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TIN DEPOSITS OF THE REPUBLIC OF MEXICO

BY

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TIN DEPOSITS OF THE REPUBLIC OF MEXICO

By William F. Foshag and Carl Fries, Jr.

ABSTRACT

The tin deposits which are reported to occur in 19 States of the Republic of Mexico are all on the high lava-covered plateau extending from the border with the United States to the State of Oaxaca. They are of three types: (1) Deposits associated with granite, (2) deposits associated with lead-zinc-silver ores, and (3) deposits closely associated with extrusive rocks. The total production of metallic tin between 1800 and 1940 has probably been somewhat more than 6,000 metric tons; the annual production between 1936 and 1940 has averaged 330 tons. About half of the tin came from deposits of type 2 and the rest from deposits of type 3; none has yet been mined from deposits of type 1.

The only district known in which tin deposits are associated with granite is near Guadalcázar, San Luis Potosí. Here granite is intruded into Cretaceous limestone and crops out in a roughly circular area a mile and a quarter (2 km.) in diameter. Cassiterite is apparently a late accessory mineral in the granite and may occur in some of the lead-silver veins mined in the peripheral zone of the intrusive body, but no tin deposits of economic value are known. Large deposits of gravel derived from the granite contain cassiterite, cinnabar, gold, and silver; parts of these deposits may contain valuable metals in sufficient quantity for profitable placer mining.

The only known Mexican tin deposits associated with lead-zinc-silver ores are at the San Antonio mine, near Santa Eulalia, Chihuahua. Tertiary clastic and volcanic rocks unconformably overlie the lead-zinc-silver deposits, which replace Cretaceous limestone, and dikes of rhyolite and andesite intrude all the rocks. The exact mode of occurrence and origin of the tin are unknown; the tin may be related in origin either to the rhyolite dikes or to the lead-zinc ores. Although the San Antonio mine has yielded about half the tin produced in Mexico, it has not produced any tin since 1939, and its tin ore is said to be exhausted.

Probably more than a thousand tin deposits, most of them small veins but some of them placers, are known in volcanic rocks on the plateau of Mexico, largely in the States of Durango, Zacatecas, and Guanajuato. All these deposits and some in the United States--in the Black Range of southwestern New Mexico and in northern Lander County, Nevada--are very similar in occurrence and mineral composition and differ, so far as known, from all other tin deposits yet described. Most of the deposits are in late Tertiary rhyolite flows, but a few are in latite and andesite that underlie the rhyolite. The veins consist largely of specularite intimately associated with cassit-

erite. The cassiterite forms pockety incrustations on walls of irregular, branching, steeply dipping fissures, and is nowhere disseminated through large bodies of rock. The deposits, in general, are believed to have formed within 2,000 feet (600 m.) of the surface and shortly after extrusion of the lavas. Most of the cassiterite is believed to have come from small bodies of crystallizing rhyolitic magma that had been intruded near the surface, though some of it may have come from crystallizing flows. The deposits appear to have been localized by minor faults near the centers of eruption of the rhyolitic lavas.

Production of tin from the veins in the lavas has been sporadic; most of the veins have yielded less than 5 tons of tin and only a few have yielded more than 20 tons. Four attempts to mine deposits on a large scale have proved unprofitable, apparently owing to the small size of the individual ore bodies. No valid estimate of reserves can be made. No deposit has been proved to contain more than 120,000 tons of rock containing 0.5 percent tin, and most of the deposits probably contain a much smaller tonnage of rock of that grade. There may be as much as 10,000 tons of tin in rock containing 0.1 percent or more of tin, but no method has yet been developed by which material of such low grade can be profitably mined.

Most of the tin produced between 1936 and 1941 came from placers derived from the veins. Most of these placers are extremely small and are mined entirely by hand methods. One of the deposits, indeed, may be more than 1,000,000 cubic yards in volume, but the results of extensive sampling indicate that it contains less than half a pound of tin to a cubic yard. There may be more than 10,000 tons of tin in placers containing half a pound or more of tin to a cubic yard, but most of it is in small deposits that cannot be worked profitably with machinery and that can be mined only during the rainy season--from July to December.

Under the mining conditions and at the prices prevailing in 1941 the probable production of tin from veins and placers in the lavas is not likely to exceed 400 tons a year, and even at double the 1941 price of tin the probable production is not likely to exceed 800 tons a year.

INTRODUCTION

Distribution of the tin deposits

Tin deposits have been reported to occur in 19 States of the Republic of Mexico, from the United States boundary on the north to the State of Oaxaca on the south. The deposits are most thickly distributed in the central part, in the States of Durango, Zacatecas, San Luis Potosí, Aguascalientes, Jalisco, Guanajuato, and Querétaro (see pl. 25); a few deposits each have been reported in Sonora, Chihuahua, Coahuila, Nuevo León, Nayarit, Michoacán, Hidalgo, México, Morelos, Puebla, Oaxaca, and Guerrero. There are probably more than a thousand individual deposits scattered throughout this belt, but they occur in more or less distinct groups. Only the groups are located on the map.

Climate and topography

The tin deposits are almost wholly on the lava-covered semi-arid central plateau, at elevations between 4,000 and 10,000 feet (1,200 and 3,000 m.). Although rainfall is extremely light during the greater part of the year, a rainy season, beginning in May or June in the southern part of the country and in June or July in the northern part, lasts until mid-October. During the rainy season water runs in many of the arroyos, but during the remainder of the year most of them are dry. Although there is an occasional light snowfall over the northern part of the plateau during the winter, frosts rarely occur south of San Luis Potosí except at high altitudes. Temperatures during the summer are not excessive, owing in part to the high altitude of the plateau and in part to the frequent rainfall.

North of the city of San Luis Potosí the plateau is characterized by interior drainage; more or less isolated mountain ranges and mesas rising from 1,000 to about 5,000 feet (300 to about 1,520 m.) above the general level separate the various basins, some of which contain saline or playa lakes. South of San Luis Potosí, except for a few basins of interior drainage, of which the valley of Mexico is best known, the drainage flows eastward into the Gulf of Mexico or westward into the Pacific Ocean. Westward drainage leaves the plateau through precipitous canyons (barrancas), some of which are nearly as deep as the Grand Canyon of the Colorado River; eastward drainage flows through somewhat shallower canyons.

Accessibility

An excellent all-weather highway connects Laredo, Tex., with Mexico City via Monterrey, Victoria, and Zimapán. (See pl. 25.) From Mexico City surfaced highways extend south to Acapulco, on the Pacific Ocean, west to Guadalajara, and east to Veracruz, on the Gulf of Mexico. A road extends from Guadalajara north-westward along the coast through Culiacán, Guaymas, and Nogales to Tucson, Ariz., but it is now not passable to through traffic except from Guaymas to Tucson. A surfaced highway runs from El Paso, Tex., to Chihuahua, Mexico. From Chihuahua to Mexico City there is a road passing through Durango, Zacatecas, Aguascalientes, and Querétaro, which is unsurfaced except for short stretches near those cities. This road can be travelled with some difficulty in the dry season, but it is impassable for automobiles in the rainy season.

A road, of which it is planned to make a highway, from Monterrey westward to Mazatlán, on the coast, is surfaced as far as Torreón; it is passable from there to Durango during the dry season but is impassable for automobiles between Durango and Mazatlán. From Guadalajara to the border of the United States, a distance of about 900 miles, there is not a single road that crosses the barranca country between the plateau and the west coast. The highway from Victoria, or from Antiguo Morelos, on the Laredo-Mexico City highway, to San Luis Potosí is surfaced and passable throughout the year and an extension of it from there to Guadalajara is projected. A surfaced highway extends eastward from the Mexico City highway to Tampico, on the Gulf of Mexico.

It is possible to travel in trucks or cars with high clearance on wagon roads over much of the plateau country during the dry season; during the rainy season most of the plateau country is virtually inaccessible by automobile. Many of the tin deposits, located mainly along the western edge of the plateau, can be reached by automobile during the dry season, but some can be reached only by a day's ride on horseback from the nearest road.

A main railroad line extends southward from Tucson, Ariz., through Guaymas, Culiacán, Mazatlán, and Guadalajara to Mexico City; another extends from El Paso, Tex., to Mexico City through Chihuahua, Torreón, Zacatecas, Aguascalientes, León, and Querétaro. From Mexico City a line extends eastward to Veracruz. There are railroads from Laredo and Brownsville, Tex., to Monterrey, from which a main line continues southward through San Luis Potosí and Querétaro to Mexico City; a branch line extends from Monterrey to Tampico and another to Torreón and Durango. Branches run from San Luis Potosí to Tampico and to Aguascalientes, and several others extend from the main lines for short distances. Four seaports are on the railroads: Tampico and Veracruz on the Gulf of Mexico, Guaymas on the Gulf of California, and Mazatlán on the Pacific Ocean.

History and production

Ingalls [1] records the fact that the Indians knew of tin in Mexico before the Spaniards arrived in the New World. According to Hanks, [2] the Spaniards began to mine tin in the América-Potrillos district in Durango as early as 1790. A summary of the history of tin mining during the nineteenth century is given by Ingalls. [3] When García [4] reviewed the history of tin mining up to 1926, he found that there had been little change in either methods or scale of mining from those described by Ingalls. Even in 1941, except for a few relatively extensive deposits, described farther on in this report, mining methods were the same as during the past two centuries. Most of the tin ore has been recovered on a small scale, with hand tools and without explosives, by washing the arroyo gravels and the soil on hillsides near small vein deposits, and by crushing and washing material mined from small veins.

1/ Ingalls, W. R., The tin deposits of Durango, Mexico: Am. Inst. Min. Eng. Trans., vol. 25, p. 146, 1896.

2/ Hanks, H. G., On the occurrence of durangite in the tin-bearing region of Durango, Mexico: Am. Jour. Sci., 3d ser., vol. 12, p. 276, 1876.

3/ Ingalls, W. R., op. cit., pp. 146-163.

4/ García, J. A., Monografía del estaño: Bol. minero, vol. 22, pp. 6-29, 1926.

Records of the production of tin in Mexico prior to 1916 are meager, only a few figures appearing in published reports. Ingalls 5/ quotes Humboldt as reporting that 4.602 metric tons of metallic tin was produced in 1802 in the administrative district of Guadalajara, and that about 3 tons of tin was exported from Mexico in 1803. Manzano 6/ states that 44 tons of ore was produced in 1882 from a deposit near Santa María del Río, S. L. P., and that it yielded possibly 10 tons of metallic tin. According to Ingalls, 7/ a deposit that was being operated in 1883 near Teocaltiche, Jalisco, had a maximum monthly production of about 3 tons of metallic tin during the short period it was operated. Mines in the América-Potrillos district in Durango were most actively operated in the first decade of this century, and Rangel 8/ reports that the total production from the large mines during that period was a few thousand tons of ore; he does not state the tin content of the ore, but it was probably much less than 10 percent. From these few figures it seems reasonable to infer that the average annual production from 1800 to 1916 was about 10 metric tons of metallic tin, or about 1,100 metric tons in all. The table on page 105 shows the production of tin in Mexico compiled from statistics given in Boletín Minero and Boletín Petróleo y Minero, publications of the Mexican government. The figures are incomplete, and some of them are undoubtedly too low, but they are probably of the right order of magnitude.

5/ Ingalls, W. R., op. cit., p. 147.

6/ Manzano, J. P., Informe sobre la exploración de la zona minera de Santa María del Río, S. L. P.: Bol. agricultura, minería é industrias, vol. 3, No. 2, p. 101, 1893.

7/ Ingalls, W. R., op. cit., p. 160.

8/ Rangel, Manuel, Apuntes sobre la distribución de minerales en el Estado de Durango: Soc. geol. mexicana, Bol. 7, p. 111, 1910.

Table 3.--Production of tin in Mexico 1/

Year	Metric tons	Year	Metric tons
1800-1915 (estimate)	1,100.000	1929	No record
1916	.292	1930	269.560
1917	9.214	1931	773.171
1918	13.537	1932	751.430
1919	1.588	1933 (Jan. to March)	120.378
1920 (first half)	....	1934	15.829
1921 (first half)	.492	1935	630.749
1922	No record	1936	373.476
1923	No record	1937	379.480
1924	8.849	1938	255.458
1925	1.033	1939*	293.910
1926	2.224	1940*	350.729
1927	No record		
1928	No record	Total....(about)	5,400.000

1/ More than half the tin produced between 1930 and 1939 came from the San Antonio mine, near Santa Eulalia, Chihuahua.
* From Mexican Department of National Economy.

Field and laboratory work

The authors were in Mexico for 3 months, from the first of January to the end of March 1941, and visited as many of the tin-bearing districts as time permitted, devoting special attention to those in which tin was being mined or which appeared to be promising. From 1 to 10 small mines were examined in each of 19 more or less separate districts, or 44 mines in all. Pannings were made of placer gravels in the arroyos of 7 districts, and pan concentrates of gravels, as well as specimens of ore and country rock from each district, were collected for laboratory study. Owing largely to scarcity of water during the dry season, only half a dozen of the mines visited were being worked, and placer deposits were being mined in only three of the districts visited. No deposits were mapped, partly because the time allotted for the field work did not permit it, and partly because the size of the deposits did not seem to warrant it.

Brief laboratory investigations have been made in order to identify the rocks and minerals collected and to determine roughly the tin content of some channel samples collected from the most promising deposits. Miss Jewell J. Glass of the Geological Survey collaborated in this work. Some of the results are presented in subsequent sections.

Acknowledgments

The field work was done by the Geólogical Survey, United States Department of the Interior, and the Smithsonian Institution, in cooperation with the United States Department of State, and with the permission and aid of the Government of Mexico. The authors wish to thank the staff of the Instituto geólogíco de México for expediting the field work and for the many valuable suggestions they have offered. Further aid in the field was given by more persons than can be enumerated here, but the authors must acknowledge particularly the assistance and courtesies extended by P. W. Avery, Antonio Cano, Carlos Freymann, Manuel Heyser, S. G. Jenkin, Jésus de Lara, D. B. McAllister, E. Mouret, Francisco Salazar, Rafael Solís, and Martin Sutti; they are indebted also to many persons for valued information, especially to W. E. Brock, Colonel Gordon McCoy, E. M. Flynn, Francisco Galarza, Major H. K. Kicklighter, J. F. Morton, the Cia. Minera de Peñoles, S. A., and members of the Consular staff of the United States in Mexico. The many kindnesses extended the authors by the Mexican miners and ranchers are also gratefully acknowledged. For aid in the office the authors are indebted to many members of the Geological Survey, particularly to J. J. Glass for assistance in petrographic and mineralogic studies; to R. C. Wells, J. J. Fahey, and George Steiger for chemical and spectrographic work; and to H. G. Ferguson and F. C. Calkins for constructive criticism of the manuscript.

TIN DEPOSITS

The known tin deposits in Mexico are of three types: (1) Deposits associated with granite, (2) deposits associated with lead-zinc-silver ores, and (3) deposits closely associated with extrusive rocks (lava flows, breccia, and tuff). Deposits of the first and second types are thus far known to occur in only one district each, but more than a thousand small deposits of the third type are known in the more or less separate districts scattered over the plateau. The deposits of the first two types are younger than Cretaceous, though it is not known how much younger; the deposits in the lavas are largely late Tertiary. Erosion of the tin-bearing veins has given rise to many small placers, for the most part of recent origin.

Deposits associated with granite

Location and history

The only tin deposits in Mexico known to be directly associated with granite occur near the town of Guadalcázar, San Luis Potosí, in a famous old mining region 60 miles (96 km.) by road northeast of the city of San Luis Potosí and 12 miles (19 km.) northeast of the Villar station on the Tampico branch of the Mexican Central Railroad. The district is easily reached by car during the dry season over 11 miles (18 km.) of narrow dirt road from a point on the San Luis Potosí-Victoria highway 48 miles (78 km.) from the city of San Luis Potosí. The ancient mines near Guadalcázar, in which stone hammers have been found, were probably worked for mercury by the Indians before the colonization which took place between 1614 and 1620. This district contained important silver mines as early as 1622, and it later became the largest producer of mercury in Mexico. Gold has been washed from placer deposits in the district intermittently for many years, but cassiterite was not recognized there until about

1937. Since then parts of the gravel deposits have been tested for tin, mercury, gold, and silver, but no tin had been mined up to December 1941.

General features

The district is dominated by the Sierra de Guadalcázar, a westward-trending mountain range flanked on the east by the Abrego basin, on the south by the Guadalcázar basin, and on the northwest by the Realejo basin. The highest point in the range is Cerro San Cristóbal, which is 7,382 feet (2,250 m.) above sea level and about 1,500 feet (460 m.) above the Guadalcázar basin. (See pl. 26.) This peak forms the center of a small roughly circular body of granite intruded into Cretaceous limestone, which surrounds the granite on all sides except the northwest, where fan deposits lap directly against the granite. The granite is a little higher than the surrounding limestone and is outlined by arroyos that have developed along the greater part of the contact. Debris eroded from the contact zone was deposited in large alluvial fans along the sides of the contiguous basins. Subsequent erosion lowered the arroyo bottoms, dissected the fans, and caused the formation of secondary deposits of gravel. The basins are now drained largely through sinks (resumideros) in the underlying limestone.

The western part of the Sierra de Guadalcázar is a gently rolling upland, which gradually decreases in altitude westward from Cerro San Cristóbal and which appears to be about in the same plane as the tops of the granite hills. This upland is underlain by limestone and is characterized by sink holes, collapsed slopes, and deep caverns open to the surface. It undoubtedly represents an old karst topography that was formed prior to erosion of the steep-walled canyons. A broad, shallow valley at a high elevation, into which the Arroyo Las Papas has been cut, south of Cerro San Cristóbal, and a narrow bench on the limestone along the front of the range east of Arroyo Las Papas, facing the Guadalcázar basin, probably are remnants of this old topography.

Broad, gently sloping alluvial fans extend out from the Sierra de Guadalcázar into the Abrego, Guadalcázar, and Realejo basins. The distribution of these fans is such that they could not have been formed by the present drainage but must have been built by ancestral streams flowing at higher levels. The easternmost fan in the Guadalcázar basin was built at the mouth of a high valley that corresponds in position to Arroyo Minas Viejas. This fan has a gentle slope toward the southeast and forms the low divide that separates the Guadalcázar and Abrego basins. A second large fan was built by drainage carried through a high valley having the approximate position of Arroyo Las Papas, and a third fan was constructed at the mouth of another high valley a little farther west. These fans have coalesced to form a continuous alluvial apron along the mountain front. The small Realejo basin is filled with a large fan that slopes gently toward the northwest, away from the granite. These old fans are more closely related to the old upland surface than to the present more youthful topography.

All the arroyos are steep-walled and narrow, and the old topography and the fan deposits are being actively dissected, parts of the fans having typical badlands topography. During this recent period of erosion the soft, highly altered contact zone of the granite has also been extensively eroded, and at the edge of the Realejo basin this altered granite has a badlands topography similar to that of the eroded fans.

