Geology of the Quicksilver Deposits of Canoas, Zacatecas Mexico

By DAVID GALLAGHER

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By David Gallagher

ABSTRACT

The Canoas quicksilver deposits and the manner in which the structure that controlled their localization is reflected by later structures suggest a method of scientific prospecting for deposits that may be buried elsewhere beneath similar rocks.

The deposits at Canoas, in the desert country of southeastern Zacatecas, Mexico, have produced about 30,000 flasks (870,000 kg) of quicksilver since their discovery in 1878. The mines are at an altitude of 2,250 m above sea level in the top of the Mesa de Canoas, which is part of an isolated group of mountains composed of rhyolitic volcanic rocks. These mountains rise about 250 m above the general level of the central plateau of Mexico, which is here underlain chiefly by Jurassic and Cretaceous limestone.

The rhyolite is the most widespread rock in the mapped area, forming all the mesas. It generally inundated the entire region. Flow layering is remarkably well developed in it, consisting of layers 2 to 5 mm thick separated by discontinuous fracture planes that stand open a fraction of a millimeter and are coated with a white powder of feldspar and tridymite. Contours of the contact between the overlying rhyolite and the underlying latite and perlite reveal a pronounced dome, and the field evidence indicates that this dome was formed tectonically after the formation of the perlite.

The only valuable mineral deposits known at Canoas are the quicksilver deposits; they have been found only in the top of the latite dome, which was much fractured during the doming process. The latite at the top of the dome has been subjected to two alterations. Much of it was altered to halloysite by acid solution. It was then further altered by alkaline solutions which deposited abundant opal and some montmorillonite, chalcedony, and cinnabar. During the alkaline mineralization, which may have been colloidal, a second period of fracturing occurred. The localization of the ore was controlled primarily by the latite dome itself and secondarily by the major zones of fracturing within it.

The ore zone consists essentially of a stockwork in the crest of the dome, at least 400 by 250 m in horizontal extent and grading downward, between 20 and 40 m in depth, into six major lodes of diverse orientation that form its roots. The lodes are zones up to about 10 m wide in which the effects of fracturing, brecciation, alteration, and mineralization are more intense than in the surrounding rock into which the lodes grade laterally. The principal mines are at the places where two or more of these six major lodes intersect.

The near-surface stockwork has been mined to exhaustion in about a thousand holes, but the dumps, gob, and unmined ground probably constitute a reserve of several million tons of low-grade ore from which the quicksilver might be recovered at a profit by large-scale methods under favorable price conditions. One of

the lode intersections has been inadequately explored to a depth of 82 m, but none of the others has been explored below a depth of 40 m. Adequate exploration of these lode intersections might result in the discovery of quicksilver ore, but because of the stockwork-with-roots structure of the ore zone, the lower parts of the deposits cannot be expected to yield more than a fraction of the amount of quicksilver already produced at Canoas.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The quicksilver camp of Canoas, in the State of Zacatecas, Mexico, is at longitude 101°54′30″ W. and latitude 22°11′ 44″ N., as measured on the "Million Map" of the American Geographical Society, edition of 1932 (fig. 6).

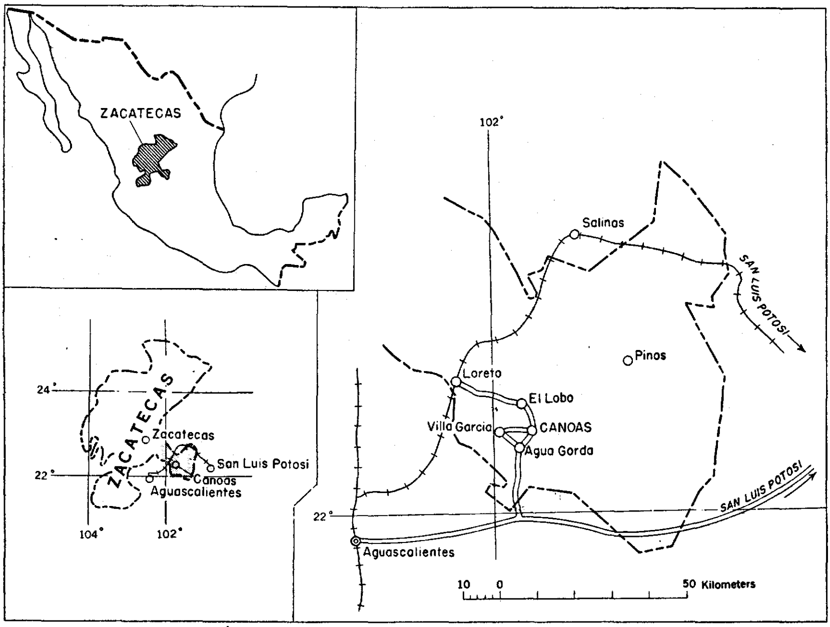


FIGURE 6.—Index map showing the location of the Canoas quicksilver district, Zacatecas, Mexico.

Canoas is 16 km east, by all-weather dirt road, of the railroad station at Loreto, which is 59 km by rail northeast of the city of Aguascalientes on the Aguascalientes–San Luis Potosí branch of the Ferrocarriles Nacionales de México. Canoas is also accessible by a 56-km dirt road that extends in a general north-northwesterly direction from the Aguascalientes–San Luis Potosí macadam highway at the place where it crosses the line between the States of Aguascalientes and Jalisco, 24 km east of Aguascalientes city or 156 km west of the city of San Luis Potosí.

FIELD WORK AND ACKNOWLEDGMENTS

This study is one of the geologic investigations conducted in Mexico by the Geological Survey, United States Department of the Interior, in cooperation with the Dirección General de Minas y Petróleo, Secretaría de la Economía Nacional de México, and the Instituto de Geología, Universidad Nacional Autónoma de México, as part of the geologic program in the American Republics sponsored by the Interdepartmental Committee on Scientific and Cultural Cooperation under the auspices of the United States Department of State.

Field work was done between October 25, 1943, and March 6, 1944. A topographic and geologic map of 15.4 sq km was made by plane table and alidade at a scale of 1:10,000 and with a contour interval of 10 m; the principal mine workings were mapped at a scale of 1:500.

The work was greatly facilitated by the hospitality and friendly cooperation of Thomas B. Miller, owner of the Compañía Minera Metalúrgica, S. A., and his brother, J. Crosson Miller, to whom the author wishes to express his thanks. The work benefited from brief but stimulating discussions in the field with Rafael Pérez Siliceo, Henry Vizcaino, and John G. Barry. The program was directed in Washington by John Van N. Dorr 2d and in Mexico by William F. Foshag.

Much assistance has been received from colleagues of the U. S. Geological Survey. C. S. Ross identified the minerals and advised on their genetic significance; Robert L. Smith examined some of the rocks; and J. J. Fahey, Michael Fleischer, and others contributed stimulating suggestions. The manuscript was read critically and greatly improved by H. G. Ferguson, N. D. Stearns, W. C. Smith, G. F. Loughlin, W. T. Schaller, and W. D. Johnston, Jr.

GEOGRAPHY

TOPOGRAPHY

The part of central Mexico in which Canoas is situated consists essentially of a great, flat desert, at a general altitude of about 2,000 m above sea level, underlain by Jurassic and Cretaceous limestones. Scattered over the desert are numerous detached mountain ranges, rising a few hundred meters above it and composed of Tertiary rhyolitic volcanic rocks. The Canoas quicksilver camp is situated on one of these rhyolite mountain ranges at an altitude of 2,250 m above sea level.

