for planning the future development of all the deposits.

6. The Chivos mine at depth. The deposit consists largely of an irregular vein controlled by northwest-striking fractures that are probably related to a northeast-striking fault. The fracture system and the fault almost certainly contain more ore at depth.

7. The ground in the Reyes mine that lies below the two largest ore bodies, which were found in an embayment of altered limestone almost completely surrounded by porphyry. The Reyes I tunnel explored the northern contact of one lobe of the porphyry for a short distance, but a short crosscut through the porphyry which would explore the much more favorable embayment of limestone was not driven. This limestone has good possibilities for undiscovered ore at depth, and should be explored by extending the Reyes IV workings from their present northeastern limits (see pl. 8).

8. Two hundred meters west of the Escondida mine (see pl. 1), in the limestone core of an anticline. Some ore found in the gullies, in bodies of clay in limestone, may have come from concealed ore bodies north and south of the gullies, under the middle shale.

9. The clay body between the two porphyry intrusions on the south end of the Yucunani mine. This should be explored from the Dolores III tunnel. The area between the Dolores I and Dolores III tunnels is probably not so favorable, but it may contain some ore.

10. The contact of the small body of porphyry north of the Aguila mine. The contact should be explored underground from the Aguila tunnel, which now ends about 10 or 15 meters east of the contact.

11. The porphyry contact just north of the Escondida mine, from the Escondida II tunnel. The tunnel explored the area under the surface workings but did not reach the contact 50 meters to the north.

12. The Paz mine at depth. It could be explored by means of tunnels driven from the east, below the level of the main pit.

O