Rock formations

Limestone.--The oldest formation in the district is a cherty, light-gray limestone of middle Cretaceous age.[9/] Its

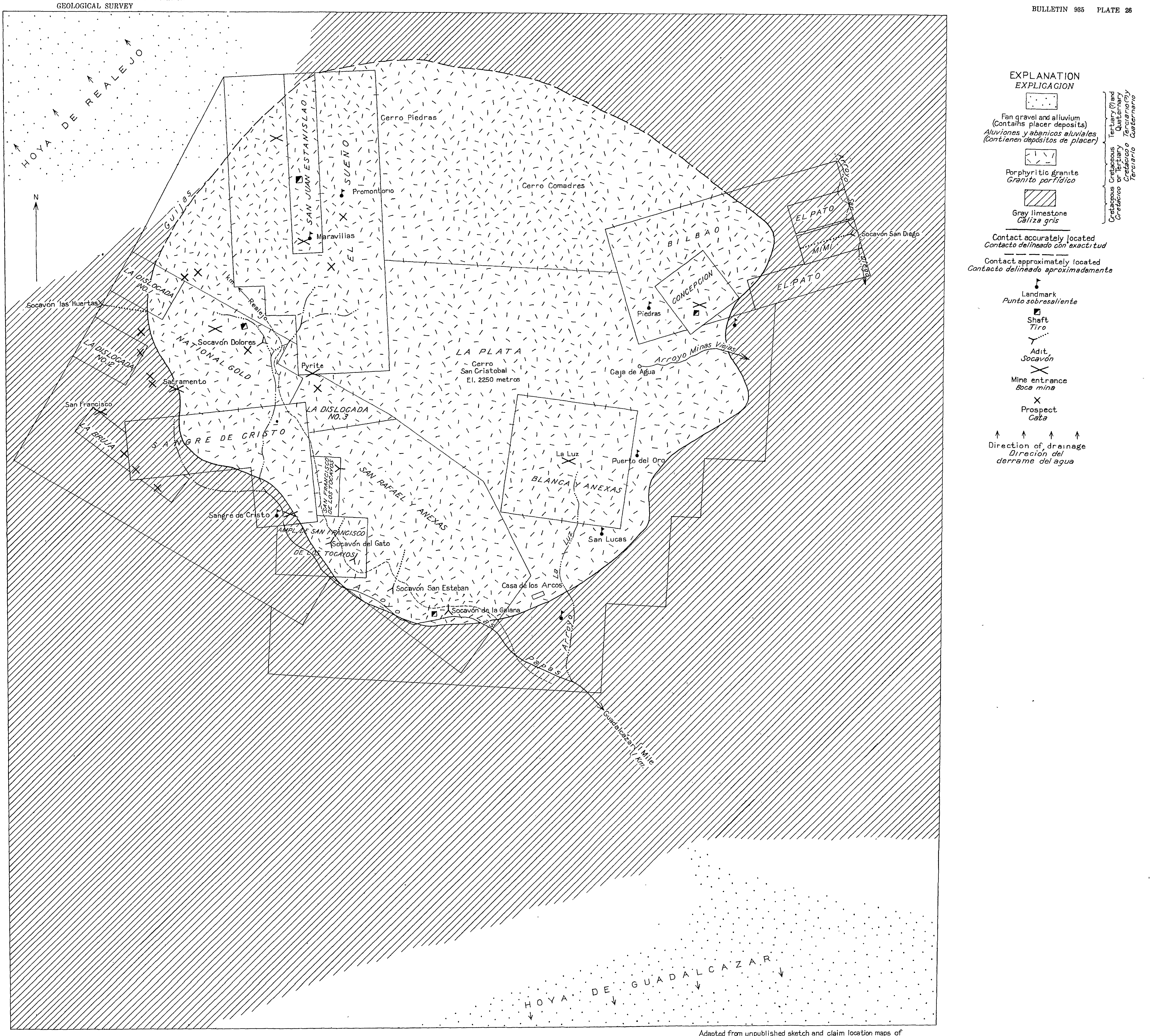
9/ Wittich, Ernesto, and Ragotzy, Federico, La geología de la región minera de Guadalcázar, San Luis Potosí: Bol. minero, vol. 12, p. 665, 1921.

thickness exceeds 1,500 feet (450 m.). In places along its contact with the granite, the limestone is partly marmorized and contains lime-bearing silicate minerals, such as diopside, andradite, epidote, and vesuvianite. Some of the silicate bodies contain sulfides of iron, lead, silver, copper, zinc, and antimony. The large mercury deposits at San Antonio and Trinidad, as well as some of the other sulfide deposits, are wholly within this limestone. The numerous caverns that have formed in the limestone in the upland areas and in the broad basins are due to the relatively high solubility of this rock.

Granite.--The granite is a light-gray rock, whose texture is variable, but most of which is porphyritic, with a medium- to fine-grained groundmass. The principal minerals are quartz and orthoclase, which occur both as phenocrysts and as smaller crystals in the groundmass. There are smaller quantities of biotite, sericite, muscovite, oligoclase, hornblende, and chlorite. A specimen from near the top of Cerro San Cristóbal (see pl. 26), apparently representative of the granite in that area, proved to contain a small quantity of microscopic grains of fluorite, zircon, hematite, apatite, epidote, tourmaline, garnet, topaz, brookite, cassiterite, scheelite, and molybdenite. A sample from the north side of Cerro Piedras contained, besides the common accessory minerals, a few grains of scheelite but apparently no cassiterite. Samples of granite taken at three places on the north side of Arroyo Las Papas between Casa de los Arcos and Socavón Dolores each contained cassiterite, and two also contained scheelite.

Tourmaline occurs in patches scattered through much of the granite and also with quartz in narrow veinlets cutting the granite. Ill-defined pegmatitic veinlets containing beryl, topaz, and dumortierite are present in some places, and Wittich reports that danburite and axinite have been found.[10/]

10/ Wittich, Ernesto, and Rogotzy, Federico, op. cit., p. 669.



GEOLOGIC SKETCH MAP OF THE GUADALCAZAR DISTRICT, SAN LUIS POTOSI

CROQUIS GEOLOGICO DEL DISTRITO DE GUADALCAZAR, SAN LUIS POTOSI

300 0 1500 Feet

100 0 500 Metros

Adapted from unpublished sketch and claim location maps of Cia de Minerales de Potosi, S.A., and Cia Metalurgica Mexicana.

Adaptado de un croquis y mapas inéditos de las pertenencias la Cia de Minerales de Potosí, S.A., y la Cia Metalúrgica Mexicana

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A small sample taken from one of these veinlets near Casa de los Arcos contained a few grains of cassiterite but no scheelite. Along the southern border of the granite, there are a few dikes of fine-grained aplite with patches of tourmaline, and a sample from one of these at the junction of Arroyo La Luz with Arroyo Las Papas contained cassiterite and scheelite. It thus appears that small quantities of cassiterite and scheelite are widely distributed as late accessory minerals of the granite.

The border zone of the granite, except along the northeast side, is a soft rock in which the feldspars are more or less completely altered to clays. Samples of this rock taken at four places contained small quantities of cinnabar. Most of the ore deposits mined are in this peripheral altered zone, as shown in plate 26, and contain gold and sulfides of iron, zinc, lead, silver, antimony, and copper. Fluorite and quartz form a large part of the gangue in these ores at some places. The lime-silicate minerals are abundant immediately adjacent to the limestone contact.

Fan deposits.--The deposits of gravel along the east, south, and northwest base of the Sierra de Guadalcázar were derived mainly from the limestone-granite contact zone. The exposed thickness of gravel in the walls of the arroyos that have dissected the deposits is about 70 feet (21 m.), but the maximum thickness is somewhat greater, for most of the arroyos have not cut down to the underlying limestone. The bedding in the deposits is indistinct in most places, and the observed dips are generally less than 10°.

The deposits are composed in large part of poorly cemented coarse sands with a reddish clay matrix. Owing to this reddish color, the dissected parts of the fans are known locally as tierras coloradas, or red ground. Texturally the material changes within short horizontal distances from sand to silt or from sand to fine-grained conglomerate. A section through 53 feet (16 m.), which is exposed along one of the arroyos and which is characteristic of the deposits, shows: Caliche-cemented coarse angular sand, 3 feet (0.9 m.); coarse angular sand, 2 feet (0.6 m.); brown bentonitic clay, 3 feet (0.9 m.); gray sand, 2 feet (0.6 m.); iron-cemented sand, 2 feet (0.6 m.); silty sand, 4 feet (1.2 m.); and coarse sand with small pebbles, interbedded with 6-inch (0.15-m.) lenses of brown soapy clay, 25 feet (7.6 m.). Beds of fine-grained gravel are most abundant near the heads of the fans and along their axes, where clay occurs only as part of the matrix rather than as separate beds. There are boulder beds in only a few places. Beds of bentonitic clay are most abundant and thickest along the lateral margins of the fans.

The deposits are almost wholly derived from the granite. They contain only a small proportion of limestone pebbles, even though the material was transported across the limestone. Erosion may have been slow enough to permit the limestone to be largely removed by solution, leaving only fine clays; or it is possible that some of the limestone pebbles, small in amount to begin with, may have been dissolved from the gravels after their deposition. Heavy minerals, to be described later, form between 0.5 and 1.0 percent of the material.

Secondary deposits of gravel.--Erosion of the fans has resulted in extensive dissection of parts of the deposits. A cover of from 1 to 5 feet (0.3 to 1.5 m.) of secondary gravel was left on top of the primary gravel at many places while the arroyo bottoms were being lowered, and the present beds of the arroyos generally contain 1 to 3 feet (0.3 to 0.9 m.) of the secondary gravel. This material differs from the primary gravel mainly in that the clay has been washed out, resulting in a greater concentration of the heavier and more resistant minerals. Limestone pebbles are more abundant in the gravel in the bottoms of the arroyos that now drain the limestone-granite contact zone than they are in the primary fan gravels.

Placers

Gold has been recovered on a small scale intermittently for many years from the secondary deposits of gravel in the bottoms of the arroyos in the fan gravels in the Guadalcázar basin. This work has been done entirely by individual miners, who pan the gravels by hand when water flows in the arroyos during the rainy season. So far as known, the grade of the primary fan gravels is too low for profitable mining. Some attempts have been made to distill mercury from the pan concentrates of the secondary gravels on a small scale.[11/] An examination of the heavy minerals proves that all the gravel deposits sampled contain mercury, tin, and tungsten; assays show small quantities of gold and silver.

Heavy minerals in the gravels.--Vertical channel samples of the primary gravels were taken by the authors from the walls of 10 arroyos that cut the fan deposits in the Guadalcázar and Realejo basins; none were taken in the Abrego basin. These samples ranged from 20 to 60 feet (6.6 to 20 m.) in length and averaged about 35 pounds (16 kg.) each in weight. After screening out the gravel larger than a quarter of an inch (0.6 cm.), the undersize was concentrated by hand-panning to a ratio of 1 part to 25. Rough pannings were also made of the secondary gravel from the beds of some of the arroyos. All these concentrates were separated in methylene iodide (sp. gr. 3.3), and the heavy minerals were identified by their optical or crystallographic properties. Qualitative results of the mineral studies, which are presented in table 4, show a wide distribution of the mercury, tin, and tungsten minerals.

11/ Wittich, Ernesto, Observaciones acerca de placeres de cinabrio y oro, encontrados en el Distrito de Guadalcázar, San Luis Potosí: Bol. minero, vol. 10, p. 256, 1920.

Table 4.--Heavy minerals 1/ in the gravel deposits in the Guadalacázar and Realejo basins 2/

	G1	G2	G3	G4	G5	G6	G7	G8	G13	MG7	G9	G11	G15	MG6	MG8	MG10	MG11	161	162	163	164	165	166
Anatase	..	..	..	..	R	R	R	..	R	...	R	R	...	...	...	....	R	...	R	R	R	R	R
Andradite	X	..	..	X	X	X	..	X	...	X	X	X	...	X	X	X	....	X	...	X	...	...	...
Anglesite	..	..	..	..	..	..	..	..	...	...	..	...	...	...	...	....	....	...	...	R	...	R	...
Bindheimite	..	..	..	..	..	..	..	..	...	...	..	...	...	...	R	....	....	...	...	...	...	R	...
Brookite	..	..	R	R	R	R	R	R	R	...	R	R	R	...	...	....	R	...	...	...	...	...	R
Cassiterite	R	R	R	R	R	R	R	R	R	X	R	R	R	R	R	R	R	R	R	R	R	R	R
Chalcopyrite	..	..	..	..	..	..	..	..	...	...	..	...	...	...	R	....	....	...	...	...	...	...	...
Cinnabar	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R
Corundum	..	..	..	..	..	..	..	..	R	...	..	...	R	...	...	....	....	...	...	...	...	...	...
Diopside	..	..	..	..	..	..	..	..	...	...	..	R	...	...	...	....	....	...	...	...	...	...	...
Epidote	X	..	..	X	X	X	X	X	...	X	X	X	...	X	X	....	....	R	R	R	R	X	R
Galena	..	..	..	..	..	..	..	..	...	...	..	X	...	...	X	....	....	...	...	R	...	...	...
Grossularite	X	..	X	X	..	..	X	..	...	X	..	...	...	...	X	....	....	...	...	X	X	X	X
Hematite (specularite)	X	X	X	X	X	X	..	..	...	...	..	X	X	X	...	X	X	X	X	...	X	X	X
Ilmenite	R	..	..	..	R	..	..	..	R	...	R	...	R	...	...	....	R	...	...	...	...	...	...
Limonite (some goethite)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Magnetite	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Malachite	..	..	..	..	..	..	..	..	...	...	..	...	...	...	...	....	....	...	...	...	R	...	...
Manganese oxides	..	X	X	..	X	..	X	..	...	...	X	X	...	X	...	....	....	...	...	...	...	...	...
Mimetite	..	..	..	..	..	..	..	..	...	...	..	...	...	X	X	....	....	...	...	...	...	...	...
Powellite	..	..	..	..	..	R	..	..	...	...	..	...	...	R	R	....	....	...	...	...	...	...	...
Pyrite	..	..	..	X	..	..	..	..	...	...	..	X	...	...	X	X	....	X	X	X	X	X	X
Rutile	..	..	..	..	..	..	..	R	...	...	R	R	...	...	...	....	....	...	...	...	...	...	...
Scheelite	..	..	..	..	..	..	..	..	...	...	..	...	...	R	R	R	....	...	...	...	R	...	...
Siderite	..	..	..	..	..	..	..	..	...	...	..	...	...	...	...	....	....	...	...	...	...	R	...
Sphalerite	..	..	..	..	..	..	..	..	...	...	..	...	...	...	...	....	....	...	...	...	...	R	...
Spinel	..	..	..	..	..	..	..	..	...	R	..	...	...	...	...	R	....	...	...	...	R	...	R
Svabite	..	..	..	..	..	..	..	..	...	...	..	...	...	...	...	R	....	...	...	...	...	...	...
Titanite	R	..	..	R	..	..	R	R	...	...	..	...	...	...	...	....	....	...	...	...	...	...	...
Topaz	X	X	X	X	X	X	X	X	R	X	R	R	R	X	R	X	X	X	X	X	X	R	X
Vesuvianite	..	..	..	..	..	..	..	..	...	...	..	R	...	...	...	R	....	R	R	X	X	...	R
Wolframite	..	..	..	..	R	..	..	..	...	...	..	...	...	...	...	R	....	R	R	...	R	...	R
Xenotime	..	..	..	..	..	..	..	..	...	...	..	...	...	...	...	....	....	R	...	...	...	...	...
Zircon	X	X	X	R	X	X	R	X	X	X	X	X	X	R	R	X	X	X	X	X	R	R	X

G1	Arroyo Cieneguilla; 60-foot (18.3-m.) vertical channel sample of primary fan gravel.
G2	Arroyo Soldado; 40-foot (12.2-m.) vertical channel sample of primary fan gravel.
G3	Arroyo Difunta; 22-foot (6.7-m.) vertical channel sample of primary fan gravel.
G4	Arroyo Papas; 20-foot (6.1-m.) vertical channel sample of primary fan gravel.
G5	Arroyo Pinal; 45-foot (13.7-m.) vertical channel sample of primary fan gravel.
G6	Arroyo Roble; 20-foot (6.1-m.) vertical channel sample of primary fan gravel.
G7	Arroyo Escondido; 45-foot (13.7-m.) vertical channel sample of primary fan gravel.
G8	Arroyo Profundidad; 45-foot (13.7-m.) vertical channel sample of primary fan gravel.
G13	Arroyo Santa Elena; 20-foot (6.1-m.) vertical channel sample of primary fan gravel.
MG7	Arroyo Santa Elena; 15-foot (4.6-m.) vertical channel sample of primary fan gravel.
G9	Secondary gravel on low bench at north edge of town of Guadalcázar.
G11	Secondary gravel from bed of Arroyo Santa Elena.
G15	Do.
MG6	Secondary gravel from bed of Arroyo Minas Viejas at junction with Arroyo San Diego.
MG8	Secondary gravel from bed of Arroyo Dolores.
MG10	Secondary gravel from Guadalcázar basin just south of village cemetery.
MG11	Secondary gravel from Guadalcázar basin along ridge just south of village cemetery.
161	Secondary gravel from bed of Arroyo Cieneguilla.
162	Secondary gravel from bed of Arroyo Sangría.
163	Secondary gravel from bed of Arroyo Difunta.
164	Secondary gravel from bed of Arroyo Las Papas.
165	Do.
166	Secondary gravel from beds of Arroyos Pinal and Roble.

1/ Heavy minerals are those with a specific gravity greater than 3.3.

2/ The letter R in the table signifies that the mineral is rare in the gravel; the letter X signifies a small to moderate quantity of the mineral in the gravel.

The mineral cassiterite, which occurs mainly in small crystals and crystal fragments but also in sparse fragments of banded wood tin, appears to be the only tin-bearing mineral present. The color of the cassiterite ranges from red to yellow to dark brown or nearly black. The mercury is in the mineral cinnabar, which occurs as rounded bright- to dull-red crystal fragments. The tungsten-bearing minerals are wolframite and scheelite, the former occurring as shiny black rectangular and platy crystal fragments and the latter as white to cream-colored grains with greasy luster. The wolframite in the concentrates is similar in appearance to the specularite. The gold forms small warty grains. No silver minerals have been recognized, but some of the silver shown by assays may be in the galena, which occurs as subrounded grains partly incrusted with white anglesite.

Grade of the deposits.--Rather detailed studies of the quantities of tin, mercury, gold, and silver in parts of the gravel deposits were made by the Cia. Minera de Peñoles, S. A., in 1938, and by the Cia. Minera de Guadalcázar, S. A., in 1940 and 1941, and tests were being conducted by the San Luis Mining Co. in December 1941. The studies by these companies and by the authors show that the primary fan gravels north of the town of Guadalcázar contain from 0.005 to 0.03 percent tin and between 0.0008 and 0.04 percent mercury; they also contain from 0.0006 to 0.003 ounce (0.017 to 0.085 gm.) of gold and about 0.2 ounce (5.7 gm.) of silver per metric ton. About 40 percent of the gold and silver, 35 percent of the mercury, and 30 percent of the tin appear to be in the fines, which form about 20 percent of these primary gravels. No quantitative tests for tungsten have been made.

Rough channel samples of the primary fan gravels taken by the authors indicate that the gravels in the Realejo basin contain more tin and mercury than those in the Guadalcázar basin.

Preliminary tests indicate that the secondary gravels in the beds of the arroyos contain appreciably larger quantities of the metals than the primary fan gravels.

Possible production.--The total amount of alluvial material in the Guadalcázar and Realejo basins may be more than 75,000,000 tons, of which all but a few million tons are in the Guadalcázar basin. It is doubtful whether, at 1941 prices, the valuable metals--tin, mercury, gold, and silver--could be extracted at a profit from the primary gravels in the Guadalcázar basin, not only because of the low grade of this placer material but also because too great a percentage of the metals are in the fines. However, the primary gravels of the Realejo basin seem to be of a somewhat better grade.

The secondary gravels, which are confined mainly to the Guadalcázar basin, appear to contain enough of the metals for profitable mining, and their volume is moderately large. Although these deposits have not been sampled in detail, it is believed that they are well worth testing.

It is probable that enough water for placer mining could easily be obtained by pumping, since wells in the Guadalcázar basin reach the water table 15 to 30 feet (4 to 10 m.) below the surface.

Deposits associated with lead-zinc-silver ores

Deposits associated with lead-zinc-silver ores are known to occur in only one district in Mexico, and only in a part of a single mine--the San Antonio mine at Santa Eulalia, 12 miles (20 km.) east of the city of Chihuahua. Tin was first discovered in milling and smelting some of the ore in 1926. A process was devised for recovering the tin, and by 1939 about 3,000 tons of tin had been produced, which is about half of Mexico's total production. No tin has been recovered from the mine since 1939, the tin ore having then apparently been exhausted, although the other metals are still being produced. The authors did not examine the deposit.

The dominant rocks in the region, according to Prescott,12/ are Cretaceous limestones, which are overlain by beds of Tertiary clastic and volcanic rocks. Sills of diabase and a larger intrusive mass of diorite have been discovered in the mine workings in recent years. All the formations are cut by dikes of light-colored fine-grained aplitic rock, called "rhyolite", and of a dark-colored dioritic rock, called "andesite". One of the largest of the "rhyolite" dikes is exposed in the San Antonio mine. The lead-zinc-silver ores are described by Prescott as replacement deposits in the limestone. They consist largely of pyrite, pyrrhotite, galena, sphalerite, and iron-lime-silicate minerals. No description of the exact mode of occurrence of the tin has been published so far as known.

In 1927 Foshag collected from the ore pile specimens of rock similar in appearance to the "rhyolite" dikes; these specimens consisted of porous quartzose rock containing small crystals of brown cassiterite and black specularite. The cassiterite may, however, be more closely related to the lead-zinc ores than to the dikes. In the Sullivan mine, at Kimberly, British Columbia, according to Schwartz,13/ cassiterite occurs in a lead-zinc-silver deposit very similar to the Santa Eulalia deposit and is closely associated with the sulfide ores.