The quicksilver mines and the little village of Canoas are on the southern part of the Mesa de Canoas (pl. 7), which trends north-northwest and lies between the northwestward-flowing Arroyo de Canoas on the east and the northward-flowing Arroyo de los Mimbres on the west. These two streams converge at the northern end of the Mesa de Canoas, at a place called El Travesaño, and then continue in a general northerly and northeasterly direction toward the village of El Lobo, near which there is a confluence with the Arroyo de las Abujes. The Arroyo de las Abujes drains northward from the east side of the next mesa east of Canoas, variously called in its different parts, from south to north, Mesa de las Palomas, Mesa de La Concepción, and Mesa del Lobo. The Mesa de Canoas is flanked on the west by the large, flat-topped Mesa de Carmona and on the southwest by the Mesa de los Canelos. The drainage westward from these two mesas is called the Arroyo de los Colorados. The southern ends of the Mesa de las Palomas, Mesa de Canoas, and Mesa de los Canelos are truncated by a southwestward-trending escarpment which forms the northwest wall of the large Valle del Arenal, in which the Arroyo del Picacho drains southwestward, is joined by the Arroyo de los Colorados near the town of Agua Gorda, and disappears in the desert a few kilometers to the south.

VEGETATION

Vegetation is sparse and consists of short dry grass, some sage, thorn-bearing shrubs, and several varieties of cacti. Joshua trees are scattered over most of the mapped area and are unusually abundant and large on the Mesa de Carmona. There is no usable timber in the region, and even firewood is scarce.

POPULATION

The region is sparsely populated. In the lowlands tiny ranches and dilapidated haciendas occur every few kilometers, supported by marginal farming and cattle raising on a self-subsistence, rather than a commercial, basis. The mountain areas are practically uninhabited, except by a few goatherds with their flocks. The population of Canoas village varies with the price of mercury. At times when the price was high, the population has exceeded a thousand, but early in 1944 it diminished to only a few hundred, and by the summer of 1944 the town was almost deserted. Mine labor is cheap and abundant throughout the region, but not highly skilled.

WATER

Water is very scarce. The stream beds carry torrents at times during the rainy season, from June to September, but throughout much of the year they are entirely dry. Barely sufficient water for household use is obtained from a few small seeps and stagnant water holes. Mine water from the bottom of the deepest shaft, La Cruz (85 m deep), amounts to only 1 or 2 cu m daily.

HISTORY

The following account of the early history of Canoas is summarized from information kindly gathered for the author by Dr. Carlos Rodríguez, presidente of the nearby town of Villa García, who questioned several of the older inhabitants. The later history was obtained from the records of the Compañía Minera Metalúrgica, S. A.

In 1878 Sr. Carlos Ibarra, of Pinos, Zacatecas, engaged Gertrudis Lemas, Esteban Guerrero, Miguel Guerrero, and Sabuás Magallanes to prospect for quicksilver ore in the region south of Pinos. They visited the old Santa Margarita mine at Villa García and the nearby hill called El Capulín, but at both places the quicksilver ore was very low in grade. Sr. Ibarra appealed to President Porfirio Díaz, who responded by sending two engineers, Sr. Emilio Mussón and a man named Goyugo, to assist in the prospecting. Indications of cinnabar were found on the east side of the Mesa de Canoas near the present mines, and one of the prospect holes penetrated the rich San Antonio ore shoot.

About 1900 the mine was sold to an American, John Walker, who worked it until about 1910. Then for 3 years it was operated for him by an American named Hogg. Walker returned in 1914 and worked the mine until 1918, when he abandoned it.

In 1919 the mine was redenounced (to "denounce" under Mexican mining law is to "stake claim to") by Sr. Ibarra and two men named Salinas, who worked the property until 1929, when Sr. Ibarra withdrew. The Salinas men continued to work the property until 1934, when it reverted, as at all times of abandonment, to the small, independent local operators called "gambusinos."

The property was acquired in 1939 by Sr. Andrés Vallejo, who worked it chiefly by allowing the gambusinos to continue to operate and pay him a 25-percent royalty in ore.

In the latter part of 1941 the Compañía Minera Metalúrgica, S. A., was organized by Claude D. Moll and Sr. Vallejo. In June 1942 Mr. Moll bought out Sr. Vallejo's interest and installed a 40-ton Herreshoff furnace. It was Mr. Moll's plan to clean out the old workings, preparatory to deeper exploration and development, and to furnace the low-grade fills thus obtained, but the venture failed to yield the expected quicksilver recovery, and early in 1943 Mr. Moll sold the property to Thomas B. Miller and Enrique López. Production continued on a small scale, and a development program was partly carried out before the enterprise was closed down early in April 1944 coincident with the collapse of the price of mercury.

GEOLOGY

The mapped area consists essentially of mesas carved in extensive flows of rhyolite. The structures in the rhyolite reflect the influence of an underlying dome of latite against and around which the rhyolite flowed. The quicksilver ore is localized in the top of the latite dome. These volcanic rocks probably rest on an underlying basement of Jurassic or Cretaceous limestone.

GEOMORPHOLOGY

Study and interpretation of the geomorphology of the area is essential in two respects. The geomorphology plays an important part in the interpretation of (1) the structures in the rhyolite, which afford a means of scientific prospecting for ore deposits buried elsewhere beneath similar rocks, and (2) the conditions under which the quicksilver ore was deposited. The land forms and the geomorphic history of the mapped area cannot be fully interpreted without detailed mapping and a study of a much wider area, but some conclusions are tentatively presented on the basis of the observed evidence.

The geomorphic development of the area has been brought about largely by the streams, and they have been controlled primarily by the structure of the flow layering in the rhyolite. The flow layering of the rhyolite is rarely horizontal and in places is vertical, as it has been contorted into "anticlines" and "synclines." Although these terms, in a strict sense, refer to convex-upward and concave-upward folds in sedimentary rocks induced by deformation after the rocks were formed, they are here used, for lack of better terms, to refer to similarly disposed structures that formed in the still plastic lavas as a result of flow movement before the lavas had become consolidated.

The major streams, for the most part, have been initiated in places where the flow layering is horizontal, as in the vicinity of El Travesaño, and have progressed headward along synclines in the rhyolite. This headward development is particularly well shown by the Arroyo de Canoas, by the tributaries in the northern part of the mapped area, which flow both from the Mesa de Carmona and from the Mesa del Lobo, and also by the headwaters of the Arroyo de los Mimbres.

The flow layering of the rhyolite is in part related to the form of the underlying dome of latite, so that the stream pattern likewise is in part indirectly related to this domal structure. The headward progress of the Arroyo de Canoas followed the general strike of the flow layering, taking advantage of the synclinal depression between the northeastward-dipping flow layering in the rhyolite that conformed to the northeast slope of the latite dome and the southwestward-dipping flow layering in the rhyolite of the Mesa del Lobo.

The history of the Arroyo de los Mimbres appears to be more complex. It originated as a tributary of the Arroyo de Canoas, initiated in the horizontal flow layering at El Travesaño. Its headward progress was accelerated by the northerly dip of the flow lavering in the rhyolite sloping down the north side of the latite dome. When it had cut deeply enough to reach the more easily erodible latite beneath the rhyolite, it progressed headward more rapidly and captured the Arroyo del Palmar, which was probably the headwaters of the Arroyo de los Colorados.

This unusual localization of the major streams along synclines is interpreted to mean that the streams are not superposed, but are consequent upon an initial surface that was never buried under a cover of younger rock; also, that the drainage is still in a very early stage of development.

Although the major streams are localized along synclines in the rhyolite, some of the tributaries are adjusted to other structures in the flow layering. In places the second-order tributaries are adjusted to zones of locally intense crenulation, and some of the streams that plunge over the southern escarpment do so at places where the flow layering is vertical. Many of the third-order tributaries are adjusted to low anticlines whose limbs dip about 5°.

A few segments of some of the streams are controlled by joints. These joints appear to have merely a local effect, such as causing individual small bends in the streams, and as an influence on the stream development they are entirely subordinate in importance to the structures in the flow layering of the rhyolite.

In many places the mesas are bounded by steep cliffs 5 to 50 m high. Because of their imposing aspect they assume predominance in one's visual impression of the region, but actually less than half the periphery of each mesa is bounded by cliffs. In many places the sides of the mesas are steep, bouldery slopes, and in some places they are dip slopes conforming to the flow layering of the rhyolite.

Riding through the valleys one sees the rhyolite best in the cliffs because they are so conspicuous. As the cliffs are developed only where the flow layering is horizontal, the casual observer might be misled into thinking that the mesas are carved in horizontally layered rhyolite. In most places, however, the flow layering is not horizontal. Even where it is steeply inclined within 1 or 2 m of the edge of a cliff, the flow layering swings to horizontal at the brink of the cliff itself.

Several factors appear to be involved in limiting the development of cliffs to places where the flow layering is horizontal. The rhyolite disintegrates by spalling in flakes parallel to the flow layering, thus developing plane surfaces. Where such surfaces are inclined, (1) the loosened fragments are readily washed away, and (2) rain water can more easily enter the upturned, and therefore exposed, fractures parallel to the flow layering. Where such surfaces are horizontal, rain water flows more slowly across them and can less easily enter the horizontal fracture planes. Therefore, where the flow layering is horizontal, the rhyolite is more resistant to erosion than where the flow layering is inclined, and it stands in cliffs.

Rain water can most readily attack the horizontal rocks of the cliffs along vertical joints; hence the crude joint columns in the cliffs have been accentuated by erosion into picturesque columns and spires. A slight inward dip of the flow layering, into a mesa, has aided the formation of the columns and spires, and in a few places the concentration of rain wash in what was originally a little synclinal structure parallel to the cliff face has developed a deep chasm, 1 or 2 m wide, separating the cliff from the mesa.

The three principal mesa masses are more or less flat-topped and more or less covered with a thin mantle of soil. The surface of the Mesa de Carmona is so flat that a car can be driven all over it more easily than on the roads of the region. Of the three mesas, the Mesa de Canoas has the most irregular upper surface. It is highest at its southern end and becomes lower, narrower, and more dissected northward toward its terminus at El Travesaño. The surface of the eastern mesa, named Palomas-Concepción-Lobo, is intermediate between the flatness of the Mesa de Carmona and the hilliness of the Mesa de Canoas.

The flat surface of the Mesa de Carmona truncates the contorted structures in the flow layering of the rhyolite. This truncation is true also of the tops of the other mesas, but to a less marked degree. Vesicular lava, indicative of the top of a flow, is absent from all the mesas. Evidently the tops of the mesas have been subject to some erosional planation. The blocky, vesicular character of the top of the rhyolite probably allowed it to be quickly weathered and easily removed by erosion. However, the extent of this planation and the amount of rock removed were probably small, because—as has already been stated—the localization of the principal streams along synclines indicates that the drainage is consequent upon an initial surface and that the geomorphic development is still in a very early stage.

Thus a study of the geomorphology reveals that (1) the rhyolite is nearly in its pristine state, (2) the region was not overlain by younger rocks, (3) the structure of the rhyolite cannot be judged with assurance by viewing its disposition in cliffs, and (4) the ore must have been deposited at very shallow depth or near the surface.

ROCKS

The mapped area consists chiefly of volcanic rocks: rhyolite, which blankets the area and forms the mesas, and latite, which is locally revealed as a dome beneath the rhyolite. Small quantities of sandstone, tuff, and perlite are present, a thin loess covers the uplands, and valley deposits lie in the valley bottoms. The quicksilver deposits are in the top of the latite dome.

BASEMENT ROCKS

The basement rocks buried beneath the rhyolite mountains are probably the Jurassic or Cretaceous limestones that underlie much of this part of Mexico, as limestone has been found at several places within a few kilometers of Canoas.

The Valle del Arenal is probably underlain by limestone. This valley is geomorphically distinct from, and unrelated to, the rhyolite mountains; it is geomorphically a part of the great desert flats of this part of central Mexico, which are elsewhere known to be underlain by limestone. Much of the valley floor is coated with caliche, which, in itself, does not prove the presence of limestone below, but admits of that possibility. Semirounded limestone pebbles and cobbles litter the surface in places and are found imbedded in some of the caliche. If the Valle del Arenal is underlain by limestone, the mountain mass also is probably underlain by limestone at some unknown depth.

LATITE

The latite, which forms a dome beneath the rhyolite, is best seen west and northwest of the mines, where it is well exposed along the western flank of the Mesa de Canoas. It is the principal rock seen in the mine workings, but nearly all the latite seen underground has been greatly altered during the deposition of the ore. The latite is probably of wide regional extent beneath the rhyolite, as suggested by its exposure also along the southern escarpment.

The latite is a buff to red-brown, medium-coarse, granular volcanic rock composed of phenocrysts of quartz, andesine, and some biotite and pyroxene, making up 20 to 50 percent of the rock, in a fine-grained groundmass of feldspar and tridymite. The phenocrysts of andesine are more abundant than those of quartz. They are idiomorphic and approximately equidimensional, and they range in size from 2 to 6 mm. Most of the ones seen were altered, because those in the natural exposures on the slopes have been weathered and those exposed in the mine workings were altered in connection with the mineralization. The quartz grains are generally round and 1 to 2 mm in diameter.

The latite shows flow layering, but in many places this structure is not pronounced and may even be lacking. Where it is clearly visible the layers are generally about 20 cm thick and are indicated more by alinement of the constituent mineral grains than by any tendency to break into layers.

The latite weathers more readily than does the rhyolite, and it is more easily eroded. On weathering the surface of the latite changes in color to chestnut brown, and much of the latite now at the surface is friable. In the saddle just north of the mines the ground is littered with chalcedony amygdules that have accumulated as a residual deposit on the surface after being liberated from the latite by weathering of the surrounding rock.

These chalcedony amygdules occur in places in the upper 1 or 2 m of the latite. They are irregular to flattish in form and are a few millimeters to 2 or 3 cm in diameter. In some places they are so numerous and so closely spaced that they form an almost continuous layer resembling a chalcedony-filled fracture. This amygdule zone evidently represents the original vesicular top of the highest latite flow, and the fact that it occurs in only a few places and is absent throughout much of the exposed upper part of the latite indicates that the latite was subject to weathering and some erosion before the overlying rocks were formed.