Deposits associated with extrusive rocks

Most of the tin deposits of Mexico are in extrusive rocks. About half the total production of tin in Mexico has come from these deposits and from placers associated with them. As the general features described in the introductory section of this report refer mainly to deposits in extrusive rocks, it will not

12/ Prescott, Basil, The main mineral zone of the Santa Eulalia district, Chihuahua: Am. Inst. Min. Eng. Trans., vol. 51, pp. 57-99, 1916.
13/ Schwartz, G. M., Microscopic features of Sullivan ore: Eng. and Min. Jour., vol. 122, pp. 375-377, 1926.

be necessary to describe them here. These deposits appear to form a unique type. Two districts in the United States in which deposits of this type are known have recently been described by Fries. One of these is in southwestern New Mexico,[14] the other in northern Lander County, Nevada.[15] Apparently no other such deposits have been described, though some specimens received by Lindgren from Bolivia suggested to him that similar deposits may occur in acidic lavas there.[16]

Geology

The volcanic rocks that contain the tin deposits of the 18 districts that have been investigated in the States of Michoacán, Guanajuato, San Luis Potosí, Aguascalientes, Zacatecas, and Durango are predominantly rhyolitic. In the Jaula district, in Guanajuato, the veins are in latite, and at El Santín mine in the same State they are in andesite, but in both localities these rocks are overlain by rhyolite. Throughout the plateau, particularly along its west side and in its northern part, the rhyolitic lava flows are interbedded with volcanic breccia and tuff. The pyroclastics are not abundant, however, in the tin districts. Most of the tin-bearing veins are in the lava flows; a few are in breccia; none of those examined are in rocks clearly identified as tuff. The age of the rhyolitic rocks, according to Ordoñez,[17] probably ranges from Miocene to Pliocene, thus being about the same as that of the tin-bearing rhyolite in New Mexico and Nevada.

14/ Fries, Carl, Jr., Tin deposits of the Black Range, Catron and Sierra Counties, N. M., a preliminary report: U. S. Geol. Survey Bull. 922-M, pp. 355-370, 1940.

15/ Fries, Carl, Jr., Tin deposits of northern Lander County, Nev.: U. S. Geol. Survey Bull. 931-L, pp. 279-294, 1942.

16/ Lindgren, Waldemar, Mineral deposits, 4th ed., p. 659, New York, McGraw-Hill Book Co., 1933.

17/ Ordoñez, Ezequiel, Las rhyolitas de México: México Inst. geol. Bol., No. 14, pp. 66-67, 1900.

The rhyolite flows are in general distinctly layered. The layers are nearly horizontal in most of the places where the lavas are interbedded with pyroclastic rocks, but in the vicinity of the tin-bearing veins this attitude is the exception rather than the rule. There the layers generally have irregular strikes and steep dips, which change markedly within short distances. No attempts were made to interpret in detail the meaning of this confused structure, but in most places it was clearly a result of original flow rather than of later tectonic movements. This peculiar structure and the relative scarcity of pyroclastic rocks suggest that the tin-bearing areas are near the centers of eruption of the lavas.

The rhyolite is reddish brown to light gray or white; the latite and andesite are dark reddish brown. Lithophysae, vugs, and cavities of all shapes are abundant in some parts of all the flows. The rocks are generally lighter in color around the cavities than in the rest of the groundmass, apparently owing to coarser crystallization; some of the rocks consequently have a spotted or mottled appearance. In all the tin districts the tin-bearing rocks are porphyritic, and their groundmasses are completely devitrified, finely crystalline, and more or less spherulitic. The phenocrysts, which make up from about 5 to nearly 30 percent of the rocks examined, are largely sanidine and quartz, but most of the flows also contain a few percent of plagioclase phenocrysts, ranging in composition from calcic albite to sodic andesine in different flows. In general the flows contain less than 1 percent biotite or hornblende, or both, now mostly altered to hematite, quartz, and feldspar. Most of the alteration apparently occurred just before and during the crystallization of the groundmass. The phenocrysts in the andesite are chiefly calcic andesine or sodic labradorite, and less than 2 percent of them are biotite and pyroxene. A brief description of the rocks in each of 15 of the districts visited is given in table 5.

The fine-grained groundmass of most of the rhyolite flows is composed largely of sanidine and quartz, but in some of the flows the silica forms tridymite and cristobalite, which may or may not be accompanied by quartz. A fine dust of hematite and tiny crystals of specularite form a small part of the groundmass. Magnetite is scarce in most of the rocks. In most of the rhyolites the only nonopaque microscopic accessory mineral is zircon, but the andesite and latite contain both zircon and apatite. The most abundant mineral in the lithophysae and cavities of the rhyolitic lavas is quartz, but lithophysal tridymite is abundant in some of the flows and opal and chalcedony in others. Small quantities of lithophysal sanidine, specularite, topaz, pseudobrookite, cristobalite, zeolites, and fluorite also occur in parts of some flows.

Overlying the tin-bearing formations are lava flows and pyroclastic rocks ranging in composition from rhyolite to basalt. The most recent of these are largely basalt. Still more recent deposits consist of fan gravels, which lap against and surround the ridges and ranges of volcanic rocks that rise above the general level of the plateau. Many of these deposits of detritus have been deeply dissected by arroyos, in which secondary deposits of gravel have been formed. Some of the gravel deposits contain placer tin near the veins.

The lavas and pyroclastic beds of the Mexican plateau country are for the most part nearly horizontal. None of these late volcanic rocks are known to be folded, although they appear to be gently tilted in places. Many of the lava-capped ridges and ranges undoubtedly owe their elevation to normal faulting, but no important faults were observed close to any of the tin deposits.

Vein deposits

Occurrence.--The tin-bearing veins are largely incrustations on the walls of narrow open fissures, and they appear to occur mainly in the more open parts of the fissures. These fissures are in most places extremely irregular in strike and dip and pass within short distances into tight joints. In some places they branch at various angles and connect with other parallel or diverging fissures. Most of the veins are less than 50 feet (15 m.) in length, a few of those examined are as much as 200 or 300 feet (60 or 90 m.) long, and one vein appears to be continuous for about 1,000 feet (300 m.) on the surface. The majority of the deposits have been mined to depths of from 20 to 50 feet (6 to 15 m.), where the vein material seems to pinch out. The deepest exploration known extends about 300 feet (90 m.) from the surface. The thickness of the vein material varies along the fissures and is generally less than half an inch (1.3 cm.), but some bodies as thick as 10 inches (25 cm.) have been mined. These thicker bodies, which have the form of small lenses or pockets, are locally enlarged parts of the veins, but, as the fissures leading to some of them are very obscure, they have been mistakenly regarded as local segregations from the lavas. In places the incrustations follow branching and reticulating fissures and form lodes from 1 to 5 feet (0.3 to 1.5 m.) wide. The length of these lodes appears to be generally less than 20 feet (6 m.) and the depth about the same.

The vein minerals were deposited for the most part in open fissures, but they occur locally in the wall rocks of all the deposits, filling cavities and tiny openings or replacing the wall rock to a slight extent. No large bodies of rock have been found through which the vein minerals are uniformly disseminated, and all dissemination of these minerals appears to be limited to the immediate vicinity of the small tin-bearing fissures, ordinarily extending only an inch or two (2.5 to 5 cm.)

Table 5.--Mineral composition of the rocks and tin veins in some of the tin districts of Mexico 1/

Locality (Numbers refer to numbers in text and on pl. 25.)	Rock name	Rock description	Phenocrysts		Minerals in groundmass 2/	Microscopic accessory minerals	Minerals in vugs and lithophysae 1/	Minerals in the veins 1/	Alteration 3/
			Percent	Minerals (In order of abundance)					
1. Los Cabires mine, Tepuxtepec, Michoacán.	Porphyritic rhyolite.	Reddish brown to light gray; in places spotted, vuggy, lithophysal; largely well layered; coarsely porphyritic; spherulitic; lava flows.	15	Sanidine Quartz Oligoclase Biotite (Hydrobiotite)	Sanidine Quartz Tridymite Cristobalite Hematite	Zircon	Specularite Tridymite Topaz Quartz Chalcedony Opal	Magnetite Specularite Cassiterite Cristobalite Tridymite Quartz Opal Montmorillonite	In places highly porous; contains zeolites and minor quantities of clay minerals; phenocrysts unaltered.
2. Tin deposit 15 miles (24 km.) west of Dolores Hidalgo, on road to Guanajuato, Gto.	....do.....	Reddish brown to light gray; in places vuggy and lithophysal; in part well flow-layered; porphyritic; highly spherulitic in part; lava flows.	10	Quartz Sanidine Hornblende?	Sanidine Quartz Hematite	....do.....	Specularite Tridymite Quartz Chalcedony Opal	Magnetite Specularite Cassiterite Cristobalite Tridymite Quartz Mimetite Opal Zeolites Montmorillonite	In places highly porous; contains some zeolites and minor quantities of clay minerals; phenocrysts unaltered.
3. Tin deposits 2 miles (3 km.) east of Tlachiquera, between San Felipe and León, Gto.	....do.....	Reddish brown to light gray; in places spotted, vuggy, lithophysal; moderately well layered; coarsely porphyritic; lava flows.	25	Sanidine Quartz Oligoclase Biotite?	Sanidine Quartz Hematite Tridymite?	....do.....	Specularite Topaz Tridymite Quartz Chalcedony Opal	Magnetite Specularite Cassiterite Cristobalite Tridymite Chalcedony Quartz Opal Clays	In places somewhat porous; rock generally fresh.
4. Tin deposits in Cerro del Toro, northwest of Tlachiquera, between San Felipe and León, Gto.	....do.....	Light reddish brown to light gray; in places vuggy and lithophysal; porphyritic, with some spherulites in the crystalline groundmass; flow-layered; lava flows.	10	Quartz Sanidine Albite Biotite	Quartz Sanidine Hematite Tridymite?	....do.....	Specularite Tridymite Quartz Chalcedony Opal	Magnetite Specularite Cassiterite Clays	In places plagioclase altered to a mixture of quartz and clays; sanidine fresh; rock somewhat porous near some veins.
5. Tin deposits 10 miles (16 km.) north of San Felipe, Gto.	....do.....	Reddish brown to light gray; in part vuggy and lithophysal; moderately coarse porphyry; groundmass crystalline, with spherulites; in part well flow-layered; lava flows.	20	Sanidine Quartz Biotite? or hornblende?	Sanidine Quartz Tridymite Hematite	....do.....	Specularite Pseudobrookite Topaz Tridymite Quartz Sanidine	Magnetite Specularite Cassiterite Topaz Cristobalite Tridymite Quartz Huebnerite? Chalcedony Opal Clays	Wall rock porous in places; groundmass contains some clays; along one vein there was brecciation and recementation with opal and chalcedony; feldspars fresh.
6. Queensland mine near Santa Bárbara, northwest of San Felipe, Gto.	....do.....	Reddish brown to light gray; in part vuggy and lithophysal; moderately coarse porphyry, with some spherulites in finely crystalline groundmass; in part well layered; lava flows.	20	Sanidine Quartz Biotite? or hornblende?	Sanidine Quartz Tridymite Hematite	....do.....	Specularite Pseudobrookite Sanidine Tridymite Quartz	Magnetite Specularite Cassiterite Tridymite Quartz Chalcedony Opal Clays	Rock generally dense and firm near veins, but in a few places porous; some clays in groundmass; phenocrysts not altered.
7. El Santín mine near Santa Catarina, southeast of San Luis de la Paz, Gto.	Porphyritic andesite.	Dark reddish brown to dark gray; in part vuggy; porphyritic, with some spherulites in finely crystalline groundmass; in places spotted; in part well layered; lava flows.	15	Calcic andesine Biotite Pyroxene	Plagioclase Sanidine Hematite	Apatite Zircon	Specularite Tridymite Quartz Others not determined.	Magnetite Specularite Cassiterite Tridymite Quartz Zeolites Opal Montmorillonite	In places plagioclase phenocrysts altered to clays; in some zones feldspars in groundmass strongly altered; alteration not along all veins; zeolites present in places.
8. Tin deposits on Hacienda Sauceda, about 25 miles (40 km.) north of San Luis de la Paz, Gto.	Porphyritic rhyolite.	Reddish brown to light gray; in part vuggy and lithophysal; moderately coarse phenocrysts; some spherulites in finely crystalline groundmass; well flow-layered, lava flows.	15	Quartz Sanidine Biotite	Sanidine Tridymite Quartz Hematite	Zircon	Specularite Topaz Tridymite Quartz Chalcedony Opal	Magnetite Specularite Cassiterite Tridymite Quartz Opal Chalcedony	Rock somewhat porous near some veins; apparently some clays in groundmass; phenocrysts unaltered.
9. Tin deposits on road from San Luis Potosí to San Luis de la Paz, between Santa Domingo, S. L. P., and Jaula, Gto.	Porphyritic latite.	Light brown; in part vuggy; finely porphyritic; well layered; probably lava flow.	10	Andesine Sanidine Biotite	Sanidine Plagioclase Hematite	Apatite Zircon	Specularite Quartz Chalcedony Opal	Magnetite Specularite Cassiterite Chalcedony Quartz Opal Montmorillonite	Some phenocrysts largely altered to kaolinite; some biotite altered in part to chlorite; montmorillonite and other clays, possibly some zeolites, in groundmass.
10. Tin deposits 10 miles (16 km.) southwest of Calvillo, Aguascalientes.	Porphyritic rhyolite.	Reddish brown to light gray; in part vuggy and lithophysal; porphyritic, with some spherulites in groundmass; in part well flow-layered; lava flows.	15	Sanidine Quartz Albite Hydrobiotite	Sanidine Quartz Hematite	Zircon	Not determined.	Magnetite Specularite Cassiterite Chalcedony Quartz Opal	Rock along some veins highly porous; along other veins there has been slight brecciation and recementation with chalcedony and opal; apparently some clays in groundmass of porous rock.
11. Tin deposits at La Quemada Indian ruins, about 40 miles (64 km.) southwest of the city of Zacatecas.	....do.....	Reddish brown to light gray; in places vuggy and lithophysal; fine-grained porphyry, with some spherulites in crystalline groundmass; well flow-layered; lava flows.	10	Sanidine Quartz Biotite?	Sanidine Quartz	....do.....	Specularite Tridymite Quartz	Magnetite Specularite Cassiterite Tridymite Quartz Chalcedony Opal	None observed; phenocrysts entirely fresh.
12. Tin deposits 25 miles (40 km.) northwest of Fresnillo, Zacatecas.	....do.....	Reddish brown to light gray; in part vuggy and lithophysal; porphyritic, with some spherulites in groundmass; in part well flow-layered; lava flows.	10	Sanidine Quartz Biotite	Sanidine Quartz Hematite	....do.....	Specularite Topaz Quartz	Magnetite Specularite Cassiterite Quartz Chalcedony Opal	Rock along some veins porous; possibly some clays in groundmass; phenocrysts unaltered.
13. Cerro de los Remedios at the city of Durango.	....do.....	Reddish brown to light gray; in places vuggy and lithophysal; fine-grained porphyry, with spherulites; in part well flow-layered and in part flow breccia; mainly lava flows.	10	Sanidine Quartz Oligoclase Biotite	Sanidine Quartz Hematite	....do.....	Specularite Pseudobrookite Topaz Sanidine Tridymite Quartz Chalcedony Opal Fluorite	Magnetite Specularite Cassiterite Sanidine Cristobalite Tridymite Quartz Chalcedony Opal Fluorite Montmorillonite	Rock porous in places; along one vein some phenocrysts partly altered to clay; clays in groundmass in some places; some tridymite inverted to quartz; some sanidine in the veins altered to clays; fluorite in groundmass; in most places all phenocrysts unaltered.
14. Cacaria district northwest of city of Durango; rocks from El Diablo and Las Auras mines.	....do.....	Reddish brown to light gray; in places vuggy and lithophysal; moderately coarse porphyry; groundmass spherulitic in places; generally well layered; lava flows.	15	Sanidine Quartz Hydrobiotite	Sanidine Quartz Hematite	....do.....	Not determined.	Magnetite Specularite Cassiterite Cristobalite Tridymite Chalcedony Opal Mimetite Montmorillonite	Rock generally dense and firm, but porous in a few places along veins; in places groundmass contains clays; phenocrysts in wall rock along veins generally unaltered.
15. Potrillos district in Sierra de San Francisco, Durango.	....do.....	Reddish brown to light gray; in places highly vuggy and lithophysal, in other places dense and firm; generally a very fine-grained porphyry; in places well layered; appears to be mainly lava flows.	5	Sanidine Quartz Biotite Hornblende	Sanidine Quartz Hematite	....do.....	Specularite Pseudobrookite Topaz Sanidine Tridymite Quartz Chalcedony Opal Zeolites Fluorite	Magnetite Specularite Cassiterite Topaz Sanidine Cristobalite Durangite Tridymite Chalcedony Opal Zeolites Fluorite Clays	Rock generally dense and firm, but highly porous in some places; where porous, rock contains zeolites, fluorite, and clay minerals; phenocrysts generally unaltered.

1/ The minerals listed are only those actually found during a brief examination of the deposits, and it should not be assumed that all the lists are complete.
2/ Owing to the extremely small size and the intergrowth of the minerals in the groundmass, it is not possible to identify all the minerals by ordinary methods. There may be a much wider distribution of cristobalite and tridymite than is indicated. A small quantity of magnetite occurs in most of the rocks.
3/ There is also a small quantity of limonite in many places, most of it apparently supergene.

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on either side of the fissure. In a few places where two fissures containing vein material were separated by only a few inches of wall rock, all this rock was found to be impregnated with small quantities of the vein minerals.

There has been minor faulting along at least one of the tin-bearing fissures in each district visited, but none of the veins examined appear to be on major faults. Possibly, however, all the tin-bearing fissures may be related to extremely small faults. In a few places the rocks are sheeted, but in general adjacent blocks are not relatively displaced by more than a small fraction of an inch (less than a centimeter). In one place a slickensided wall incrusted with vein minerals was found, indicating that movement preceded mineralization; in other places crushed vein material gives evidence of slight movement after mineralization.

Mineralogy and paragenesis.--The veins consist of incrustations that are composed for the most part of specularite and cassiterite. Specularite is generally more abundant than cassiterite. These are the only minerals in parts of many veins; other parts of the same veins contain cristobalite, tridymite, quartz, chalcedony, and opal, usually in small quantity, though the last two are abundant locally. Other vein minerals include magnetite, sanidine, topaz, fluorite, zeolites, montmorillonite and other clay minerals, calcite, and limonite. Mimetite has been found in three localities, and the rare mineral durangite has been found in one. Wolframite has been reported to occur in some of the veins in Durango, but the report has not been verified. A few tiny crystals collected by the authors from one locality in Guanajuato have the optical properties of huebnerite, but not enough material was found for chemical tests. The identity of two other minerals collected by the authors is unknown, owing to the extremely small quantities found, but one appears to be closely related to mimetite, the lead chloro-arsenate. Pyrite and other sulfide minerals are completely lacking.

The cassiterite occurs in small, well-formed crystals and in botryoidal, banded masses known as wood tin and called riñones (kidneys) or guijilos (little pebbles) by the local miners. Both varieties are harder than a knife blade and have a specific gravity close to 6.5. The color of the crystals is generally bright red, but some are orange, greenish yellow, smoky, or brown. The banded wood tin varies in color from place to place in the same vein and also from layer to layer in a single piece; the colors range from nearly white through all shades of yellow, greenish yellow, and reddish brown to nearly black. Both varieties of cassiterite occur in all the veins, but the wood tin is much the more common. Both varieties incrust and are intimately intergrown with the specularite and have in places replaced it pseudomorphously. This association of the two minerals is so close that they cannot be separated completely by crushing as fine as 200 mesh--probably not even at 500 mesh.

Published chemical analyses, most of which are presented in table 6, show that small quantities of copper, lead, zinc, antimony, bismuth, or arsenic occur in the deposits; very little sulfur is reported in four analyses. Spectrograms of concentrates of samples collected by the authors from five tin districts were made by George Steiger in the laboratories of the Geological Survey. The elements thus looked for were: Lead, zinc, antimony, bismuth, silver, beryllium, arsenic, boron, tungsten, and germanium. All the samples contained one or more of all these elements except tungsten and germanium, neither of which was found. Qualitative chemical tests showed small quantities, also, of manganese and titanium in all the samples. The only separate mineral recognized in which one of the minor metallic elements found in the deposits forms an essential part was mimetite. It is possible that the metals occur in submicroscopic mineral grains in the vein material, or some of them may replace the iron in specularite. None of them form sulfides, for the quantity of sulfur in the veins is negligible. Some may form rare arsenic minerals, enclosed in the wood tin, as suggested by Genth [18] in his description of cassiterite from Durango.

The specularite, magnetite, cassiterite, topaz, sanidine, cristobalite, tridymite, and some of the quartz in the incrustations appear to have been deposited at nearly the same time. The specularite and magnetite were in general deposited first, and the cassiterite next, but at one place both specularite and cassiterite deposited on cristobalite were found. Some of the specularite seems to have been deposited after some of the cassiterite. Some crystals of cassiterite are coated with a film of wood tin, but some of the fibrous wood tin is encrusted with small crystals of cassiterite. The other minerals enumerated above are intergrown with or deposited on the specularite and cassiterite. The mimetite, durangite, opal, chalcedony, zeolites, fluorite, clay minerals, calcite, limonite, and some of the quartz are all clearly later than the other vein minerals. In a few places the vein material has been brecciated and recemented with opal or chalcedony, some of which, together with some of the clay minerals and of the calcite and limonite, may be supergene (deposited by descending surface water). None of the cassiterite is supergene, so far as could be determined.