The chalcedony in the amygdules is botryoidal, with hemispheres 2 to 5 mm in diameter. It generally lines the vesicles completely but does not fill them. Most of this chalcedony is white, but much of it has a bluish tint and a little of it is amethystine or pink. In a few of the amygdules the colorless opal, hyalite, has been deposited on the chalcedony in a smaller-sized botryoidal crust.

The radial fracturing characteristic of "thunder eggs" is absent; therefore it is concluded that these amygdules are merely chalcedony-filled vesicles. The walls of the vesicles were evidently somewhat silicified during the formation of the chalcedony, and for this reason the amygdules as a whole are resistant to weathering and remain as a residual accumulation on the surface in a few places.

SANDSTONE

A massive, medium-grained, easily friable sandstone composed of rounded quartz grains is found in a few places both on the surface and underground in the mines. Owing to the color of the cementing material, the rock as a whole is buff to olive in color. The largest surface outcrop of this sandstone is in the head of the tributary valley immediately west of the town of Canoas. Here the sandstone dips west in the direction of slope of the west side of the latite dome.

Small bodies of similar sandstone have been found in a few places in the mines. They are not well exposed, however, because no cinnabar has ever been found in the sandstone at Canoas and mine headings that encountered it were stopped almost immediately. One of the best exposures is in "winze 48," which is not a true winze but is called by that name locally, in the northwestern part of the mined zone. It encountered sandstone that dips northwest at a depth of 30.0 m below the winze collar, passed through it to a depth of 37.5 m, then passed through the usual latite and entered more sandstone at a depth of 43.5 m, and continued in it to the bottom of the winze at 51.8 m. Among the other occurrences of sandstone in the mines are sandstone dipping north in a heading north of La Cruz shaft and sandstone dipping northeast in the eastern part of the San Antonio mine.

Although corroborating exposures are poor and few, the sandstone evidently occurs as lenses interbedded with the latite flows. Thus the sandstone reveals that the latite consists of individual flows whose individuality cannot otherwise be readily seen. The presence of the sandstone indicates that sufficient time elapsed between the deposition of some of the latite flows for water-deposited material to accumulate, presumably in hollows on the surface. It is particularly noteworthy that wherever they have been found these sandstone masses conform in dip to the quaquaversal dip of the latite dome.

Coarse-grained sandstone lies on top of the latite in an outcrop in the west bank of the Arroyo de los Mimbres directly west of the mines at coordinates 500 W. and 300 N. This sandstone contains layers composed of pebbles which are generally 0.5 to 1 cm in diameter but which are larger in some layers. One pebble 10 cm in diameter was found. These pebbles are semirounded to well rounded and represent a number of rock types that are foreign to the immediate vicinity. Some are andesite, and others are rhyolites of various colors and textures not found elsewhere in the mapped area.

PERLITE

Overlying the latite is a layer 1 to 2 m thick of black, glassy perlite. The perlite is a separate rock, not merely the chilled upper surface of the latite; it does not occur everywhere over the top of the latite. It can be seen in most places where the top of the latite or the bottom of the rhyolite is exposed: (1) along the Arroyo de los Mimbres, (2) in the vicinity of the mines, and (3) near the road at the top of the southern escarpment. On the western slope of the Mesa de Canoas, just northwest of the mines, there are two layers of perlite separated by about 10 m of latite. A little perlite has been found in a few places underground in the mines. Evidently it occurs as thin lenses interbedded with the latite flows and not uncommonly associated with the interbedded sandstone lenses. Perlite is absent, however, at the contact between the latite and the overlying rhyolite where the road to Villa García crosses the Arroyo del Palmar. It appears to be absent also along the southwestern part of the southern escarpment, but exposures here are poor because of talus from the rhyolite cliffs above.

In some places the perlite exhibits flow layering, but this flow layering shows clearly on weathered surfaces only and is almost undetectable on freshly broken surfaces. Even though the rock is very tough and massive, hard to break, and resistant to both chemical and mechanical weathering, it does not form cliffs.It is a useful field aid in locating the contact zone between the top of the latite and the bottom of the rhyolite.

The perlite is composed chiefly of black glass whose conchoidal fracture makes it appear to consist of rounded glassy fragments a few millimeters in diameter. Throughout the glass, which is filled with microlites, are numerous phenocrysts comprising about 10 percent of the rock. The phenocrysts are andesine, commonly tabular to roughly equidimensional and 2 to 7 mm in length, and biotite, hypersthene, and magnetite.

In a few places the perlite contains round inclusions of silicified latite, about 2 to 3 cm in diameter, each containing a chalcedony-lined cavity. These inclusions are not common, but generally where one is found others are present. They are identical with the chalcedony-lined amygdules weathered out of the top of the latite and now lying on the surface in a few places; accordingly, those in the perlite are interpreted as similarly weathered-out chalcedony-lined amygdules that were lying on top of the latite at the time the perlite lava flowed over it, picking a few of them up as inclusions. These inclusions therefore afford further evidence that the latite had undergone some weathering and erosion before the deposition of the perlite, and they show that the perlite is not merely the chilled top of the latite, but is a separate and later flow.

Additional evidence of the relationships of the various rocks to one another can be seen in the northwesternmost of the small mine openings (pl. 10). In the bottom of this "shaft" is the latite, with a somewhat irregular upper surface. It is overlain by soft, fine-grained pink tuff in a layer 20 cm thick. On top of the tuff is 1 m of perlite with an undulatory bottom surface and a bouldery top showing clear evidence of spheroidal weathering. On this, and penetrating down into the openings between the weathered spheroids of perlite, is the rhyolite. The bottom of the rhyolite is granular throughout a thickness of about a meter. This granular bottom zone grades upward into a second zone about a meter thick in which there are numerous vesicles, flattened parallel to the contact. The vesicles range up to 2 or 3 cm in width and 2 to 3 mm in height. They diminish upward in size and number, with a gradation, within about 2 m, into the normal, flow-layered rhyolite. This exposure clearly demonstrates a time break between the latite and the perlite and again between the perlite and the rhyolite.

TUFF

In a few places a little soft, friable, fine-grained tuff, yellowish, creamy, or pink in color, lies on top of the perlite, separating it from the overlying rhyolite. The best exposure of this tuff is the outcrop of the contact in the west bank of the Arroyo de los Mimbres directly west of the mines. Here the tuff is pisolitic. In one part of the outcrop the pisolites are 2 to 3 mm in diameter and comprise 50 to 70 percent of the rock, but a few centimeters higher up the pisolites are 1 cm in diameter and constitute only about 5 percent of the rock. They are perfectly round, have a concentric structure with layers 0.1 mm thick, and are composed of mustard-colored cherty silica.

RHYOLITE

Rhyolite is the most widespread rock in the mapped area, forming the tops of the three main mesa masses and generally blanketing the entire mountain region. It is a pinkish or violet-brown rock consisting of a very fine grained groundmass of feldspar and tridymite, that contains phenocrysts of quartz and sanidine. These phenocrysts generally make up 5 to 10 percent of the rock, although in some places they are more abundant. The quartz phenocrysts are fewer in proportion to the feldspar phenocrysts than in the latite, but, as in the latite, they are rounded and many of them are smoky quartz. The sanidine phenocrysts are generally bright and pearly and, commonly, almost transparent. They are euhedral and tabular, with their greatest dimension about 2 to 3 mm, although a few of larger size were found.