Alteration.--The country rock close to many of the tin veins is more or less altered, the most strongly altered rock observed being the andesite adjacent to some of the veins at the El Santin mine, in Guanajuato; but in a few places it is no different from any of the surrounding lava. Although much of the rhyolite is highly vesicular, indicating that it contained large quantities of gases when extruded, its porosity is in general espe-

18/ Genth, F. A., Contributions to mineralogy: Am. Philos. Soc. Proc., vol. 24, pp. 30-31, 1887.

Table 6.--Chemical analyses of vein material, cassiterite, and bars of smelted tin

	1	2								3	4	5	6	7
		a	b	c	d	e	f	g	h					
Sn	91.61	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Pb	.04	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	None	.....	Trace
W	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	None	.....	.....
Cu	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Trace	Trace	.....
Fe	.02	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Bi	.03	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	None	.....	.....
As	Trace	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Sb	8.30	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Trace	.....	.....
SnO_2	.....	23.160	92.84	93.98	92.09	86.90	92.26	84.25	92.50	21.75	92.26	82.99	91.38	67.96
PbO	.....	9.680	.....	.....	.....	.....	.....	.....	.....	.88	.....	.....	.....	.....
CuO	.....	.195	Trace	None	None	.05	Trace	Trace	.16	None	Trace	.....	.....	.....
ZnO	.....	3.940	None	None	None	None	.57	3.01	1.89	1.13	.57	.....	.....	.....
MgO	.....	.200	.....	.....	.....	.....	.....	.....	.....	.32	.....	.10	.....	.....
CaO	.....	2.120	.....	.....	.....	.....	.....	.....	.....	.21	.....	.45	.....	.....
Fe_2O_3	.....	7.900	4.12	5.62	5.45	12.15	4.58	1.43	.22	32.80	4.50	8.40	5.29	.....
Al_2O_3	.....	10.838	.....	.....	.....	.....	.....	.....	.....	2.72	.....	1.48	.....	.....
SiO_2	.....	11.875	2.70	.23	.66	.55	.44	.33	.24	37.08	.44	5.70	1.08	.....
Sb_2O_3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.13	2.16
Sb_2O_5	.....	1.303	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Bi_2O_3	.....	5.190	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.01
As_2O_5	.....	16.134	Trace	None	2.11	Trace	1.25	10.10	4.56	.....	.....	.03	.....	.83
As_2S_3 (?)	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.25	.....	.....	.....
H_2O	.....	7.320	.34	.24	.07	.27	.26	.48	.26	1.84	.....	.....	.....	.....
P_2O_5	.....	.075	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
SO_3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.10	.....	.49	.....	.18
Cl	.....	.070	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	100.00	100.000	100.00	100.07	100.38	99.92	99.36	99.60	99.83	99.83	99.02	99.64	97.88	71.14

1. Average of two analyses of 25 tons of tin metal smelted in the Sierra de San Francisco, Durango. Analyst, Gideon E. Moore, New York. Ingalls, W. R., The tin deposits of Durango, Mexico: Am. Inst. Min. Eng. Trans., vol. 25, p. 155, 1896.

2. Genth, F. A., Contributions to mineralogy: Am. Philos. Soc. Proc., vol. 24, pp. 25-29, 1887. Analyst, F. A. Genth, University of Pennsylvania.

a. Vein material containing cassiterite, specularite, mimetite, and yellowish earthy material from Mina del Diablo, Cacaria district, Durango.
b. Bright-red fibrous crystalline cassiterite from Durango.
c. Red wood tin from Coneto district, Durango.
d. Dark reddish-brown fibrous cassiterite from Coneto district, Durango.
e. Average of two analyses of bright-red finely crystalline cassiterite from Mina del Diablo, Cacaria district, Durango.
f. Dark reddish-brown wood tin from Guanajuato, Guanajuato.
g. Average of three samples of yellowish fibrous wood tin from Mina Varosa, Durango.
h. Fibrous, concentrically laminated, yellowish wood tin from Mina Varosa, Durango.

3. Concentrates from the Queensland mine, Santa Bárbara, Guanajuato. Analyst, S. D. Bridge, Monterrey, Nuevo León. Bromly, A. H., Tin mining and smelting at Santa Bárbara, Guanajuato, Mexico: Am. Inst. Min. Eng. Trans., vol. 36, p. 233, 1905. (Recalculated as oxides.)

4. Wittich, Ernesto, El estaño en la Sierra de Guanajuato: Soc. geol. Mexicana, Bol. 6, p. 192. 1910.

5. Stream tin. Analysts, John H. Banks & Son, New York. Sampson, E. H. S., Unpublished report on placer deposits near Dolores Hidalgo, Guanajuato, for Natural Products Producers Corporation, New York.

6. Stream tin. Analysts, Ledoux & Co., Inc., New York. Sampson, E. H. S., op. cit.

7. Partial analysis of shipment of 15 tons of concentrates from El Santín mine, Guanajuato. Analysts, Williams, Harvey & Co., Liverpool, England. (Recalculated as oxides.)

cially great near the tin veins, where the groundmass appears to be weakly leached. In these places the rock is so friable that it can be easily crushed. In some places the groundmass of the altered rock contains small quantities of clay minerals, which appear to be mainly of the montmorillonite group but in smaller part kaolin; in other places the groundmass contains zeolites or fluorite or both. Generally the feldspar phenocrysts are unaltered, but in a few places, particularly where there has been faulting, they are almost completely altered to clay minerals. Silica was deposited almost entirely within the fissures, but it extends an inch or two (2.5 to 5 cm.) into the walls along some parts of the veins. Some of the quartz phenocrysts and a few sanidine phenocrysts are secondarily enlarged.

Although alteration of the vein minerals is not common, many crystals of specularite are weakly corroded. Part of this corrosion may have occurred at the time the cassiterite was deposited; but in some places the corrosion was clearly later, for cavities have been left where the crystals of specularite have been dissolved out of the mixtures of the two minerals. In one place the sanidine in the incrustation is partly altered to clay, whereas that in the wall rock is unaltered. In a few places the tridymite has inverted to quartz but has retained its characteristic crystal form. The cassiterite apparently was highly resistant to attack by later solutions.

It is clear that alteration and leaching of the wall rock occurred after the deposition of the specularite and cassiterite. In some places the incrustations cover small cavities that would have been filled up if they had been present before the deposition of the specularite and cassiterite. Had the wall rock been porous prior to the deposition of the cassiterite, this mineral should be widely disseminated throughout the rock, but very little disseminated cassiterite has been found. The minerals deposited in the altered rock are the same minerals that were last deposited in the veins.

Origin.--As no one deposit has been thoroughly explored, the origin of this type of tin deposit must be inferred from scattered bits of evidence gathered not only in Mexico but in southwestern New Mexico and in northern Nevada. It is believed that the source of the tin was largely rhyolitic magma that was intruded near the surface of the earth rather than deep down; some deposits were possibly derived in minor part from the lava flows themselves. It is believed, further, that the veins were deposited in fissures formed by minor structural adjustments after extrusion of the lavas and during the waning stages of volcanism. The mineralization is thought to have occurred during one continuous cycle, in whose initial stages residual gases, depositing cassiterite from the crystallizing rhyolitic magma, escaped at temperatures probably above 600° C., and in whose final stages hot waters filled the fissures, forming zeolites and clay minerals. As sulfide minerals are absent from the deposits, it would seem that, when temperatures had dropped low enough to permit the presence of aqueous solutions at the existing pressures, the magmatic fluids must have contained little but water.

The veins apparently were formed soon after the extrusion of the rhyolite, for in a few places they are overlain by unmineralized basalt and in other places by other unmineralized lavas probably extruded after mineralization. The cassiterite was clearly deposited at relatively shallow depths. The lavas have not been either folded or metamorphosed, and field relations indicate that no great thicknesses of rock have been eroded from the deposits. The fissures in which the incrustations were deposited are not in general filled with the vein minerals. They are extremely irregular and discontinuous, many of them branching or feathering out in a manner characteristic of fissure veins formed at shallow depth. Although some of the veins are at least 1,000 feet (300 m.) below the present upland surface and may have been formed at a depth of 2,000 to 3,000 feet (600 to 1,000 m.), others may have been formed within a few hundred feet (less than 100 m.) of the surface. Evidence from outcrops and from explored veins indicates that some groups of veins have a vertical range of at least 400 feet (120 m.), but exploration has been insufficient to prove how much greater the range may be.

The fact that the veins occur only in certain parts of the lavas, there being vast quantities of rhyolitic lava that do not contain tin veins, indicates that certain localizing factors were operative. One such factor appears to have been proximity to the vents from which the lavas were extruded; some of the deposits clearly occur near centers of extrusion, whereas few deposits occur in the thin flows, with interbedded pyroclastic rocks, which apparently are distant from these centers. Faulting is known to have occurred along some fissures before the incrustations were formed, and faults occur in some part of each deposit examined. Although none of these appear to be of large displacement, it is believed that they provided channelways extending from some depth below the present outcrops of the veins, and that these faults resulted from structural adjustment consequent upon the extrusion of the lavas rather than from later earth movements.

The source of the tin is believed to have been the rhyolitic magma. All the tin deposits are closely associated with rhyolitic extrusive rocks, and most of them are actually in such rocks. Spectrograms of the freshest rhyolite from two districts show about 0.0005 percent tin, indicating that tin is a minor element of the rhyolite in those districts. All the minerals of the incrustations, except the arsenic minerals and possibly cassiterite, occur also in the lithophysae of the rhyolite flows, as normal late products of crystallization deposited after the lavas solidified. Some of these minerals are abundant throughout all the rhyolite flows, while others are of rare occurrence. The relative scarcity of tin in the rhyolite may account for the apparent absence of cassiterite in the lithophysae.

The tin-bearing fluids that formed the minable deposits must have been concentrated in small areas or directed along a few conduits. The relatively small extent of the mineralization indicates that the fluids were of small volume and therefore that the bodies of magma from which they came were either small or poor in fluids. The localization of the deposits indicates that the mineralizing fluids did not come entirely, though they may have come in part, from the flows themselves; it seems probable, rather, that they came chiefly from crystallizing rhyolitic magma that never reached the surface. Some of the deposits may have been formed, while the lavas were cooling, by intermingled fluids from both sources. The solutions that formed the tin veins in the latite and andesite of eastern Guanajuato are believed to have had their source in the reservoir of rhyolitic magma from which the rhyolitic flows overlying these more basic lavas came.

The early formed vein minerals are believed to have been deposited from gases at moderately high temperatures, possibly at first above 600° C. and later at somewhat lower temperatures. The minerals in the incrustations that are generally believed to form at high temperature are magnetite, specularite, cassiterite, sanidine (the high-temperature form of potash feldspar), cristobalite and tridymite (generally formed at fairly high temperature), topaz, garnet (in New Mexico and Nevada), and bixbyite (only in New Mexico). The fact that the early metallic vein minerals are oxides and mixtures of oxides, not accompanied by sulfides, indicates that the environment was an oxidizing one and that the temperatures were high enough to permit the sulfur, which must certainly have been present in the ore-forming fluids, to be carried away in the gases. Zies 19/ points out that in the fumarolic incrustations of the Valley of Ten Thousand Smokes in Alaska the sulfides and sulfates were formed abundantly at the vents where temperatures had dropped below the boiling point of water, and only rarely at the high-temperature gas vents, where the compounds formed most abundantly were oxides. Although these fumarolic incrustations were formed at the surface, whereas the tin-bearing incrustations under consideration were formed below the surface, the physical conditions under which the two sorts of deposits were formed were probably not very different, except that the gas pressures in the fissures during the formation of the tin deposits were greater.

Most of the alteration and leaching of the wall rocks along the tin veins occurred after the deposition of the cassiterite (see p. 128). Some of this alteration may have been effected in part by hot gases, but in the final stages it probably was the work of liquids, as indicated by the occurrence in the veins and altered rock of clay minerals, chalcedony, opal, and zeolites. This hydrothermal stage appears in most of the deposits to have been of short duration, for in general its effects are slight. The liquids must have been nearly neutral and have carried very little material in solution, since most of the specularite is unattacked, calcite is rare in the deposits, and little silicification has taken place. In discussing the lavas of the San Juan region in Colorado, Larsen 20/ points out that where the lavas are strongly altered by hydrothermal agencies tridymite and cristobalite invert to the more stable form, quartz. Such inversion is rare in the tin deposits.

19/ Zies, E. G., The Valley of Ten Thousand Smokes; I. The fumarolic incrustations and their bearing on ore deposition: Nat. Geog. Soc., Contributed Technical Papers, Katmai series, vol. 1., No. 4, pp. 5-61, 1929.

20/ Larsen, E. S., Irving, John, Gonyer, F. A., and Larsen, E. S., 3d, Petrologic results of a study of the minerals from the Tertiary volcanic rocks of the San Juan region, Colo. 2. The silica minerals (by E. S. Larsen): Am. Mineralogist, vol. 21, pp. 692-694, 1936.

Mining and concentration.--Many of the small tin deposits have been mined with profit to the operators, mostly without the aid of machinery or even of explosives. The mining has consisted in the gouging out of rich vein material from between relatively barren walls. The openings in most of the mines are, in the main, only wide enough for one man to squeeze through, though they widen somewhat where pockets of ore have been found. Some of these mines are reported to have yielded as much as 50 tons of metallic tin, but most have yielded probably less than 5 tons. Renewed work in some of the abandoned mines has revealed additional small pockets of ore. "Dead work" has not usually proved profitable. A typical small mine is illustrated in plate 27, A, a photograph of a mine 10 miles (16 km.) north of San Felipe, Guanajuato.

The ore obtained from the veins is crushed by hand and is washed and concentrated on gently sloping rock or earth platforms (planillas) or in shallow wooden pans (bateas). Some of the miners may lose more than 50 percent of the cassiterite during these operations, but in general the recovery is somewhat higher. The concentrates consist almost entirely of cassiterite and specularite and contain from 15 to 70 percent tin, averaging around 45 percent. Some of the kidneys of wood tin contain as much as 75 percent tin, but none are completely free from iron.

The amount of cassiterite disseminated in the wall rock of the veins in rhyolite is extremely small, and the cassiterite is generally confined to a very narrow zone immediately adjacent to the vein. Since the veins are almost without exception less than 10 inches thick and are usually mere incrustations on the walls of narrow fissures, punctuated erratically by small pockets or kidneys of ore, very little of the material that must be mined to extract the ore contains recoverable tin. Workings must therefore be kept to minimum dimensions and regular methods of development by machine methods obviously will fail.

There are few figures showing grade of ore and production for deposits that have been mined on a large scale, but those available suffice to show that such mining has nowhere been profitable. Bromly reports that around 1900 an attempt was made at Santa Bárbara, Guanajuato, to mine with the aid of machinery a deposit that proved to average only 0.4 percent tin to a depth of 130 feet (40 m.). He remarks, "On the whole, it would be correct to describe the deposit as one that carries a small percentage of iron contaminated with tin."[21/]

The Pittsburgh & Mexico Tin Mining Co., according to Rangel, spent more than $200,000 (United States currency) on the deposits in the América-Potrillos district in Durango around 1907 but recovered only a few thousand tons of ore. The operation failed, it is said, because of poor management and lack of knowledge.[22/] The amount of tin recovered is not recorded, but the grade of the ore was presumably low, as no further large-scale mining has been done.

The Durango Tin Mining Co. of St. Louis, as Ingalls was informed by Mr. H. Winninghoff, operated mines in the Cacaria district in Durango from 1881 to 1882; the most extensive work was in the Diablo mine, which was opened to a depth of 273 feet (83.2 m.). It is said that the vein material contained about 3 percent tin; how much barren rock had to be mined to obtain the vein material is not known. The enterprise was abandoned as unprofitable. Ingalls makes the comment that "The delusion as to the extraordinary richness of the Durango tin fields is largely due to the assay of specimens of the remarkable nodules of cassiterite found there."[23/] No further large-scale mining has been attempted in the Cacaria district, although several small veins have been mined or prospected.

21/ Bromly, A. H., Tin mining and smelting at Santa Bárbara, Guanajuato, Mexico: Am. Inst. Min. Eng. Trans., vol. 36, p. 229, 1905.

22/ Rangel, Manuel, Apuntes sobre la distribución de minerales en el Estado de Durango: Soc. geol. mexicana, Bol. 7, pp. 110-111, 1910.

23/ Ingalls, W. R., The tin deposits of Durango, Mexico: Am. Inst. Min. Eng. Trans., vol. 25, p. 159, 1896.

It is doubtful whether any of the deposits can be profitably mined and milled by bulk methods. Judging from the few published descriptions of deposits that have been mined and from studies of samples collected by the authors from the most promising deposits in several districts, it seems very doubtful whether any deposit contains as much as 120,000 tons of ore averaging more than 0.5 percent tin; indeed, it is doubtful whether many deposits averaging even 0.1 percent tin contain that much ore. The small size of the individual deposits thus precludes large-scale mining by bulk methods, for few of the deposits contain enough tin to pay for the equipment needed for efficient large-scale operation.

The recovery of tin from these low-grade ores is likely to be low, partly because the abundance of specularite and its intimate association with the cassiterite would prevent a clean separation, and partly because much cassiterite would be lost in the slimes when the ore was milled. Furthermore, the smelting of concentrates high in iron, such as these would be, results in loss of some of the tin or in increased costs. At the Queensland mine, near Santa Bárbara, Guanajuato, where rock assaying 0.4 percent tin was crushed and concentrated by means of tables, the concentrates, according to Bromly,[24] contained only 29 percent of the tin. When a sample of these concentrates, containing about 15 percent tin, was panned down to half its weight and smelted with charcoal in a small furnace constructed at the mine, only 40 percent of the tin in the concentrates, or 12 percent of the tin in the ore, was recovered as metal. The recovery from ore of that grade would undoubtedly be much higher with more efficient, modern methods of milling, gravity concentration, and smelting, but the losses would probably still be high.

Tests conducted by the Bureau of Mines on rock from deposits of this type in southwestern New Mexico, averaging 0.03 percent

24/ Bromly, A. H., op. cit., pp. 230-232.

tin, gave concentrates ranging from 0.05 to 0.8 percent tin, with a recovery of from 10 to 47 percent. Although no attempt was made to concentrate this material further nor to smelt the concentrates, it was considered doubtful whether concentrates could be made that would be suitable for smelting and yet give a satisfactory recovery of tin.[25/]

Although every commercial method of recovering cassiterite from its ores is based largely on separation by gravity, flotation is also being applied to some ores. The standard procedure for treating the cassiterite-sulfide ores of Bolivia is to depress the cassiterite and to float off the sulfides in concentrates made by gravity methods. Processes also have been developed for floating off cassiterite in ores containing quartz, feldspar, sericite, and tourmaline. Gaudin [26/] outlines a process that gives concentrates containing 50 percent tin from an ore of this type assaying 0.8 percent tin; the recovery is 70 percent of the tin in the ore. Experiments were being conducted at Mexico City in 1941 on the flotation of cassiterite in ores from the tin deposits in rhyolite. It is said that 90 percent of the tin can thus be recovered, but the process has not yet been used commercially.

A process for recovering tin as a byproduct from the lead-zinc ores of the Sullivan mine in British Columbia, Canada, was developed and put into operation in March 1941, by the Consolidated Mining & Smelting Co. at Trail.[27/] The material treated, which consists of the flotation tailings remaining after the recovery of zinc and lead, contains only 0.05 percent tin; but by concentrating to a ratio of more than 2,000 to 1, concentrates containing 67 percent tin are obtained. These, when smelted in an electric furnace, yield plus-99 percent "standard"

25/ Strategic minerals investigations; progress report on exploration of tin deposits: U. S. Bur. Mines Inf. Circ. 7154, p. 5, March 1941.

26/ Gaudin, A. M., Flotation, p. 379, New York, McGraw-Hill Book Co., 1932.

27/ Banks, H. R., Tin at the Sullivan concentrator: Canadian Inst. Min. Met. Eng. Trans., vol. 44, pp. 611-622, 1941.

tin. The recovery of tin is about 45 percent of that shown by assay in the "tailings ore." It should be emphasized that the lead and zinc pay for all costs of mining and milling and that the tin need pay only for the additional cost of its recovery from the tailings, whereas the tin deposits in rhyolite, now under consideration, contain no appreciable quantity of any other metals of commercial value.

Possible production.--At the present stage of tin metallurgy it is doubtful whether any of the tin deposits in rhyolite can be mined profitably on a large scale. The future value of the deposits depends on the development of efficient, low-cost methods of recovering tin from low-grade ores by means of processing plants that, owing to the small size of the individual deposits, would have to be small and portable. Until such methods are developed, the production of tin from these deposits will continue to come from many small mines and will not be appreciably greater than during the past few decades--probably no more than a few hundred tons a year. It has been suggested by persons who have bought cassiterite concentrates from the miners that the lending of tools and equipment, to be paid for in concentrates subsequently mined, would stimulate production somewhat.

Placers

Occurrence.--Most of the tin-bearing veins exposed at the surface have given rise to small placers, many of which are eluvial; that is, they consist merely of the soil mantle that overlies and extends downhill from the outcrops. These soil deposits are thin, because of the steep slopes and arid climate, and none of them contains much tin, as the supply of cassiterite at the source is small. Most of the cassiterite is carried down the hillsides into small arroyos, where it accumulates in small alluvial placers. Where denudation is the dominant process, the thickness of the gravel in the arroyos is at most only a few feet (about one meter). This gravel is likely to be rich near the outcrops of the veins, but the rich gravel is generally of small extent; little of the gravel that lies more than a mile (1.6 km.) from an outcrop is worth mining. Most of the tin placers in Mexico are of this type. One of them is shown in plate 27, B, a photograph of a small arroyo that is being mined a few hundred feet (about a hundred meters) downhill from the outcrop of some small veins.

In a few districts where the tin veins are widely scattered rather than more or less isolated, cassiterite is carried down the small tributary valleys to the main arroyos. The Coneto district, in the Sierra de San Francisco, Durango, is the best example of such a district. Here the bottoms of the main arroyos are from 100 to 300 feet (30 to 90 m.) wide and contain gravel as much as 15 feet (4.6 m.) in thickness. The cassiterite is concentrated mainly in the lower part of the gravel, within 1 or 2 feet (about 0.5 m.) of bedrock. At a distance of about 2 miles (3.2 km.) beyond the nearest outcropping vein, dilution with gravel from barren areas has reduced the percentage of cassiterite below the point of profitable recovery.

Thick deposits of gravel have accumulated at the bases of some of the rhyolite ridges containing tin deposits, notably in the valley of the Laja River, which extends along the east side of the Sierra de Guanajuato, near Dolores Hidalgo, Guanajuato. These deposits consist of coalesced alluvial fans, more than 500 feet (150 m.) in aggregate thickness, composed of debris eroded from the higher country. Tests made by the authors have shown that these fans contain cassiterite in places, but nowhere have they yet been found to be rich enough for profitable mining.

aggrading conditions under which they were formed are not favorable to the concentration of heavy minerals.

In some places where the fan gravels have been deeply eroded, cassiterite has been reconcentrated on the bottoms of the

A. SMALL ABANDONED TIN MINE NEAR SAN FELIPE, GUANAJUATO.

B. SMALL TIN PLACER NEAR TLACHIQUERA, GUANAJUATO.

arroyos in secondary gravels, which have been further enriched with cassiterite freed by further erosion of the tin veins. Probably because of this two-fold enrichment, the gravels yield a profit in the little small-scale mining that has been done. But even these reworked gravels, though richer than any of the other gravel deposits and in part adapted to dredging or to the use of a dragline, have not been proved by the tests made thus far to be worth mining on a large scale.

In most of the placers worked hitherto the gravels are less than 4 feet (1.2 m.) thick, but in some they are as much as 15 feet (4.6 m.) thick. Boulders as much as 3 feet (0.9 m.) in diameter are common where the gravels are thin, but in the thicker deposits most of the material is less than 1 foot (0.3 m.) in diameter, though only a minor percentage consists of clay. The heavy minerals are chiefly specularite and magnetite; cassiterite is generally much scarcer. In many places topaz is abundant, but, being much lighter than cassiterite, it can be washed out of the concentrates with relative ease. There are small quantities of zircon and other heavy silicate minerals, which also can easily be eliminated from the concentrates. As in the vein material, cassiterite and specularite are so intimately intergrown that they cannot be completely separated.

Mining and concentration.--The placers have been mined entirely by hand, not even the simplest machinery being employed. The gravel, like the vein material, is concentrated by washing it first on inclined rock or dirt platforms (planillas) and then in shallow wooden pans (bateas). As concentrates containing much iron bring low prices, the miners wash the concentrates vigorously to eliminate as much of the specularite as possible. In so doing they lose a part of the cassiterite but obtain concentrates containing from 45 to 65 percent tin. The loss is naturally much greater if the concentrates are fine than if the cassiterite occurs as large kidneys, and therefore most of the mining is done near the veins, where the material is coarse.

As the grade of the gravel must be fairly high to permit this wasteful method of mining, large tonnages undoubtedly remain of gravel that contains more than half a pound of tin to a cubic yard (0.1 percent) (the lower limit for minable gravel in the Malay States). Such gravel might be worked by mechanical methods, but, as almost all the deposits are small, any mechanical equipment used in mining and milling them should be small and portable. Small jigs and tables could probably be used to obtain rough concentrates, which would then, like those from the vein material, have to be treated further to separate the cassiterite from the iron minerals. In this respect the Mexican deposits differ from those in the Malay States, where concentrates of nearly pure cassiterite can readily be made, and therefore the lower limit for minable gravel would probably be somewhat higher in Mexico than in Malaya.

Water supply for placer operations presents a serious problem over much of the plateau country during the dry season; hence most of the placer mining is done between July and January, when small streams of water flow in the larger arroyos. As the miners eliminate the coarse material before washing the gravel and wash only small quantities of fairly rich material, using the same water repeatedly, not much water is required. A few tanks for storing water have been made by building earthen and stone dams, and additional tanks would undoubtedly aid somewhat in maintaining a supply during at least a part of the dry season. In most of the tin districts, enough water for small-scale mechanical concentrating plants could be obtained during the dry season from shallow wells in the larger arroyos.

Possible production.--It is impossible to estimate reserves of tin in the placers, because the number of small placer deposits, though large, is unknown and none have been sampled and blocked out in an engineering sense. It is clear that several thousand tons of tin can be obtained from placers that contain half a pound or more of tin a cubic yard (more than 0.1 percent tin). Even with a moderate amount of stimulation, however, it is doubtful whether the annual production could exceed a few hundred tons with present methods of mining. The use of small portable power jigs or tables would increase the production, but it is doubtful whether any placer containing enough cassiterite for profitable mining is large enough for dredging or the use of a dragline or scraper.

Summary of possible tin production

Production of tin in Mexico is not likely to exceed 400 tons of metallic tin a year if the price of tin remains at 50 cents (United States currency) a pound (5.50 pesos a kilogram) and mining conditions and methods continue as in the past. The production might be doubled by making loans to miners and by paying higher prices for concentrates. The large placer deposits at Guadalcázar, San Luis Potosí, are of extremely low grade, and it is not yet certain whether any tin can be produced from them. The tin ore in the lead-zinc-silver deposits at Santa Eulalia, Chihuahua, is said to be exhausted, and unless more of such ore has already been found no tin is likely to be produced there in the near future. The vein deposits in rhyolite and the placers related to them, though numerous, are all small and of low grade. Production from them cannot be greatly increased unless machinery can be employed in mining and milling, and no satisfactory methods for doing this have yet been devised. If such methods could be devised, all vein deposits containing 0.1 percent or more of tin could perhaps be mined. The total amount of recoverable tin in the known vein deposits might then exceed 10,000 tons. Large-scale working of the gravel deposits containing half a pound a cubic yard (28 grams a metric ton) or more might yield another 10,000 tons.

MINES, DEPOSITS, AND DISTRICTS EXAMINED

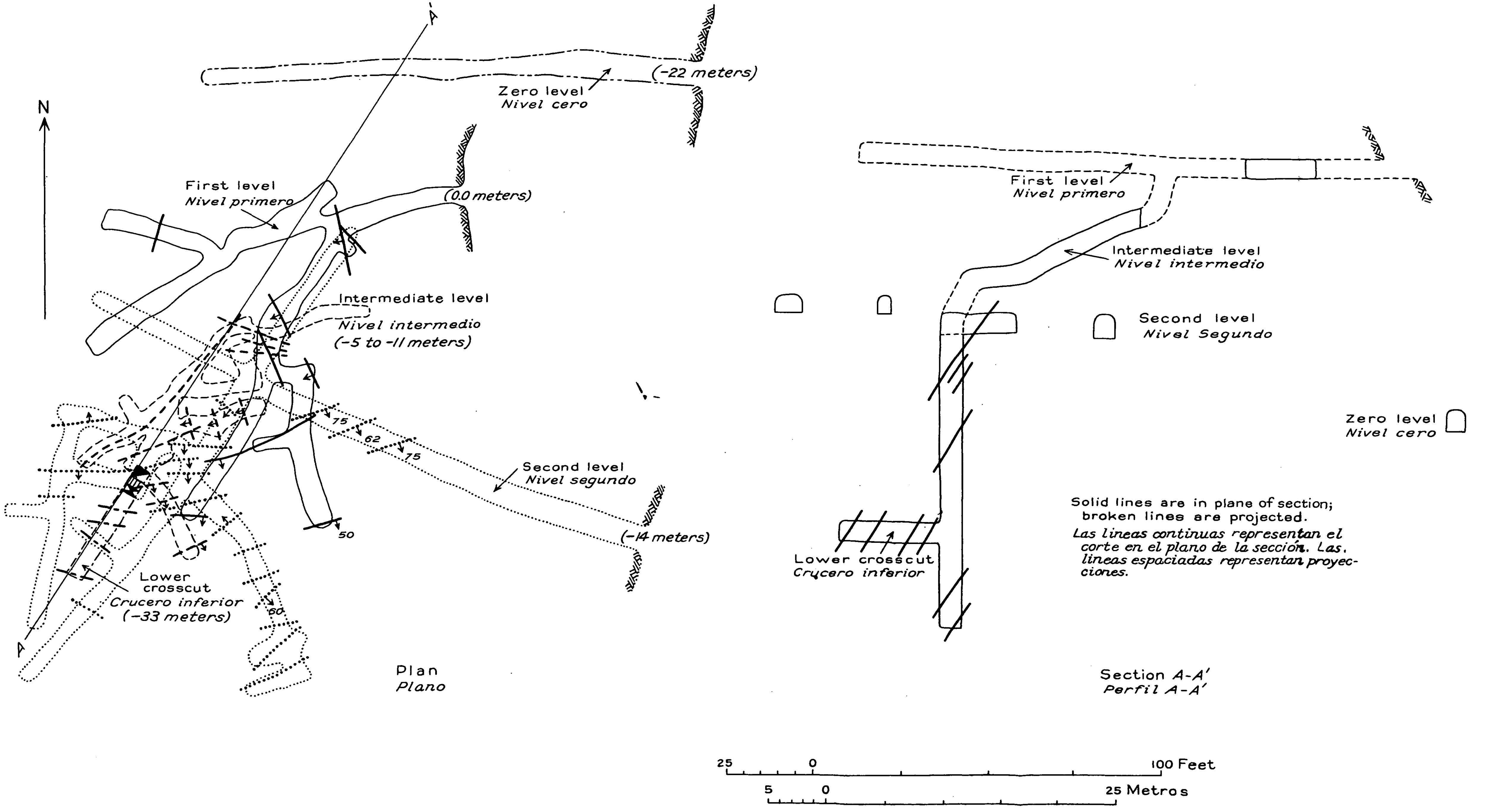
The number of individual tin deposits in Mexico is so great, and exact information concerning most of them is so scanty, that only those deposits or districts actually visited by the authors are described in this report. The most recent compilation of the location and occurrence of the deposits known in 1926 was made by García [28] and presented in his monograph on tin. All other important references have been cited on previous pages of this report. Brief notes on the rocks and on the mineralogy of the veins in the individual districts described in the following sections are given in table 5. The numbers in parentheses that follow the headings refer to those on plate 25 and table 5.

Michoacán

Los Cabires mine (1)

Los Cabires mine is near the crest of Cerro Frío, about 10 miles (16 km.) northwest of the village of Tepuxtepec in the district of Contepec, and is only a few miles south of the Guanajuato-Michoacán State line. The mine is at the head of a deep arroyo known as the Cañada de los Lobos. A small mill, a repair shop, bunk houses, and stables have been erected in the valley at an altitude 600 feet (180 m.) lower than the mine, which is reached from the mill by a good pack trail. A dirt road extends from the mill to Tepuxtepec, which is at the end of a branch railroad line connecting with Mexico City. A dam impounding about 31 billion cubic feet (900,000,000 cubic meters) of water when the reservoir is full has been built at the edge of Tepuxtepec, where there is a small plant for generating light and power. Several hundred tons of ore have been

28/ García, J. Aurelio, Monografía del estaño: Bol. minero, vol. 22, pp. 6-29, 1926.



EXPLANATION
EXPLICAGION

First level
Nivel primero

Intermediate level
Nivel intermedio

Second level
Nivel segundo

Zero level
Nivel cero

Lower crosscut
Crucero inferior

Major fractures, some containing cassiterite; shown by same patterns as the levels on which they occur

Fracturas mayores; algunas contienen casiterita; indicadas por el mismo tipo de línea que se usa para el nivel en que ocurren

Shaft
Tiro

Inclined shaft
Tiro inclinado

Country rock is porphyritic rhyolite
La roca de la región es riolita porfídica

Adapted from unpublished maps by W. Gerzabek for American Smelting & Refining Co., 1939

Adaptado de mapas inéditos por W. Gerzabek para American Smelting & Refining Co., 1939

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PLAN AND SECTION OF LOS CABIRES MINE, TEPUXTEPEC, MICHOACAN
PLANO Y PERFIL DE LA MINA LOS CABIRES, TEPUXTEPEC, MICHOACAN

mined, but the mine is still in a stage of development and no tin has yet been produced.

The crest of the Cerro Frío is about 9,800 feet (3,000 m.) above sea level and about 1,000 feet (300 m.) above the valley. The upper 400 feet (120 m.) of the ridge in the vicinity of the mine is composed of rhyolite flows, which are underlain by 200 feet (60 m.) of bedded tuff. Other volcanic rocks underlie the tuff. The rhyolite at the mine is well layered, and its layers dip steeply into the hill. The flows exposed in the Cañada de los Lobos, east of the mine, appear to be nearly horizontal.

Small tin veins that crop out on the hillside have been explored by means of three adits and several drifts and shafts. (See pl. 28.) The vertical range of exploration is 150 feet (46 m.), and the total length of the workings is about 1,200 feet (365 m.). The rock is more or less strongly fractured, and many of the fractures contain sporadic incrustations of cassiterite. The strike of most of the fissures varies from east to northeast, but a few strike northwest; the dip averages about 60° S. The fissures apparently show no regularity of pattern, many of them seeming to branch and feather out. There is no positive evidence of displacement along most of the fractures, and slickensides are rare.

The incrustations in the tin-bearing fissures are composed largely of botryoidal wood tin with a little specularite, and in some places there are drusy crusts of small red cassiterite crystals and black specularite. Tridymite incrusts some of the cassiterite and also occurs in fissures without cassiterite. The wall rock appears to be essentially barren, although in a few places cassiterite is disseminated in the walls for a few inches. The incrustations, to judge from the few available exposures, pinch out somewhat in the lower part of the mine, where the wall rock is less altered than above. There is no apparent change in the mineralogical character of the veins with depth.

The rhyolite throughout most of the mine is fairly firm and dense, but in places it is altered to a porous, friable, light-gray rock. Although some of the fissures are partly filled with clay minerals, the wall rocks do not seem to contain much clay. The devitrified groundmass of the rhyolite along the vein has undergone much leaching, and a small quantity of zeolites has been introduced into the altered rock, but there apparently is no silicification. It is notable that the sanidine, a mineral that in general is readily altered, is here completely fresh.

As far as can be determined by the limits of exploration, the mineralized body forms an elliptical stockwork, which has a maximum diameter of about 150 feet (46 m.) and dips about 60° SW. The vertical extent of mineralization is not less than 150 feet (46 m.). A block of rock containing about 120,000 tons has been explored, but as this material has not been adequately sampled its tin content is uncertain. Judging from assays made for the owners and from a study of samples taken by the authors, this block probably averages less than 0.5 percent tin and may average less than 0.1 percent. Thorough sampling should be done before attempting to mine the material blocked out. Several tons of tin could undoubtedly be recovered by mining the veins. Owing to the steepness of the arroyo leading from the vein outcrops at Los Cabires, no placer appears to have been formed near the mine.

Other vein deposits in the Cerro Frío have been reported, but none of them have yet been mined.

Hidalgo

Deposits near Zimapán (18)

Cassiterite-bearing veins have recently been discovered in rhyolite about 7 miles (11 km.) west of Zimapán, an important lead-silver mining center on the Laredo-Mexico City Highway.

The topography in the region is extremely rugged, and at present the tin locality can be reached only over a rough mountain trail. The deposit has not yet been mined.

The rhyolite caps Cretaceous limestone on the high mountains that form one side of the canyon of the Moctezuma River. It is a dark reddish-brown fine-grained rock, differing markedly from the lighter-colored, porphyritic rhyolite in most of the other tin districts. The cassiterite forms small broken kidneys in a brecciated zone partly cemented with chalcedony and opal. Clays and fine-grained yellow mimetite (?) are abundant in some of the fractures. Owing to the small amount of prospecting, the size of the deposits and the extent of the mineralized area are unknown.

Guanajuato

District west and northwest of Dolores Hidalgo (2)

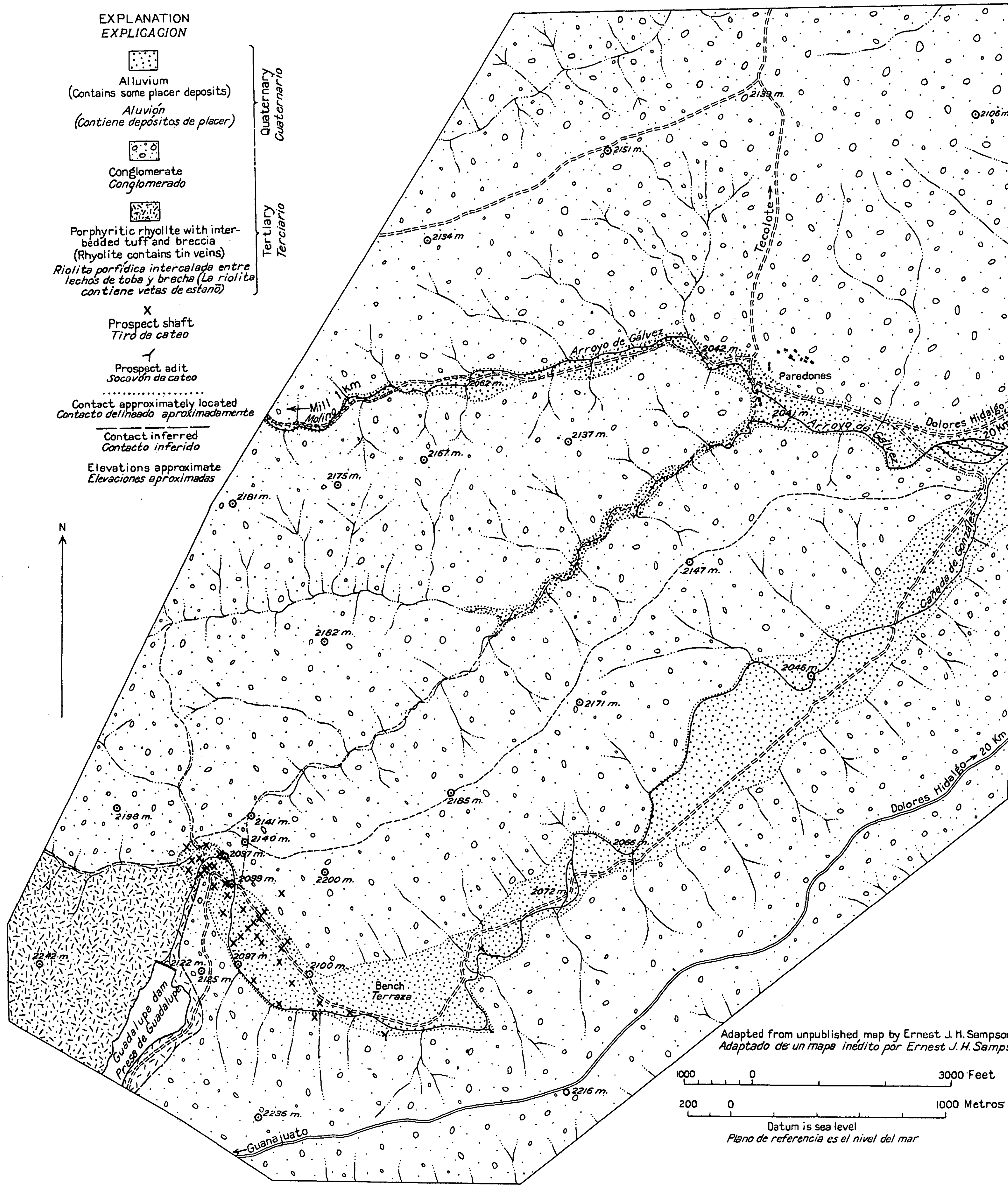
Small tin deposits occur on the west side of the northward-trending Sierra de Guanajuato west and northwest of Dolores Hidalgo. The mountain range consists of folded and metamorphosed pre-Tretiary igneous and sedimentary rocks overlain by Tertiary volcanic rocks, including rhyolite. The tin deposits are in the rhyolite. Thick deposits of gravel lap against the rhyolite on the east side of the mountains and extend eastward to the Laja River, which flows southward through Dolores Hidalgo. The gravels are deeply dissected by steep-sided, flat-bottomed arroyos floored with secondary deposits of gravel, some of which contain placer cassiterite. Tin-bearing veins and placers have been mined in this district for many years, but at most only a few tons of tin has been produced annually.