The rhyolite shows well-developed layering. The individual layers are commonly 2 to 5 mm thick and are separated from one another by fracture planes coated with a fine white powder consisting of minute feldspar crystals and tridymite crystals. These fractures are discontinuous, so that at intervals adjacent layers are welded together, but in many places the fractures stand open a fraction of a millimeter. The rock breaks easily along these fractures, giving many of the outcrops an almost shaly aspect. The individual layers are actually lenticular and generally cannot be traced laterally for more than a few meters. Furthermore, they are not perfectly flat and uniform, but in general are slightly irregular or wavy.

In addition to this type of layered structure in which the layers are separated by fracture planes, another type of layering in places is due to concentration of feldspar phenocrysts into parallel layers. An excellent example may be seen on the west slope of the Mesa de La Concepción, northeast of the mines along the footpath to El Lobo. Here, at intervals of a few centimeters, the grayish rhyolite contains white layers richer in feldspar phenocrysts. These layers range in thickness from 2 mm to 2 cm. Traced laterally, they are found to be lenses that pinch out within a few meters. Both types of layering are believed to be caused by flow movement of the lava (pp. 64–69).

It is not always as easy to distinguish between the latite and the rhyolite in the field as one might suppose from the descriptions. The following tabulation of contrasting features may be helpful to prospectors:

Comparison of latite and rhyolite in the Canoas area

LATITE	RHYOLITE
Occurs low on slopes or on eroded flats.	Occurs high on slopes, in cliffs, and on mesa tops.
Makes inclined slopes and only a few small cliffs.	Forms conspicuous cliffs.
Restricted in outcrop extent.	Widespread distribution.
Medium- to coarse-grained.	Medium- to fine-grained.
Generally about 50 percent phenocrysts.	Generally about 10 percent phenocrysts.
Poorly defined layering; layers about 20 cm thick.	Extremely well defined layering; layers about 2 to 3 mm thick.
Buff to red brown.	Gray, violet gray, light cocoa brown, or pink.
Weathered surface chestnut brown.	Weathered surface pale brownish gray.
Contains chalcedony-lined vesicles.	No chalcedony in vesicles.
Associated with interbedded perlite lenses and sandstone lenses.	No interbedded rocks, although tuffs might be found.
Number of quartz phenocrysts not much less than number of feldspar phenocrysts.	Number of quartz phenocrysts much less than number of feldspar phenocrysts.
Gray-green lichens common, but no yellow-green lichens on outcrops.	Some gray-green lichens occur, but brilliant yellow-green lichens and some orange lichens are common on outcrops.

LOESS

The upper surfaces of the rhyolite mesas are partly mantled by a thin soil that supports a growth of short dry grass. This soil is light gray in color, uniformly fine-grained, and structureless. It lies directly on the unweathered rhyolite and is therefore not a soil in situ. It tends to occur in hollows in the surface of the rhyolite and in places that are sheltered from the wind. As the geomorphic history of the region precludes its having been deposited by streams, it is evidently of eolian origin and therefore loess.

VALLEY DEPOSITS

The surface material of the Valle del Arenal consists largely of a deposit of white calcareous evaporite, a few centimeters to 2 m thick. This evaporite overlies an unknown thickness of crudely stratified alluvial sands and gravels, which are composed of volcanic detritus and which are well revealed in the vertical banks, as much as 22 m high, of the Arroyo del Picacho.

The other valleys of the mapped area are underlain by rhyolite and contain calcareous and detrital valley fill that on casual inspection appears to be similar to the evaporite in the Valle del Arenal but actually possesses essential differences that indicate a different origin. This type of valley fill is best exposed along the Arroyo de Canoas where the stream has cut through it and now flows on the bedrock surface of the rhyolite beneath. The valley-fill deposit is about 5 m thick in the stream banks near the center of the valley and wedges out laterally against the bases of the hills that form the valley sides.

This deposit is not a simple flood-plain alluvium, for it is made up of a mixture of genetically different components. At the sides talus and other colluvium merge into it. In places there are lenticular beds of alluvial sand and accumulations of pebbles worn to semiroundness by stream abrasion. Much of the material has probably been washed down into the valley bottom from the adjacent slopes and is therefore neither colluvium nor flood-plain alluvium in the sense of having been deposited by the main stream itself. Most of it is cemented with white calcareous material. It is crudely bedded in layers about half a meter thick, some of which contain about as much calcareous material as do the surficial deposits in the Valle del Arenal.

The accumulation of this large quantity of calichelike calcareous material within a catchment area that is underlain by rhyolitic volcanic rocks seems incongruous, but clear evidence of its origin can be found on the tops of the mesas. In some places where the thin loess has been stripped from the rhyolite, the rhyolite surface is partly crusted with a thin coat of white calcareous material. This crust occurs, for the most part, as disk-shaped patches 1 or 2 cm in diameter and 1 to 2 mm thick, with edges that round downward. In many places these small disk-shaped patches have coalesced to cover larger areas. Some small troughlike depressions, in the surface of the rhyolite, that have served to concentrate the flow of rills beneath the loess are partly filled with a hard cake of white calcareous material having a triangular cross section.

Evidently the loess is calcareous in composition, because it is dust acquired from the surrounding desert flats that are largely underlain by Jurassic or Cretaceous limestones and these calichelike deposits are made up of calcareous material leached from the loess by percolating rain water and precipitated on the rhyolite. They therefore show one of the steps in the process by which the calcareous material of the valley fills within the rhyolite mountains was derived by leaching from the loess and transportation in solution down the slopes into the accumulated rock debris lying in the valley bottoms in which it was deposited from the solutions by evaporation.

Geologic literature shows a wide diversity of opinion among geologists regarding the origin and definition of evaporites. The term "caliche," which seems an obvious choice for this material, has been used in so many ways and has been so variously defined that it now lacks a precise meaning. The consensus seems to be that a caliche is formed by the upward capillary leaching of soluble material and its deposition at the surface by evaporation. In this sense the surficial calcareous crust in Valle del Arenal may be a caliche, but in the same sense the material in the valley of Arroyo de Canoas is not a caliche, for it has been transported laterally.

STRUCTURE

Interpretation of the structural geology provides the principal key to an interpretation of the rocks and ore deposits at Canoas. The latite and its thin cover of perlite were tectonically domed, causing intersecting fracture zones near the crest of the dome. The fractures were the receptacles for the cinnabar ore that was subsequently deposited by mineralizing solutions. After the tectonic doming of the latite, and probably after the mineralization, the region was inundated by rhyolite that flowed from the southeast in a northwesterly direction, piling up against the latite dome, then splitting and flowing around both sides of it, coalescing beyond, and covering the region to a depth about level with the top of the latite dome.

This interpretation of the flow history of the rhyolite is the outcome of a detailed analysis of the flow structures in the rhyolite. It is evident that these flow structures reveal the influences, and hence the presence, of the latite dome around which the rhyolite flowed. The latite dome and the contained ore deposits at Canoas were not quite covered by the rhyolite. Had they been covered, they would have remained undiscovered. Similar study of rhyolite structures elsewhere could reveal the influences, and hence the presence, of another underlying dome, perhaps entirely buried by the rhyolite, thus affording a clue to a promising locality in which to prospect by diamond drilling for a buried ore deposit.

STRUCTURES IN THE LATITE

The latite is not well exposed. It is largely buried under the later rhyolite, and the few poor exposures on the sides of the Mesa de Canoas and elsewhere are obscured by talus from the rhyolite above. Although the latite was formerly exposed on the top of the Mesa de Canoas in the vicinity of the cinnabar deposits, except where mantled by the discontinuous layer of perlite, it has now been buried to a depth of 1 to 10 m by mine dumps. Only a small fraction of the near-surface mine workings is accessible. About half the deeper mine workings are accessible, but as most of them followed ore they are largely in latite that has been subject to wall-rock alteration during the mineralizing process. However, although for all these reasons the latite is poorly exposed, sufficient data are available to reveal the major features of its structure, and at Canoas these major features far outweigh the minor structures in significance.

In many places only a few meters intervene between the lowest outcrop of rhyolite and the highest outcrop of latite, so that it is possible to plot the contact zone accurately on the map. Aids to the location of the contact are features that indicate either the bottom of the rhyolite or the top of the latite. The bottom of the rhyolite is indicated lithologically by the presence of flattened vesicles or, less commonly, by flow breccia. It is suggested topographically by the break in slope at the base of rhyolite cliffs, a feature that also serves to locate the top of the latite. Much better evidence of the location of the contact is afforded by the chalcedony-lined amygdules characteristic of the top of the latite. Another reliable guide is outcropping perlite, which is rarely found more than a few meters downhill from the outcropping rhyolite.

Contours of the base of the rhyolite throughout much of its extent in the vicinity of the Mesa de Canoas where the latite is present, plotted on plate 8, show clearly that the latite under the Mesa de Canoas and beneath the rhyolite in that vicinity has a domal form. As this dome is the key to the localization of the quicksilver deposits at Canoas, the interpretation of its nature and origin is of primary significance.

It has already been shown that the latite was subject to some erosion before the formation of the overlying perlite, and the contours at the base of the rhyolite suggest at least one valley depression on the flank of the dome. The most obvious interpretation is that the latite dome is a hill that was carved in the latite during a period of erosion preceding the outpouring of the rhyolite. Much evidence, however, shows that this interpretation is incorrect.

The topography of the dome is not typically erosional, because valleys on the flanks are not sufficiently numerous and in their form are not characteristic of erosion. Amygdules indicating the top of the latite are found, not only on top of the dome, but principally high on its flanks, and they are particularly abundant near the head of, and extending down into, the principal "valley" on the northwest flank of the dome. Although some weathering and erosion of the top of the latite occurred before the formation of the perlite, the extent of both was very slight.

The perlite was sufficiently weathered to develop spheroidal weathering forms before it was overlain by the rhyolite. Evidence is lacking by which to determine whether the discontinuous distribution of the perlite was an initial feature or the result of removal of part of it by erosion. However, the distribution, thickness, and character of the perlite show that the latite dome was not an erosional feature but the result of tectonic doming.

Wherever the perlite occurs on top of the latite, whether high or low on the flanks of the dome, it is of essentially uniform thickness.

Had the latite dome existed before the perlite was formed, this would not be true. The fluid perlite lava would have flowed down the sides of the dome, and the perlite would have been thicker low on the flanks than high up near the crest of the dome. If the latite dome had existed before the perlite was formed, the perlite lava coming from a source other than the top of the dome would have crowded up against the dome, probably filling depressions adjacent to the dome rather than attaining uniform thickness even high on the flanks. If the perlite came from a vent on the top of the dome at least some evidence of that vent should have been discovered in the myriad of mine workings that fully explore the top of the dome, but none has been found. It is therefore evident that the perlite was deposited on the latite before the dome existed and that the perlite was involved with the latite in the process that formed the dome. This process was not erosion, and it is therefore concluded that the dome was formed tectonically.

That this is a structural dome of tectonic origin is confirmed by the quaquaversal dip of the latite flows as indicated by the attitude of the interbedded lenses of perlite and sandstone and also by the quaquaversal attitude of the thin layer of perlite on top of the latite.

The rhyolite was not deposited on top of the perlite until after spheroidal weathering had affected the upper surface of the perlite, indicating a lapse of time between the eruption of the perlite and the eruption of the rhyolite. This time interval is further corroborated by the presence of tuff in some places between the perlite and the rhyolite. Lastly, study of the structure of the rhyolite shows that during this lapse of time the tectonic doming of the latite and perlite was accomplished, for the structures in the rhyolite reveal that it flowed against and around the preexisting dome of the older volcanic rocks.

STRUCTURES IN THE RHYOLITE

The rhyolite is well exposed, and as the flow layering is well developed in it nearly everywhere, the structures in the rhyolite can be observed in detail. Over 2,000 strike and dip readings on the flow layering in the rhyolite were recorded in the field. These are summarized in simplified form for clarity of presentation on plate 8.

The attitude of the flow layering ranges from horizontal to vertical. The commonest structure are anticlines and synclines, but there are some homoclines, some zones of crenulation, some places in which vertical flow layering is so abundant as to look like isoclinal folding, and three small domes. Although the flow layering may pass from horizontal to vertical within 1 or 2 m the transition is commonly more gradual. Vertical flow layering passes into horizontal flow layering, not only laterally, but also along the strike; and the same change even occurs vertically, both upward and downward. In a few places a dip in one direction, when traced along the strike, is found to pass through the vertical to a dip in the opposite direction, indicating that some overturning has occurred, but in the absence of criteria for distinguishing top from bottom it is rarely possible to recognize it.

The form of the anticlines is different from that of the anticlines generally found in sedimentary rocks. Only parts of the large anticlines are exposed, but several small anticlines that are more fully exposed provide a key to the form of the larger ones.

This type of anticline (fig. 7) has a central portion in which the flow layering is vertical and parallel to the axial plane of the anti-