Vein deposits.--Small vein deposits have been mined along the road from Dolores Hidalgo to Guanajuato at a point about 15 miles (24 km.) west of Dolores Hidalgo. All the old workings are merely shallow cuts in the bedrock, none apparently extending more than 10 feet (3 m.) below the surface. All the vein material in sight has been removed, and the deposits offer no promise of containing any large amount of tin.

A small mine known as the San Marcos has recently been opened in the rhyolite on the northwest side of the Guadalupe dam and reservoir, about 2 miles (3 km.) northeast of the deposits along the road. The vein has been stoped for a length of 15 feet (4.6 m.) and to a maximum depth of 12 feet (3.7 m.). Not all the vein material has been removed, but that exposed is scarcely more than an inch (2.5 cm.) wide. As the wall rock is essentially barren, it is doubtful whether much tin can be recovered from the deposit. A few other small veins crop out nearby.

Placers.--Some of the gravel deposits that have yielded placer cassiterite are on the Trancas estate, near the Guadalupe dam in the Cañada de Gonzales; others are in the Arroyo de Galvez, on the north side of the Dolores Hidalgo-Guanajuato road and 14 miles (23 km.) west of Dolores Hidalgo. (See pl. 29 and fig. 10.) These deposits were extensively sampled from 1926 to 1928 by E. H. S. Sampson for the Natural Products Producers Corporation of New York. The placers have not been mined on a large scale, but local miners now and then recover a little cassiterite. The district is easily reached by automobile.

The gravels consist of debris deposited in coalesced alluvial fans extending eastward from the front of the mountains. The contact of the gravels with the older volcanic rocks is near the Guadalupe dam. The gravels are partly consolidated and well exposed in both the Cañada de Gonzales and the Arroyo de Galvez and are at least 500 feet (150 m.) thick. They are composed of fragments ranging in size from fines to boulders 3 feet (0.9 m.) in diameter. The Cañada de Gonzales has a nearly flat though terraced bottom. The stream bed is mainly in secondarily deposited gravel averaging about 10 feet (3 m.) thick, but some of it



GEOLOGIC MAP OF PLACER AREA WEST OF DOLORES HIDALGO, GUANAJUATO

MAPA GEOLOGICO DE LOS PLACERES DE ESTANO AL OESTE DE DOLORES HIDALGO, GUANAJUATO

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is in primary gravel. On the average, 35 percent of the secondary gravel is coarser than 1 inch (2.5 cm.), and the primary gravels probably average about the same. The gravel deposits

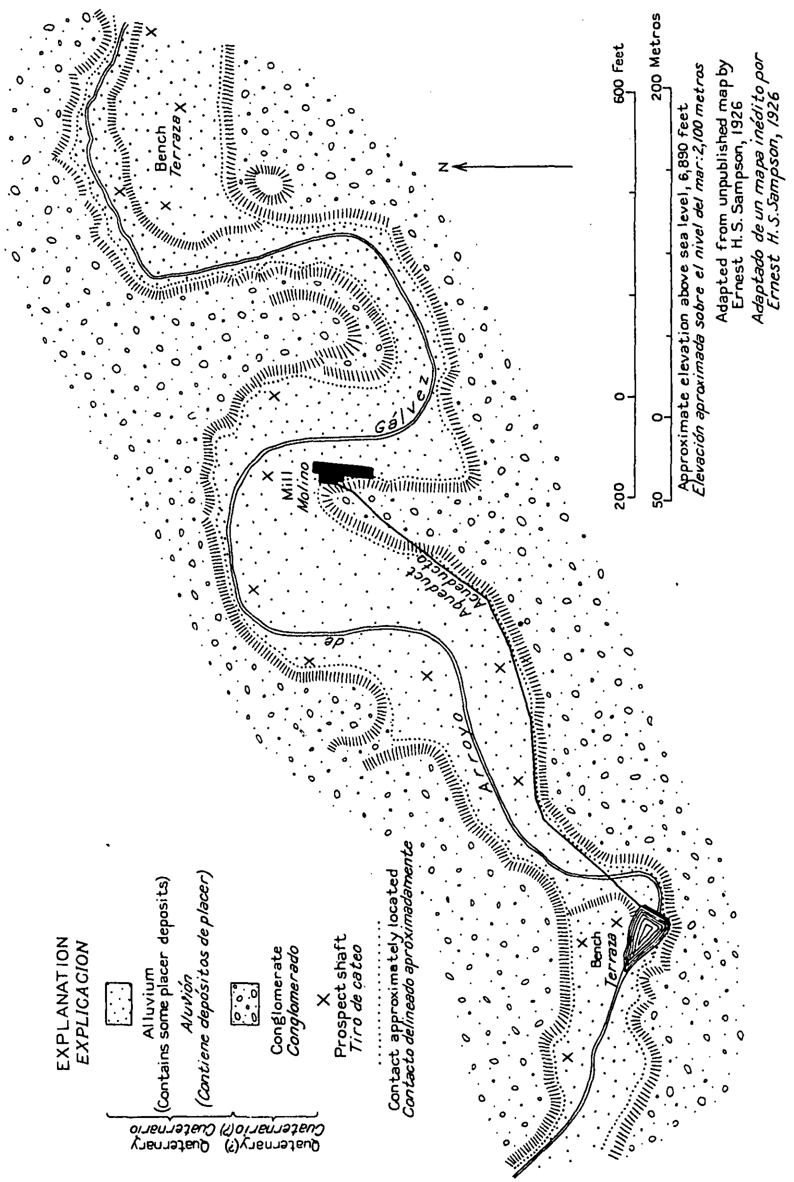

Figure 10.--Geologic map of placer area along Arroyo de Galvez west of Dolores Hidalgo, Guanajuato.

contain only a few percent of clays and other fines. If a dredge were used to mine the deposits, the primary gravel would also have to be mined, but more selective mining could be done with a dragline or scrapers.

An area covering about 80 acres (32 hectares) in the Cañada de Gonzales and just below the Guadalupe dam (see pl. 29) was prospected by Sampson [29] by means of 73 pits, 3 short adits, and 3 shafts. Channel samples a foot square (0.09 square meter) and a foot (0.3 m.) deep were taken at 3-foot (0.9-m.) intervals from one or more of the walls of each pit. After screening on a 1-inch (2.5-cm.) screen and washing the undersize in Klondike rockers, the concentrates were collected and weighed. Precautions were taken to recover as much of the heavy material in the gravel as possible, and the tailings were occasionally rewashed in order to check the recovery. Some of the heavy minerals undoubtedly were lost in washing but the quantity lost was probably no greater than that recovered.

Some of the concentrates were assayed for tin and gold. The concentrates averaged 0.03 percent of the total gravel. Assuming that half the heavy minerals were lost, their original average weight would be 0.06 percent. Assays of the concentrates ranged from 0.45 to 13.43 percent tin, probably averaging less than 10 percent. Assuming that the concentrates contained 10 percent tin, the average tin content of the gravel would be about 0.006 percent, or nearly 0.2 pound a cubic yard (60 gm. a metric ton). As some of the pits were partly in the primary gravel, which in general does not contain as much tin as the secondary gravel, the grade of the secondary gravel is probably somewhat higher than the figure given. The gravels appear to contain also about 0.003 ounce of gold a cubic yard (0.57 gm. a metric ton).

The authors briefly examined these deposits and estimate that the volume of secondary gravel may be about one million cubic yards (760,000 cubic meters). From the results of the

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29/ Sampson, E. H. S., The tin and gold-bearing gravels of the San Joaquin de Trencas, San José de la Quemada, and La Palma estates, Guanajuato, Mexico: Unpublished private report for Natural Products Producers Corporation, New York, 1928.

sampling by Sampson, the authors infer that this gravel probably contains between 0.1 and 0.5 pound of tin a cubic yard (28 to 140 gm. of tin a metric ton), of which possibly half might be recovered. Possibly 0.0003 ounce of gold a cubic yard (0.06 gm. of gold a metric ton)--about one-tenth of the gold shown by assay--might be recovered.

A small permanent stream flows through the Cañada de Gonzales, and an abundant supply of water could be obtained from shallow wells.

An area covering about 5 acres (2 hectares) near the old mill in Arroyo de Galvez, 2 miles (3 km.) west of Paredones, was also tested by Sampson.[30] (See pl. 29 and fig. 11.) The secondary gravel here averages about 6 feet (1.8 m.) in thickness. The total volume of gravel is about 45,000 cubic yards (34,000 cubic meters), and the grade is somewhat lower than in Cañada de Gonzales--probably less than 0.1 pound of tin a cubic yard (28 gm. of tin a metric ton). A supply of water can be obtained from wells in the gravel.

The secondary gravels farther downstream in both the Cañada de Gonzales and the Arroyo de Galvez contain cassiterite, but their tin content appears to be much lower than that of the gravel farther upstream.

Placer cassiterite is mined intermittently southeast of the Guadalupe dam in the Arroyo de Salta Peña Colorado, which is on the south side of the ridge traversed by the road to Guanajuato. (See pl. 29.) The arroyo carries drainage from areas containing tin veins, and its bottom, though fairly narrow, contains thin secondary deposits of gravel at several places. Pannings made by the authors show that some of this gravel contains as much as 1 percent tin, but its volume is small. One bench or terrace 150 feet (46 m.) wide is covered with 2 feet (0.6 m.) of gravel that may contain a few pounds of tin a cubic yard (more than a

30/ Sampson, E. H. S., op. cit.

kilogram a metric ton). The total volume of material is about 12,000 cubic yards (9,000 cubic meters). Another terrace half a mile (0.8 km.) downstream is a little larger but appears to

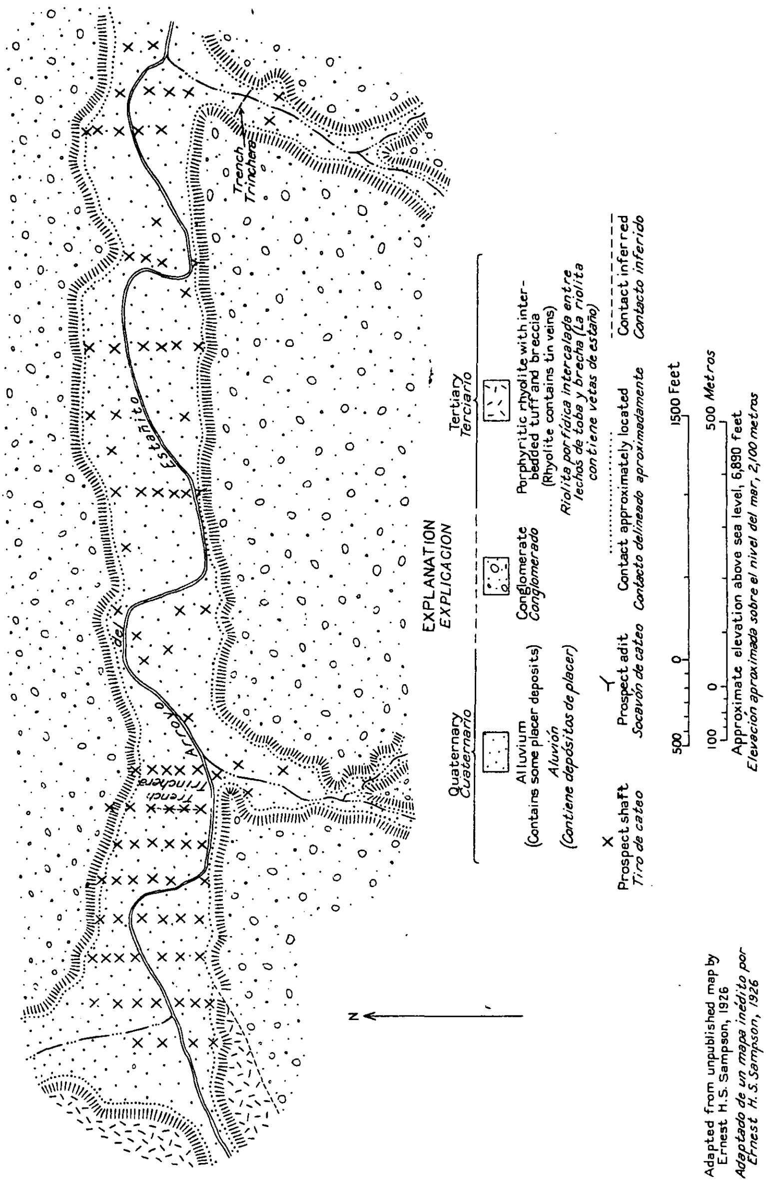

Figure 11.--Geologic map of placer area along Arroyo del Estañito southwest of La Quemada, Guanajuato.

contain a lower percentage of tin. A small supply of water can be obtained from the gravel in the bottom of the arroyo.

Local miners have washed cassiterite from placer gravel in the Arroyo del Estañito, which is known by the name Arroyo Blanco where it joins the Laja River at La Quemada, a village

4 miles (6 km.) northeast of the placer area and 18 miles (29 km.) northwest of Dolores Hidalgo. The Guadalupana mercury mine is a quarter of a mile (0.4 km.) upstream from the placer area. The geology here is much the same as in the Cañada de Gonzales. (See fig. 11.) The placers in both places were sampled by Sampson,[31] who tested a total area of 189 acres (76.5 hectares) by means of 104 prospect pits, 2 trenches, and 2 short adits. The average depth of the pits was about 12 feet (3.7 m.). The authors estimate that the average depth of the secondary gravels in the area is about 7 feet (2.1 m.) and that, therefore, about half the material sampled by Sampson was primary gravel. The secondary gravel sampled has a volume of probably 2,000,000 cubic yards (1,500,000 cubic meters). Sampson's figures are interpreted as indicating that the gravel may average about 0.1 pound of tin a cubic yard (28 gm. a metric ton) and the primary gravel somewhat less. There is a little cinnabar in some of the gravel. The arroyo does not contain water during the dry season, and although some water might be obtained from wells it does not appear to be plentiful.

Deposits near Tlachiquera (3 and 4)

Tlachiquera lies nearly halfway between San Felipe and León and is west-northwest of Dolores Hidalgo. A ton of cassiterite concentrates a week is said to be produced in the region during the rainy season, most of it from placer deposits. There is a small tin-smelting furnace in the village, but it was not being used in February 1941.

Small tin deposits occur in the rhyolite flows on Cerro de los Charcos about 2 miles (3 km.) east of the village. Beds of tuff crop out on the south side of the hill about 200 feet (60 m.) below the tin veins; they may be interbedded with the flows. Although half a dozen small vein deposits are scattered over the

31/ Sampson, E. H. S., op. cit.

upland, only four were examined. The length of the veins mined ranges from 30 to 100 feet (9 to 30 m.), and their maximum depth is about 40 feet (12 m.). Apparently the veins were small, for the average width of mining was about 3 feet (1 m.) and most of the material mined is barren rhyolite, now piled on the dumps. The veins appear to be mined out. A few small placers, such as that shown in plate 27, B, have been mined in arroyos draining this area.

Other small veins occur in rhyolite flows on Cerro del Toro, northwest of Tlachiquera. These veins appear to be even smaller than those east of the village, for one was mined to a depth of only 3 feet (1 m.) and another to a depth of 6 feet (2 m.). Small mercury mines have been operated in the vicinity. It is reported that, a few weeks before the authors' visit, two miners recovered a few hundred pounds (about 150 kg.) of cassiterite from the arroyo leading from one of the tin deposits examined. Many of the small arroyos in this region contain a little cassiterite.

Deposits near San Felipe (5)

Half a dozen tin veins have been prospected and mined in the rhyolite flows on a mesa known as Boquillas, 10 miles (16 km.) north of San Felipe. No pyroclastic rocks were observed in the vicinity of the tin veins. The broad, nearly flat upland is cut by deep, steep-sided arroyos, which drain into the broad valley wherein San Felipe lies. Some of the tin veins, such as the one shown in plate 27, A, are on top of the mesa; others are on the steep sides of the arroyos. The mine shown in the photograph has a maximum depth of 20 feet (6 m.) and is about 100 feet (30 m.) long. The veins have an average strike of N. 60° W. and dip about 65° SW., but in detail they are irregular and branching. The wall rock is little altered and quite firm. No vein material is visible in the mine, but some is in crusts on blocks in the dump. Barren rock would have to be mined in order to find more ore.

The Esperanza mine, which was prospected in 1940, is about 10 feet (3 m.) across and 15 feet (4.6 m.) deep. The flow layers of the rhyolite strike N. 20° E. and dip steeply toward the west. The deposit consists of a mass traversed by many irregular fractures in which vein material has been deposited. Some of the small blocks of rock that are taken out are almost completely incrusted with a thin layer of specularite and cassiterite, but the central parts of these blocks are essentially barren, the vein minerals being virtually confined to the fractures. The ore had not all been mined out at the time of the authors' visit.

Another small deposit along a steeply dipping, slickensided fracture was mined to a depth of 20 feet (6 m.) for about 30 feet (9 m.) along the strike. The vein material on the dump appears to be largely specularite, and no ore was visible in the mine. A small deposit prospected near the bottom of one of the arroyos consists of a zone of silicified breccia about a foot (0.3 m.) wide, in which there are small fragments of nodules of wood tin and crystals of a specular hematite. Several other deposits that were visited had apparently been mined out.

Queensland mine (6)

The Queensland mine is on a low, gently sloping rhyolite ridge extending northwest from the base of the cliffs of rhyolite that form the southeastern part of the Sierra del Pájaro. It is about 2 miles (3 km.) south of Santa Bárbara, a small village 9 miles (15 km.) west of San Felipe, and 18 miles (29 km.) by road from San Felipe. It was opened and operated around 1900 by an English-controlled company but was soon closed down because of the low grade of the ore. The amount of ore mined is not recorded, but, to judge from the extent of the workings, at least a few tons of tin must have been produced. The mine workings were inaccessible in 1941.

The deposits are in massive flows of rhyolite, and no pyroclastic rocks were observed in the vicinity. Bromly [32] reports that the veins were mined to a depth of 130 feet (40 m.) and for a maximum length of 330 feet (100 m.) along the strike. There are three nearly parallel groups of northward-trending veins, the main veins dipping 70° to 80° E., and one group was extensively mined. It is said that the veins appeared to die out, branching in many places and following joints and crevices that ramified in every direction. Some of the tin fissures mined were partly filled with a barren waxy clay. The specularite and cassiterite were frozen to the walls in some places; elsewhere they appeared to be loosely held in the clayey matrix, as if broken from the walls. The wall rocks proved to be virtually barren. Bromly believes that a large part of the rhyolite near the deposits contains traces of tin but that the grade of tin is much too low for profitable mining. The ore in the upper part of the veins averaged from 2 to 3 percent tin, but the average for all the ore mined to a depth of 130 feet (40 m.) was only about 0.4 percent.

The cassiterite was intimately associated with specularite, and it was found impossible to separate the two without losing a large part of the cassiterite. A Krupp ball mill, a Wilfley table, and a Wilfley slime-table were used in milling the ore. The concentrates from 0.4-percent ore contained only 15 percent tin indicating a recovery of only 29 percent from the ore. The concentrates were smelted in a small furnace constructed at the mine.

It seems doubtful whether there is any more ore readily available in the mine. An examination of the dumps indicates

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32/ Bromly, A. H., Tin mining and smelting at Santa Bárbara, Guanajuato, Mexico: Am. Inst. Min. Eng. Trans., vol. 36, pp. 227-233, 1905.

that most of the rhyolite near the veins is dense and firm, and it is improbable that cassiterite is disseminated through any significant volume of this rock. Bromly says "Doubtless, better knowledge would have given better results, but I strongly doubt whether the Queensland ores, even if sufficiently abundant instead of the reverse, would have commercial value."[33/] Small placers have been mined in shallow arroyos near the Queensland, but most of these appear to be worked out.

El Santín mine (7)

El Santín mine is on the south side of the Mesa de la Fajas in the southern part of the Sierra Gorda; it is about 4 3/4 miles (7.8 km.) by trail south-southeast of Santa Catarina, a small village in the valley of the Tierra Blanca River. Santa Catarina lies 42 miles (68 km.) by road southeast of San Luis de la Paz, a city at the end of a branch line of the railroad. A fair road extends from San Luis de la Paz to Victoria, but travel by truck from there to Santa Catarina, a distance of 16 miles (26 km.), is possible only at times when the trail has just been repaired. There is no road from Santa Catarina to the mine. The tin deposits, according to Antuñez,[34/] are at an altitude of 6,400 feet (1,940 m.), about 900 feet (270 m.) higher than the village. About 20 tons of tin has probably been produced from the mine.