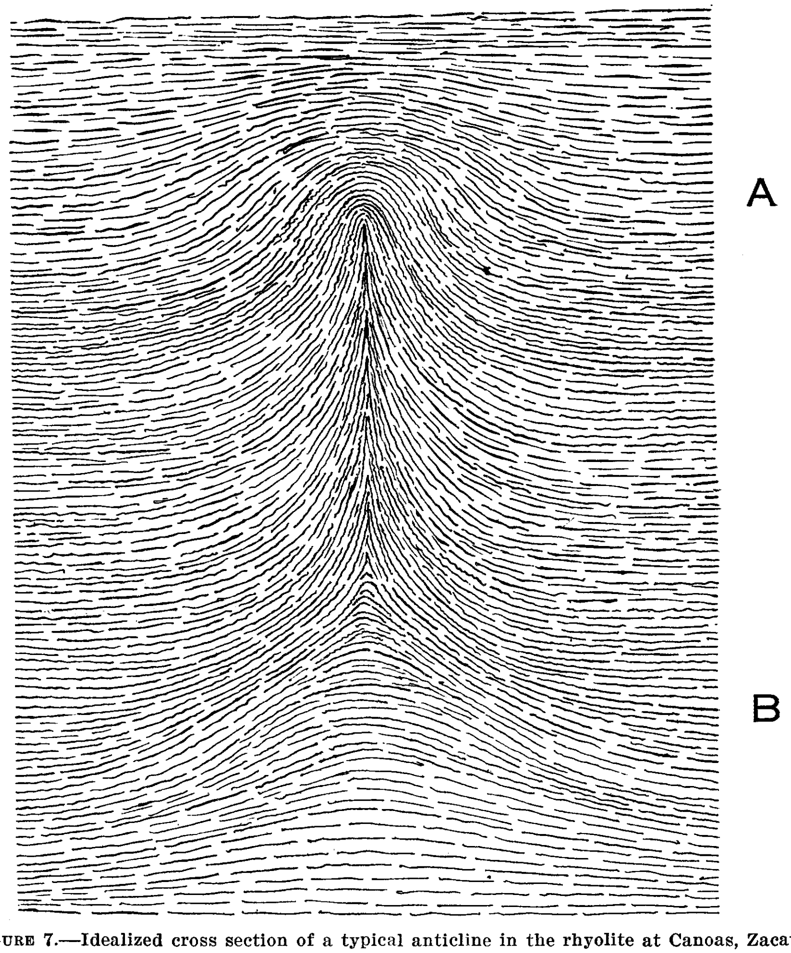


FIGURE 7.—Idealized cross section of a typical anticline in the rhyolite at Canoas, Zacatecas, Mexico, showing characteristic form.

cline. The central vertical flow layering passes laterally outward through intermediate dips to a horizontal position on the flanks of the anticline; furthermore, it passes both upward and downward into horizontal flow layering above (A) and below (B) the axial plane. The vertical distance from the top to the bottom of the small, fully exposed anticlines is about 10 m. This vertical dimension in the larger anticlines, such as the one in the southeastern part of the Mesa de Canoas, or the principal one in the Mesa de las Palomas, is about 100 m.

As the larger anticlines are only partly exposed, some show the upper part where the flow layering bends over the top, as in the usual anticlines seen in sedimentary rocks, but most of them show the vertical central portion and a few show the lower part.

In about a dozen places one or more elongated tubular cavities were found exactly in the axes of the anticlines. These holes are horizontal, or nearly so, and those that are slightly inclined have an inclination that conforms to the slight plunge of the anticline in which they occur. The holes range from 2 to 10 cm in diameter, and most of them are about a meter long, although one was found on the Mesa de las Palomas, at coordinates 1,830 E. and 370 N., that was longer than the reach of a 6-ft steel tape inserted into it as a probe. The flow layering bends around these holes. They are believed to be gas cavities that have been drawn out and elongated parallel to the direction of the flow movement of the rhyolite lava. It will be noted (fig. 7) that the lower part of the axial zone of this type of anticline is a zone of potential expansion, and in anticlines that are sufficiently well exposed to reveal the spatial relations these tubular cavities are found to be localized in this lower part of the axial zone.

On a few of the flow-layering surfaces, fluting marks with a wave length of 2 to 3 cm and an amplitude of a few millimeters are found. These are believed to be elongated parallel to the direction of the flow movement of the lava and are thought to have been formed somewhat in the manner of slickenside markings or glacial striae—that is, by the sliding of one mass over another. They were probably formed when the lava was still sufficiently plastic to allow flow movement but at the same time contained some parts that were relatively hard and therefore capable of grooving the surface of softer material over which they were moved. Although the orientation of the flow movement is shown by the flow-fluting marks, they do not reveal the direction of movement. Those in the southwest and west parts of the mapped area trend west; those in the northwest trend northwest; and those in the northeast part of the mapped area trend north-northwest. They are therefore radially disposed with respect to the southeast corner of the mapped area. They are remarkably uniform in orientation through large areas in which the attitude of the flow layering is extremely diverse, and in a few places where they are particularly well developed, notably on the small hills in the eastern part of El Cuije, they may be seen to pass up and down over folds without being diverted from their trend.

It is evident from an inspection of the structure map (pl. 8) that, in a broad way, the trends of the flow-layering fold axes are the same as those of the flow-fluting marks, and, taking into account also the elongation of the gas cavities, it is concluded that the fold axes are parallel to the direction of the flow of the rhyolite lava. Herein is an essential difference between the usual folds in sedimentary rocks and the folds in the Canoas rhyolite. The axes of the folds in sedimentary rocks are essentially normal to the direction of greatest movement; the axes of the folds in the Canoas rhyolite are essentially parallel to the direction of greatest movement. Explanation of the folds in the Canoas rhyolite therefore requires a different genetic hypothesis.

Evidently the upper and lower parts of the flowing lava were cooled more rapidly, and hence became more viscous, than the central portions, which therefore flowed with greater velocity. The resulting longitudinal withdrawal of lava from the central portions of the flows, motivated entirely by the pull of gravity rather than by an effusive or eruptive force pushing from behind, sucked lava laterally in from both sides. These two lateral components of the flowing material met at what is now the axial plane of the anticlines, which was also the locus of greatest longitudinal flow movement. Where these two opposed lateral flows of material met they pushed one another upward against the weight of the overlying upper crust of the flow, rather than downward against the unyielding basement rocks. For this reason, anticlines of this peculiar shape were formed rather than synclines.

Synclines are just as numerous as anticlines, but most of them are open, with horizontal flow layering along their axial zones. A few, however, are so tightly closed that they have vertical flow layering in their axial zones, but they are found only in places of maximum crowding where all the dips are steep and where several syncline and anticline axes are close together, possibly owing to lateral crowding of the lava against a solid obstruction.

The three small domes that were found in the rhyolite are difficult to explain, because their tops have been eroded away and their centers are filled with soil. One is just north of the road to Villa García, at coordinates 300 W. and 750 S. It is about 60 m in diameter but is less perfectly shaped than the two other domes. A second one is on the top of the Mesa de las Palomas. It lies just east of the axis of the major anticline there and is about 40 m wide and 70 m long, elongated parallel to the trend of the anticline axis. The most perfectly formed dome is on the north side of the Arroyo de las Majaditas, at coordinates 250 E. and 1,880 N. It is almost perfectly circular and about 30 m in diameter. The Arroyo de las Majaditas is localized by a zone of horizontally disposed flow layering into which it is incised to a depth of 3 or 4 m, leaving flat, terracelike areas of valley floor on each side, upheld by the horizontally flow-layered rhyolite. At the dome the flow layering swings up, within 2 m, to steep dips almost reaching the vertical. These steeply dipping rocks stand up as bold outcrops forming an almost unbroken circle that encloses a small, flat area of soil. In the absence of further data about these domes it is impossible to say with assurance just how they were formed, but they have the appearance of being large bubbles.

It is concluded, then, that the trends of the fold axes, the axial holes, and the flow-fluting marks indicate the trend, but not the direction, of the flow of the rhyolite lava. There are two alternatives of direction. Either all the lava came from the southeast and flowed in a general northwesterly direction, or two or more flows converged upon the latite dome: one from the west, flowing east, and the other from the north-northwest, flowing south-southeast.

The rhyolite is quite uniform in composition everywhere, which favors one source rather than two or more, and the disposition of the structures in the rhyolite with respect to the latite dome is readily explainable if the lava flowed from the southeast toward the northwest.