Cretaceous limestone is said to crop out in the valley at a few places near Santa Catarina. The limestone is overlain by at least 2,000 feet (600 m.) of volcanic rocks, which include flows of andesite in the lower part and flows of rhyolite near the top. The tin deposits consist of several northwest-trending groups of veins in the andesite about 1,000 feet (300 m.) below the top of the Mesa de la Fajas. Faulting has occurred along some of the tin-bearing fissures, a few of the walls being

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33/ Bromly, A. H., op. cit., pp. 232-233.
34/ Antuñez E., Francisco, Mina El Santín y anexas: Unpublished report, 1939.

slickensided, but there is little or no brecciation along most of the veins. The authors could not determine whether the faulting preceded or followed mineralization.

In detail the tin veins are similar to most of the others in the lava flows. They are highly irregular and ramify along joints and fractures in the country rock. Some of them are merely tight seams, many of which open into pockets more than a foot wide; some of these pockets have yielded as much as 220 pounds (100 kg.) of cassiterite. The vein material consists in part of arborescent and stalactitic aggregates of small crystals of cassiterite, with only minor quantities of specularite. These bodies are apparently unique; at least none so well developed have been found elsewhere. The upper parts of the veins are said to have contained mainly the ordinary banded wood tin. Minor quantities of clay partly fill some of the fissures. In some places along the veins the wall rock is strongly altered and contains a large percentage of clay, but in other places there appears to be virtually no alteration. Tests of specimens of the wall rock collected by the authors prove that cassiterite is not disseminated through large bodies of the andesite, although there is a little cassiterite in the andesite immediately adjacent to some of the tin-bearing fissures. A spectrogram of one specimen collected near a vein showed no tin.

The workings at El Santín consist mainly of an irregular inclined shaft with a maximum depth of 130 feet (40 m.), several shallow shafts, and an adit about 260 feet (80 m.) long. Short drifts, winzes, and raises of all shapes extend out from the main shaft at different levels; mining was done only where vein material was found. The largest stope is about 12 feet (3.7 m.) in diameter and 10 feet (3 m.) high, and the smallest passages are just large enough for a man to squeeze through. The stopes represent places where groups of closely spaced fissures containing vein material were found. The adit, intended to intersect the ore zone in depth, started from a point near the bottom of a small arroyo, a few hundred feet (about 100 m.) southeast of the head of the shaft, but it had not been completed in March 1941. No tin veins were cut in the adit. Several small shafts on the surface show that the fissures are mineralized at intervals along the strike for a distance of at least 300 feet (90 m.). The width of the zone of mineralized fractures may be 30 feet (9 m.).

It is impossible to make any close estimate of the amount of tin in the deposit at El Santín, for no channel samples have been taken and no assays have been made. The maximum limits of the workings, however, outline roughly a body of rock 300 feet (90 m.) long, 30 feet (9 m.) wide, and 130 feet (40 m.) deep. This block contains about 43,000 cubic yards (32,400 cubic meters), or possibly 75,000 metric tons. It certainly averages no more than 0.5 percent tin, and it may average less than 0.1 percent. At the higher figure the block would contain 375 tons of tin and at the lower figure 75 tons. It is doubtful whether more than half the tin could be recovered, even if it were possible to mine such low grade ore. Thus the limitations of the deposit are evident.

A small arroyo leading from El Santín mine contains placer cassiterite, which is mined during the rainy season. These gravels are only a few feet (1 to 2 m.) thick and quite bouldery. There may be as much as 10,000 cubic yards (15,000 metric tons) of gravel containing possibly 1 pound of tin a cubic yard (0.035 percent tin). A supply of water could probably be obtained from wells in the main arroyo a few hundred feet (about a hundred meters) below the mine.

Many other vein deposits have been worked in the district around Santa Catarina, but none were visited. The Peñita mine, on the Cerro del Rincon del Carrizal, is said to have yielded over 20 tons of tin during the past 20 years. The natives intermittently mine the small placer deposits in the district, but the annual production of tin is only a few tons.

Deposits north of San Luis de la Paz (8 and 9)

Small deposits of tin have been mined on the Hacienda Sauceda, 25 miles (40 km.) by road northwest of San Luis de la Paz and 6 miles (10 km.) by trail east of the main group of buildings on the hacienda. The area is one of low relief near the head of one of the main arroyos in the district. The veins are in flows of rhyolite and apparently contain very little cassiterite. Two prospect pits, about 6 feet (2 m.) deep, excavated along the veins showed only thin seams of vein material. Most of the cassiterite produced in the area is mined from the arroyos below the vein outcrops. The concentrates from the gravel contain many well-formed crystals of topaz, some of which are as much as 2 inches (5 cm.) long. Virtually all the mining is done during the rainy season.

Other small tin veins between Santo Domingo, S. L. P., and Jaula, Gto., along the road from San Luis Potosi to San Luis de la Paz have been explored by two shallow pits. These veins are in latite. Apparently the miners did not find enough cassiterite for profitable mining.

Aguascalientes

Deposits near Calvillo (10)

Several tin veins have been explored on the north slopes of the Sierra del Laurel south of Calvillo. A road extends from Calvillo to the Rancho Jaltiche de Arriba, a distance of 9 miles (15 km.), and the tin deposits are about 4 miles (6 km.) by trail from the ranch and perhaps 800 feet (240 m.) higher. The main workings, known as La Virgen mine, are on a hillside near the bottom of a steep-sided arroyo, and several veins cropping out on the same hillside have been explored. A few hundred tons of rock had been mined from La Virgen when the mine was visited. No attempt had been made to recover the cassiterite from this low-grade ore, but several hundred pounds (possibly 200 kg.) of vein material had been picked out by hand.

The veins are in flows of white and highly porous rhyolite whose flow layers have variable strikes and steep dips. Heavy concentrates panned from the crushed rock suggested that cassiterite might be disseminated through this porous zone, but assays of three rough channel samples collected from different parts of the workings prove that the cassiterite is not evenly disseminated, for one sample contained about 0.2 percent tin and another only about 0.002 percent. There is no direct relation between the degree of alteration and the quantity of tin; the sample of the most altered-appearing and porous rock contained the smallest quantity of tin. No veinlets were observed where the samples were taken, but the cassiterite is probably in thin seams or tight fractures cutting through the rock. The miners report that they found small veins and pockets of ore while making excavations.

The maximum depth of the La Virgen workings is about 15 feet (4.6 m.), and the short drifts outline an area about 50 feet (15 m.) in diameter. The samples taken from this area contain on the average less than 0.5 percent tin. The general average is probably somewhat higher than this, because of the small pockets and veins of cassiterite scattered through the rock, but it seems unlikely to be much higher. Moreover, unless further work reveals a much larger body of tin-bearing rock than has thus far been blocked out, the deposit is too small to be mined by bulk methods even if the grade were fairly high.

All the other veins prospected near La Virgen mine are in moderately dense, firm rhyolite. One of the veins has been slightly brecciated and recemented with chalcedony and opal, but the others are merely thin incrustations on fissure walls and contain a high percentage of specularite. Owing to the steepness of the arroyo below the tin veins, no gravel deposits have been formed near the mine, and no significant amount of workable placer has been found elsewhere in the area.

Jalisco

Deposits near Paso de Sotos and Teocaltiche

Tin deposits have been mined for many years in northern Jalisco near the villages of Paso de Sotos and Teocaltiche. None of these deposits were being mined when the authors visited this region, and it was not feasible to enter any of the mines. Some concentrates, however, that had been sold in Paso de Sotos were examined and found to be fairly typical of those from the rhyolite tin deposits, though rather high in iron. These concentrates were reported to have come from small placer and vein deposits in the rhyolite on the south side of the Sierra del Laurel. Alluvial material was panned at several places in one of the arroyos heading in the Sierra del Laurel, but no cassiterite was visible in the heavy concentrates.

Ingalls [35] reported that Los Vallecitos mine, near Teocaltiche, which in 1883 had been opened to a depth of 100 feet (30 m.) and for a length of 650 feet (200 m.), produced a maximum of about 3 tons of metallic tin a month. Cassiterite is still being mined from the rhyolite flows in the hills around Teocaltiche during the rainy season, and the concentrates are sold to buyers in the village.

35/ Ingalls, W. R., The tin deposits of Durango, Mexico: Am. Inst. Min. Eng. Trans., vol. 25, p. 160, 1896.

Los Amigos mine

Los Amigos mine is in rhyolite flows on the Cerro de la Peña, 19 miles (30 km.) by road northeast of Encarnación. It was operated by the Cia. Minera Los Amigos, S. A., until May 1932, when work was discontinued. As the workings are said to be inaccessible, the mine was not visited by the authors, and most of the following statements are from a report by Martínez.[36] The mine is said to have produced 80 tons of concentrates in 1924 and metallic tin valued at 28,890 pesos between May 1931 and February 1932.

The mine, according to Martínez, consists of an inclined shaft 390 feet (120 m.) long, four levels, several winzes, and a few crosscuts. The total length of all the workings is 2,800 feet (853 m.), and the maximum depth of the mine is 253 feet (77 m.). The ore was crushed, jigged, tabled, and smelted in plants built near the mine. Ores from the Minitas region, on the Cerro de la Pachona, which is separated from the Cerro de la Peña by the Arroyo de la Peña, were also treated in the mill. The mill did not operate properly, so that the concentrates were not clean and the cassiterite was not all extracted from the middlings and tailings. The percentage of tin recovered was not known, however, since assays of heads and tailings were lacking. Martínez concluded that the project could not be considered profitable.

Raines and Partridge, who were associated with the Cia. Minera Los Amigos, estimated that in 1933 the mine had reserves of 9,000 tons of ore containing 1 percent tin,[37] but as this estimate was not based on systematic sampling it may have been too high. As far as known, no ore has been mined from the deposit since 1933.

36/ Martínez, Juan, La mina Los Amigos, de la Cia. Minera Los Amigos, S. A.: Rev. industrial, vol. 1, pp. 390-391, 1933.
37/ Idem, p. 390.

Zacatecas

Deposits west of the city of Zacatecas (11)

A small tin deposit occurs near La Quemada, which is about 40 miles (64 km.) southwest of Zacatecas. The deposit is on the south end of a rhyolite hill on which there are ruins of prehistoric stone dwellings. The largest excavation, which is 10 feet (3 m.) deep and 30 feet (9 m.) long, reveals a single massive face of rhyolite partly incrusted with specularite and cassiterite. The incrustations also extend out along some less well defined cross fractures. The surrounding rock is light gray, quite dense, and apparently unaltered. The main fissure is nearly vertical and cuts sharply across the steeply dipping flow layers of the rhyolite. Apparently the vein was too narrow to be mined; at any rate it evidently has not been worked for several years.

Many other deposits have been reported in the region southwest of Zacatecas but none were examined.

Deposits between Fresnillo and Sain Alto (12)

Many small tin deposits are scattered over the Sierra de Chapultepec, the central part of which is 37 miles (59 km.) by road northwest of Fresnillo and about 15 miles (24 km.) south of Sain Alto. The Sierra de Chapultepec is underlain by pre-Tertiary rocks, which crop out at places in the lower parts of the deeper valleys. The tin deposits are in the rhyolite flows which form the upper part of the mountain range. The tin-bearing region is drained largely by the San Francisco River, on the south side of the mountains. Halse [38] reports that about $62\frac{1}{2}$ tons of cassiterite concentrates a year, or roughly 30 tons of metallic tin, were being smelted at Las Cuevas, a small village near Sain Alto, around 1894. It is said that about 8 tons

[38] Halse, Edward, The occurrence of tin ore at Sain Alto, Zacatecas, with reference to similar deposits in San Luis Potosí and Durango, Mexico: Am. Inst. Min. Eng. Trans., vol. 29, p. 506, 1899.

of cassiterite concentrates a month is now being produced from this region during the rainy season; the annual production may be about 20 tons of metallic tin, or about the same that it was 45 years ago.

The largest tin deposit visited is at the Leona mine, which is on the Cerro de Leona, near the crest of the Sierra de Chapultepec. About 20 men were working the mine in February 1941. The authors were not permitted to enter the mine, but the men were then said to be working at a depth of 60 feet (18 m.), and the maximum length of the workings was apparently about 30 feet (9 m.). The shaft is on a well-defined vertical fissure, which is at right angles to the steeply dipping flow layers of the rhyolite. The rhyolite that was being mined was nearly white, and moderately porous though fairly firm. The miners said that an ore pocket had been found which they had been mining for a week. The largest pieces of vein material, about an inch and a half (4 cm.) thick, were composed largely of specularite. The quantity of ore mined from the pocket was not revealed but was probably small.

Some concentrates from the Muñeca mine, said to be about 6 miles (10 km.) southeast of the Leona mine, were found to consist mainly of cassiterite. This mine is in the rhyolite flows north of the village of El Aguila. Several small veins are said to have been prospected in its vicinity.

Halse [39] describes three small tin deposits in the Sain Alto district, which were being mined in 1895 but have apparently long since been forgotten, for the inhabitants knew nothing of them in 1941. The La Desparramada deposit, about 16 miles (25 km.) southeast of Sombrerete, was mined for a length of 50 feet (15 m.) and to a depth of 40 feet (12 m.). It is a vein in rhyolite, striking N. 38° W. and dipping 75° NE., and containing wood tin and specularite. The workings of El Refugio mine,

[39] Halse, Edward, op. cit., pp. 502-503.

which is about 10 miles (16 km.) southwest of Fresnillo, extended to a depth of 30 feet (9 m.) along intersecting veins in rhyolite. The El Calabrote deposit, 20 miles (32 km.) west of Fresnillo, was mined for a length of 63 feet (19 m.) and to a depth of 50 feet (15 m.). It is in rhyolite cut by irregular, steeply dipping fractures; the cassiterite in the fractures is mainly wood tin.

Many small placer deposits in the region are mined during the rainy season. One of these, in an arroyo near the Leona mine, was being worked in March 1941. The concentrates contained well-formed crystals of topaz, besides cassiterite and a little specularite. The arroyo may contain 1,000 cubic yards (1,500 metric tons) of gravel averaging a few pounds of tin a yard (possibly 0.15 percent tin). Another placer deposit, in the valley of the San Francisco River, is said to contain cassiterite, but although this deposit has not been tested it probably contains no large body of gravel that is not of extremely low grade.

Durango

Deposits south of the city of Durango

None of the deposits between the town of Chalchihuites, in Zacatecas, and the city of Durango were visited by the authors, but concentrates from several were examined. Only a few tons of tin a year is produced from this region, and little work appears to have been done on its deposits since 1897, when they were described by Ingalls.[40] Some ore consisting mainly of specularite is said to have come from the rhyolite near the crest of the mountains at a place that is half a day's horseback ride--possibly 12 miles (20 km.)--west of Chalchihuites. It was said that the deposits at that place had not been extensively mined, owing to the narrowness of the veins and their

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40/ Ingalls, W. R., Notes on the tin deposits of Mexico: Am. Inst. Min. Eng. Trans., vol. 27, pp. 428-429, 1898.

high iron content. Some concentrates, consisting of small pieces of wood tin moderately low in iron, that were being sold in Vicente Guerrero were said to have been washed from small placer deposits in the rhyolite on the Cerro Blanco, about 28 miles (45 km.) southwest of that village. Vein deposits have been mined intermittently on the Cerro Blanco and in the Sierra de Michis northwest of Mezquital, a town in the valley of the Mezquital River, west of the Cerro Blanco. It was also said that tin deposits had been mined in the lavas near the crest of the Sierra de Sacrificio, northeast of Vicente Guerrero.

Deposits on the Cerro de los Remedios (13)

Tin deposits have been mined intermittently for at least 50 years on the Cerro de los Remedios at the southwest edge of the city of Durango. This hill is composed of gently dipping well-layered flows of rhyolite (see pl. 30). These deposits have been mined intermittently and have yielded more than 10 tons of tin.

Most of the tin veins are on the northeastern side and on the summit of the hill. The main workings are on La Vanguardia claim (see pl. 30) and consist of a narrow trench 500 feet (150 m.) long and 4 feet (1.2 m.) in average width, excavated to a depth of 3 to 95 feet (1 to 29 m.). The trench is along a poorly defined, nearly vertical fault, the footwall of which is less fractured than the hanging wall. The fault is exposed in two small pits 500 feet (150 m.) farther along its strike, making its total known length 1,000 feet (300 m.). Cassiterite and specularite locally incrust the walls of the fault and occur in some of the fissures branching from the fault. As the maximum width of the trench is about 6 feet (2 m.), the vein material apparently was not deposited far from the fault. Some of the faulting occurred after the cassiterite was deposited, as evidenced by slickensides on incrustations firmly frozen to the walls. The rhyolite along a part of the fault contains small quantities of clay minerals, but only a few of the sanidine phenocrysts are altered, and these only slightly.

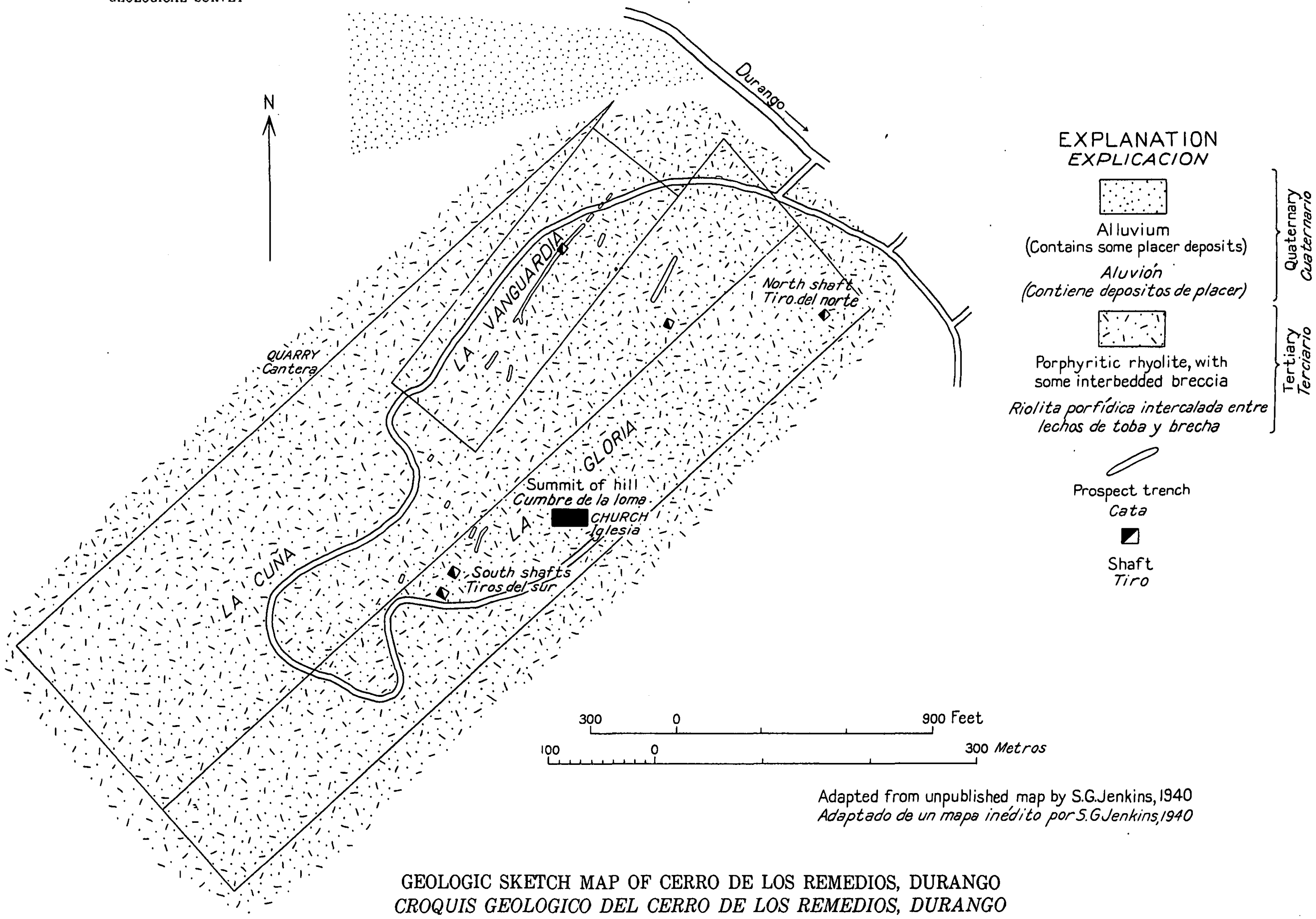
Most of the cassiterite was mined from the vicinity of the "shaft", the deepest part of La Vanguardia open cut (see pl. 30), where fairly large pockets of ore are said to have been found. Jenkin [41/] reports that the largest pocket contained as much as 8 tons of vein material assaying possibly 50 percent tin. The last operator had constructed some concrete planillas, on which the crushed ore was concentrated. It is said that for a short time 14 men were producing daily about 700 pounds (320 kg.) of concentrates assaying about 50 percent tin. According to Jenkin, a pocket which might contain several tons of high-grade ore had just been uncovered in the bottom of the "shaft" when work was halted because of the death of the owner of the mine. This discovery, however, could not be verified by the authors, the bottom of the "shaft" being flooded at the time of their visit.

The north "shaft" had been excavated along a tin-bearing fissure to a depth of 62 feet (19 m.) when city authorities halted the work for fear that the blasting might damage the city's water reservoir nearby. The rhyolite in the shaft is light-colored, and some of it is moderately porous, but in general it is little altered. Jenkin [42/] states that a pocket of vein material weighing 450 pounds (204 kg.) and containing 60 percent of tin was excavated at a depth of 26 feet (8 m.). Another pocket of vein material of the same grade weighing 855 pounds (388 kg.) was excavated at a depth of 40 feet (12 m.). The fissures in the bottom of the shaft are said to contain thin incrustations that have not been mined out.

The south "shafts", one of which is about 30 feet (10 m.) deep and the other 100 feet (30 m.) deep, were excavated along

41/ Jenkin, S. G., Unpublished report on the tin deposits of Cerro de los Remedios, Durango, 1941.

42/ Idem.



GEOLOGIC SKETCH MAP OF CERRO DE LOS REMEDIOS, DURANGO

CROQUIS GEOLOGICO DEL CERRO DE LOS REMEDIOS, DURANGO

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poorly defined fissures containing thin incrustations of specularite and cassiterite at the surface. A zone of flow breccia, possibly representing the division between two superposed flows, was cut by the shafts, and the rhyolite in general is highly vesicular and lithophysal. Although the porosity of the rock is high, the sanidine is entirely fresh and clays apparently are quite subordinate or absent in the groundmass. Incrustations composed of a mixture of chalcedony, quartz, and fluorite occur on the walls of one of the fissures. According to Jenkin small bodies of vein material were found in excavating the deeper shaft, and yielded a maximum daily production of about 65 pounds (30 kg.) of ore containing 40 percent tin. The authors collected a channel sample across the width of the shaft at 95 feet (29 m.). A separation of the crushed rock in the laboratory of the Geological Survey gave only 0.1 percent heavy minerals, and of this only about 1.0 percent was cassiterite, which probably came from a tight fissure containing a thin film of vein material. Thus it is evident that the quantity of tin in the wall rock is negligible.

Incrustations have been found in other fissures on the hill, but none of them except those already mentioned have been explored to a depth of more than 10 feet (3 m.). Small quantities of placer cassiterite have been mined intermittently around the base of Cerro de los Remedios. During the summer and fall of 1941 the alluvium north of La Vanguardia claim was extensively mined, but the quantity of cassiterite recovered is not known.

Deposits in the Sierra de Cacaria (14)

Tin deposits have been mined in the Sierra de Cacaria, about 25 miles (40 km.) northwest of the city of Durango. The district can be reached by automobile by way of Otinapa and Río Verde, a total distance of 65 miles (104 km.). Vein and placer deposits are scattered over a large area in the rhyolite flows that cover the upper, mesa-like part of the mountains; some can be reached by automobile but others only on horseback or on foot. The authors examined three groups of mines and three placers considered to be representative of the district. It is reported that about a thousand men mine the placers during the rainy season, and that during this period the production of concentrates reaches a maximum of about 3 tons a week. The annual production in the district, though not definitely known, may exceed 30 tons of metallic tin, so that the district is one of the most important in Mexico.

Vein deposits.--The largest mine in the district is El Diablo, which was operated by the Durango Tin Mining Co. in 1881 and 1882. It is on a vein that occupies a fairly well defined northeast-trending fault zone in the rhyolite flows. Genth [43] quotes Kleinschmidt as saying that the fault zone can be traced on the surface for a mile (1.6 km.), but the authors were unable to trace it so far, and its tin-bearing part is apparently no more than 1,000 feet (300 m.) in length. The mine consists of a vertical shaft 273 feet (83 m.) deep, to which a connecting adit has been driven from the bottom of an arroyo below the collar of the shaft, together with some narrow stopes along the vein. Except for the adit, which was driven in 1935, these workings were inaccessible in 1941.

Shallow excavations near the shaft expose a zone of breccia about 5 feet (1.5 m.) wide between walls of more massive rock. Specularite and cassiterite incrust some of the pieces of breccia and occupy some of the irregular fissures in the brecciated zone, but apparently they were not deposited in the less-fractured walls. Most of the rock excavated is fairly dense and firm. The more open of the fissures that were mined apparently contained a good deal of clay, clearly formed after the cassit-

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43/ Genth, F. A., Contributions to mineralogy: Am. Philos. Soc. Proc., vol. 24, p. 24, 1887.

erite was deposited. Ingalls [44] was informed by Winninghoff that the vein material (presumably the rock in the brecciated zone) did not average more than 15 percent ore, of which possibly 25 percent was cassiterite. The quantity of tin produced from the mine is not recorded, but it was not large enough to cover the cost of mining. The vein has not been mined out completely, but no estimate can be made of the quantity and grade of the ore remaining.

Two small excavations on the Las Auras claims expose an ill-defined vein trending northwest. The workings consist of a stope about 8 feet (2.4 m.) long and 20 feet (6 m.) deep and a small cut in the bedrock near the bottom of a small arroyo. The rhyolite in the excavations is moderately fractured and fairly porous, and in places the groundmass contains a little clay. The cassiterite seems to be concentrated in the fissures along which the pit was excavated, and it apparently is associated with a high percentage of specularite. A horizontal channel sample taken across 4 feet (1.2 m.) of rhyolite in one of the excavations was found, in the laboratories of the Geological Survey, to contain 0.5 percent tin, but the quantity of rock containing as much as this is probably small.

At Los Alamitos mine an old vertical shaft had been sunk to a depth of about 60 feet (18 m.), and two intersecting veins had been irregularly stoped for from 200 to 300 feet (60 to 90 m.) southeast and southwest from the shaft. No vein material was observed in the accessible part of the workings, but apparently the veins were narrow and pockety, for large bodies of the rock along their strike were left unstoped. A new, smaller excavation about 8 feet (2.4 m.) deep and 10 feet (3 m.) in diameter, near the old shaft exposes moderately fractured rhyolite in which a few of the fissures contain specularite and cassiterite.

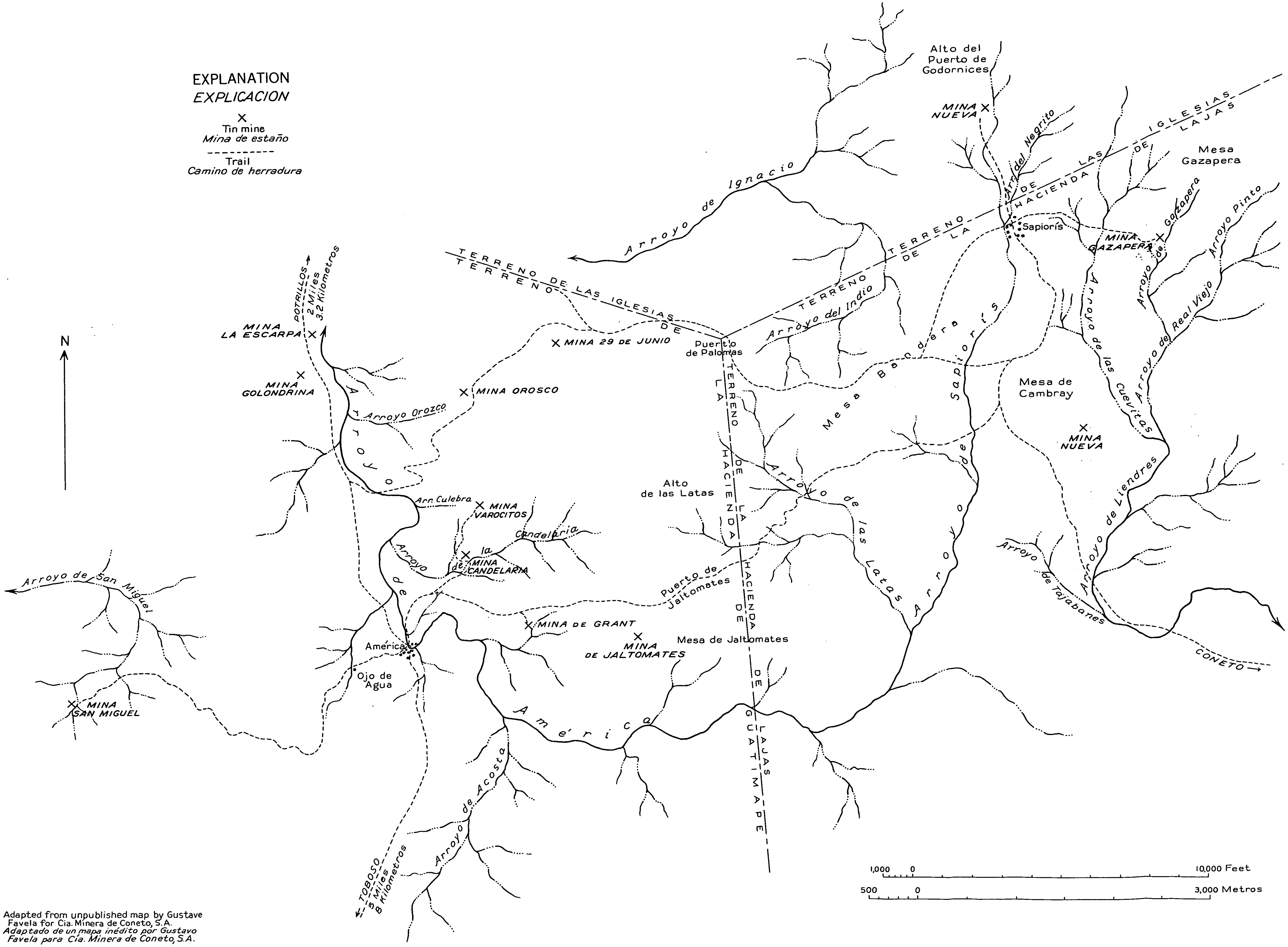
44/Ingalls, W. R., The tin deposits of Durango, Mexico: Am. Inst. Min. Eng. Trans., vol. 25, p. 259, 1896.

This body of tin-bearing rock is probably small, and its grade is obviously low. The production from these deposits is not known.

Placer deposits.--Small placer deposits in the arroyo below El Diablo mine and others below Las Auras and Los Alamitos mines, have been worked. The largest one examined is in the Cañada de las Auras, a shallow, flat-bottomed valley on the rhyolite upland which had been extensively prospected for a length of half a mile (0.9 km.) and is probably tin-bearing for a greater distance. At one place a prospect pit in the gravel exposes a vein of cassiterite in the rhyolite bedrock, indicating that at least some of the cassiterite in the gravel has not been transported far. Material on the dumps of some of the pits was panned by the authors and the concentrates were found to contain enough cassiterite to suggest that the gravel might be mined profitably. Most of the gravel is smaller in size than 2 inches (5 cm.). The width of the valley bottom may average about 100 feet (30 m.) for a distance of half a mile (0.9 km.), and the thickness of the gravel may average about 3 feet (1 m.). Thus the area examined contains at least 20,000 cubic yards of gravel (15,000 cubic meters). Although the grade is not definitely known, the authors believe it may be higher than half a pound of tin a cubic yard (0.02 percent tin). The other placers in the district were not examined, but some of them, to judge from reports, may be at least as large as that in the Cañada de las Auras.

Deposits in the Sierra de San Francisco (15)

The Sierra de San Francisco lies along the northeast side of the plains of Guatimapé and northeast of Patos, a village that lies about 100 miles (160 km.) north-northwest of the city of Durango and is connected with it by a branch railroad line. Tin occurs in what is commonly known as the Potrillos district,



Adapted from unpublished map by Gustave Favela for Cia. Minera de Coneto, S.A.
Adaptado de un mapa inédito por Gustavo Favela para Cía. Minera de Coneto, S.A.

SKETCH MAP OF TIN DISTRICT IN SIERRA DE SAN FRANCISCO, DURANGO
CROQUIS DEL DISTRITO ESTANIFERO EN LA SIERRA DE SAN FRANCISCO, DURANGO

U. S. GOVERNMENT PRINTING OFFICE: 1942 O - 480115 (faces p. 170)

on the northeast slope of the range. The district is not accessible by automobile. The shortest trail by which it can be reached is about 6 miles (10 km.) long and extends from the Rancho Tobozo, located at the southwest foot of the mountains, to the small tin-mining settlement of América in the Arroyo de América. From Tobozo the trail rises about 2,000 feet (600 m.) over a pass near the crest of the range and drops down about 1,000 feet (300 m.) to América. A wagon road from Tobozo to América was constructed about 40 years ago, but it has been washed out and would have to be completely rebuilt and possibly relocated to be passable for motor trucks.

The lower part of the Sierra de San Francisco consists of pre-Tertiary rocks and early Tertiary andesite, which contain the important silver deposits that are being mined near Promontorio, about 12 miles (19 km.) northwest of the tin district. All the known tin deposits, however, are in the late Tertiary rhyolitic rocks which form the upper part of the mountain range. All the veins examined are in what appear to be flows, and none were seen in rocks definitely identified as tuff, although thick beds of tuff and breccia occur southeast of the tin-bearing zone. The maximum monthly production in the district is reported to be about 50 tons of cassiterite concentrates containing about 50 percent tin, and the annual production of metallic tin may be as great as 100 tons. The district is now the most productive in Mexico.

Vein deposits.--The largest mines in the Potrillos district are the Candelaria and the Grant. (See pl. 31.) These mines were inaccessible in 1941, but Ingalls,[45] who described the workings as far as they were developed in 1894, showed that the ore was mined from narrow, pockety veins similar to the many that have been described earlier in this report. The deposits were later worked by the Pittsburgh & Mexico Tin Mining Co.,

45/ Ingalls, W. R., op. cit. (vol. 25), pp. 149-154.

but after mining several thousand tons of ore at a loss the company discontinued operations.[46] The maximum depth of the workings is said to be about 330 feet (100 m.).

The authors took a horizontal channel sample across 6 feet (1.8 m.) of the rhyolite in a small adit near the main shaft of the Candelaria mine, and this sample was found to contain about 0.005 percent tin. Little if any of the rhyolite on the dumps has the appearance of being any richer than this sample, and, even though material on dumps is presumably waste, it seems fair to infer that cassiterite is not disseminated in commercially recoverable quantities through any large body of the rhyolite near these deposits. The amount of tin recovered from the large mines is not known.

The Varocitos mine, in the hill above the Candelaria mine, consists of an open cut along two parallel fissures containing vein material. The veins have been stoped at irregular intervals for about 600 feet (180 m.) along the strike; the stopes have a maximum width of 6 feet (1.8 m.) and depths varying from 5 to about 30 feet (1.5 to 9 m.). So far as could be seen, the cassiterite is virtually confined to the fissures. The rhyolite is moderately firm and dense along the greater part of the stoped veins, but in a few places it is porous and contains fluorite and zeolites. The amount of tin recovered is not known.

The Golondrina mine is an old working on the west side of the Arroyo de América, north of the village of América. The deposit consists of pockety veins along irregular, branching fissures in moderately firm rhyolite containing small quantities of clay. The veins form a northwest-trending lode, which has been stoped at irregular intervals for about 300 feet (90 m.) along the strike; the maximum width of the stope is about 6 feet (1.8 m.). A shaft said to be 260 feet (80 m.) deep had been

46/ Rangel, Manuel, Apuntes sobre la distribución de minerales en el Estado de Durango: Soc. geol. mexicana, Bol. 7, p. 111, 1910.

sunk at one end but was inaccessible in 1941. The vein material apparently contains a large percentage of specularite, for miners who were reworking the dumps found little but specularite, and some veins exposed in the open cuts along the lode were also largely specularite. The quantity of tin recovered is not known.

A short distance north of the Golondrina mine a vein had been discovered, only about a week before the authors' visit, under the gravel in the Arroyo de América in the course of placer mining. A shaft had been sunk into the rhyolite bedrock to a depth of 10 feet (3 m.), and the miners were concentrating orange-colored cassiterite from the soft, porous rock along the vein. Much of the cassiterite was being lost in panning, and some of it was so fine that it colored the water orange.

A small inclined shaft 15 feet (4.6 m.) deep, located on the east side of Arroyo de América at its junction with Arroyo de Potrillos and at an altitude about 100 feet (30 m.) above the bottom of the valley, exposes an irregular vein 2 inches (5 cm.) in maximum width. The vein contains specularite, thin pencil-like crystals of topaz, and a little cassiterite. The mine was abandoned because of the leanness of the vein.

The Orosco mine, a mile and a half (2 km.) north of the Candelaria mine, consists of a group of half a dozen shafts and some small cuts excavated at irregular intervals for about 1,000 feet (300 m.) along the strike of a moderately well defined fracture zone in the rhyolite. The deepest shaft was 60 feet (18 m.) in depth. The miners who were working in this shaft had discovered a pocket of ore from which they said they had been recovering about 220 pounds (100 kg.) of concentrates daily for three weeks. The concentrates probably contained about 40 percent tin. Other miners who were working in shafts on either side of this one were getting nothing at that time, although they had previously found small pockets of ore. This deposit seems very similar to the Grant and Candelaria deposits.

The Veintinueve de Junio mine, about three-quarters of a mile (1.2 km.) east-northeast of the Orosco mine, consists of a low narrow adit 460 feet (140 m.) long, driven along an ill-defined fissure in moderately hard rhyolite. Pockets of botryoidal cassiterite weighing as much as 55 pounds (25 kg.) are said to have occurred along the fissure. The width of the largest pocket mined is said to be 8 inches (20 cm.). Two small mines nearby, obviously not on the same fissure, were being worked, but the quantity of cassiterite being recovered was small.

Several other small mines were visited, but as they had long been abandoned no information was obtained as to their production. Some mines were being operated northeast of the small village of Sapiorís, and it was reported that a large pocket of high-grade ore had been discovered in one of these, but the authors did not visit the mine nor verify the report. Many other small deposits in this district have been mined and forgotten.

Placer deposits.--Most of the tin produced in the Sierra de San Francisco in recent years has been recovered from placer deposits. It is said that about 2,000 miners work these placers during the rainy season. Assuming that 100 tons of tin a year is produced in the district, the average annual production of each miner is worth less than $50 (United States currency). The largest deposits are in the Arroyo de América, the Arroyo de Sapiorís, and the Arroyo de Liendres, and many of the tributaries to these arroyos contain small placers. Other deposits are merely soil mantle on the hillsides below the vein deposits. It is probable that most of the placer deposits in the district are already known but that many of them are left unworked because it has been possible to mine deposits of higher grade.

As the recovery of cassiterite from the gravel is poor and the small dumps cover patches of unworked ground, seemingly worked-out deposits may at some future time be reworked.

The only part of the Arroyo de América that may contain a volume of gravel large enough to warrant mining with machinery extends 3,300 feet (1 km.) upstream and 5,900 feet (1.8 km.) downstream from the settlement of América. The average thickness of the gravel in this 8,200-foot stretch may be 5 feet (1.5 m.), and its total volume about 100,000 cubic yards (76,000 cubic meters). The percentage of tin in this gravel cannot be closely estimated for want of accurate sampling, but it is certainly low--perhaps too low for profitable mining by any method. The abundance of large boulders, moreover, is detrimental to mining. There is another body of gravel in this arroyo in the vicinity of the Golondrina mine, but it is only about one-third as large. There are also gravel deposits near the junction of Arroyo de América with Arroyo de Potrillos, but they appear to be of extremely low grade. Water flows in the arroyo during most of the year.

In the Arroyo de Sapiorís, which is merely the upper part of the Arroyo de América, gravel deposits extend from a point about 4,900 feet (1.5 km.) upstream from the settlement of Sapiorís to a point 8,200 feet (2.5 km.) downstream from Sapiorís. The arroyo in this section may contain over 200,000 cubic yards (152,000 cubic meters) of gravel, having a maximum thickness of about 25 feet (7.6 m.) and consisting principally of material less than 4 inches (10 cm.) in diameter. The grade of this gravel also is unknown, but it may contain more than half a pound of tin per cubic yard (0.02 percent). Water flows in the arroyo only during the rainy season.

The Arroyo de Liendres, in which water flows during most of the year, contains gravel deposits for a distance of 6,500 feet (2 km.) upstream from its junction with the Arroyo de Tejabanes.

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(See pl. 31.) The maximum thickness of the deposit is about 15 feet (4.6 m.) and averages about 8 feet (2.4 m.). Most of the material is less than 4 inches (10 cm.) in diameter. The volume of gravel in this deposit may approach 200,000 cubic yards (152,000 cubic meters). The tin content of the deposit is unknown, but it may exceed half a pound of tin a cubic yard (0.02 percent).

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