The wide zone of vertical and steeply dipping rhyolite in the southeastern part of the Mesa de Canoas can be most readily explained as the result of the crowding of northward-moving lava against the obstruction of the latite dome. The east-southeastward-dipping homocline of rhyolite just north of it then represents the spilling over of the rhyolite lava onto the northeast flank of the latite dome and possibly some thrust upon the dome, the steep dips near the northwest edge of this homoclinal zone representing the crumbled forward edge of such a moving mass. The suctional flow that caused the large anticline at the southeast end of the Mesa de Canoas would have been formed by the increased velocity of the lava flowing northwest along the flank of the latite dome toward the apparently low ground that lay to the north of the dome as indicated by the contours at the base of the rhyolite (pl. 8).

Similarly, the homoclinal dip of the rhyolite on the south flank of the dome, immediately south of the town of Canoas, represents the slip-off of the flowing lava, diverted from its northwest flow to a westerly direction by the obstruction of the dome.

If the lava moved as postulated, from the southeast toward the northwest, and was split by the dome as indicated, it would flow around the dome on both sides and would coalesce at some place beyond. Such coalescence may account for the zone of confused structures that lies on the west slope of the Mesa de Canoas just west-northwest of the mines.

The abundant flat dips of the flow layering in the rhyolite in the northern end of the Mesa de Canoas and in the vicinity of the Rincón de las Aguilas and El Travesaño are not readily explained if the lava flowed southeast against the dome, but they might well result from flow of the lava down the slope of the northwest flank of the dome, pooling in a basin beyond the interfering dome.

Although, at the mines, evidence is obscured by the mine dumps and rock alteration has been profound, no positive evidence of rhyolite was found on the top of the dome, and it is believed that no rhyolite is present there. In many places around the crest of the dome the rhyolite can be seen to wedge out on the latite. This is well shown in several of the small mine openings, especially west of the top of the dome. Several of these penetrate through the rhyolite down into the underlying latite and show clearly how the rhyolite lies upon and wedges out on the flanks of the dome near its crest. It has already been shown that the geomorphology of the drainage indicates that the present tops of the mesas coincide essentially with the original top of the rhyolite flows. Evidently the rhyolite flooded the country to a depth just about level with the top of the preexisting latite dome but did not quite overtop it.

OTHER STRUCTURES

Joints are moderately abundant, particularly in the rhyolite. Most of them are approximately vertical, and they trend in many directions. Those which strike northeast are perhaps a little more prominent than the others, but on the whole the joints are neither an impressive nor an important feature of the rocks. They exert a small local effect in that they cause stream bends in a few places and aid the processes of erosion, particularly in cliffs, where their crude columnar pattern gives rise to picturesque spirelike shapes.

The escarpment that truncates the southeast ends of the Mesa de los Canelos, the Mesa de Canoas, and the Mesa de las Palomas and forms the northwest wall of the broad Valle del Arenal cuts abruptly across the flow structures of the rhyolite in such a manner as to suggest that it was caused by a fault. This may be true, but it cannot be confirmed without detailed mapping of a much larger area. The escarpment is far too irregular in trend to be a fault scarp; if this topographic feature is caused by faulting it is a fault-line scarp.

QUICKSILVER DEPOSITS

Except for traces of alluvial cinnabar in the Arroyo de Canoas, the quicksilver deposits in the top of the latite dome are the only known mineral deposits of economic value at Canoas. Prospectors have searched the region diligently for many years, but cinnabar has not been found in the rhyolite or other rocks within the mapped area.

The latite in the mineralized top of the dome is much fractured, brecciated, and altered. In this connection, the structure and geologic history of the latite dome itself are first in importance. The latite in the top of the dome was evidently fractured at the same time and by the same tectonic forces that raised the dome, and a definite large-scale pattern is represented within the multitude of fractures by six major zones of diverse orientation. These zones constitute the second most important feature. Within them the effects of fracturing, brecciation, and alteration are more intense than elsewhere and the ore is higher in grade, particularly where these zones intersect one another. Although they are nebulously bounded by gradational transitions to the less profoundly changed latite, they are here called lodes.

PRODUCTION

The total quicksilver production at Canoas, from the discovery of the deposits in 1878 to the shut-down in the spring of 1944, has probably been about 30,000 flasks (870,000 kg). This figure is estimated from the extent of the workings and the size of the dumps, as no production figures whatever are available for the years prior to 1942 and the production records of the Compañía Minera Metalúrgica, S. A., are of little value in ascertaining the production of the camp as a whole because the gambusinos were producing about twice as much as the company and there is no record of their output.

Production probably increased after 1939 to a maximum of about 300 flasks (9,000 kg) per month during the latter part of 1941 and early 1942. It then diminished gradually to a monthly average of about 100 flasks (3,000 kg) per month during 1943–44, the last year before production ceased entirely.

Data in tables 1 and 2 are based on the records of the Compañía Minera Metalúrgica, S. A. Most of the gambusinos operated on land owned by the company and supposedly delivered 25 percent of their ore to the company as royalty. This 25 percent is called the "hacienda" ore, to distinguish it both from the gambusinos' own 75 percent and the ore produced by the company itself. The gambusino production figures are arrived at by using the company assay figures for the ore delivered by the gambusinos, multiplying the weight of this ore by 3 to get a figure for the gambusinos' 75 percent, and then allowing a 70-percent quicksilver recovery. As these figures do not include quicksilver produced by a few gambusinos who were operating outside the land owned by the company, they represent minimum figures for the period.

TABLE 1.—*Summary of quicksilver production at Canoas, Zacatecas, 1942–44 (in flasks)*

	Processed in Herreshoff furnace	Processed in company retorts	Produced by gambusinos (estimated)	Total
1942				
January	19.2			19.2
February	57.6			57.6
March	56.1			56.1
April	36.8			36.8
May	35.0	6.8		41.8
June	27.2	58.8		86.0
July	51.1	40.2	157.0	248.3
August	45.5	64.0	147.0	256.5
September	34.6	58.5	99.0	192.1
October	22.9	43.2	85.0	151.1
November	14.6	34.7	53.0	102.3
December	10.0	31.0	66.0	107.0
Total	410.6	337.2	607.0	1,354.8
1943				
January	5.0	26.2	65.0	96.2
February	9.1	45.9	103.0	158.0
March		59.0	64.0	123.0
April		36.8	66.0	102.8
May		37.4	54.4	91.8
June		27.9	38.9	66.8
July		43.4	63.0	106.4
August		40.4	47.8	88.2
September		32.5	48.6	81.1
October		45.4	88.7	134.1
November		54.3	14.0	68.3
December		28.8	50.5	79.3
Total	14.1	478.0	703.9	1,196.0
1944				
January		43.9	52.6	96.5
February		50.4	127.9	178.3
March		75.2	109.0	184.2
April		10.2	26.9	37.1
May		15.5		15.5
June		4.1		4.1
July		8.2		8.2
August		9.7		9.7
September		12.3		12.3
October		None		
Total		229.5	316.4	545.9
Total, 1942–44	424.7	1,044.7	1,627.3	3,096.7

MINERALOGY

Much of the latite in the upper part of the dome is altered to the clay mineral halloysite. Where this alteration has been intense the entire rock is changed to a soft mass of white halloysite; where it has been less intense the ground mass is altered but the phenocrysts are unchanged. The optical properties of this particular halloysite suggest that it may have been deposited originally as endellite, which then altered to halloysite by the loss of one molecule of water.

The white halloysite rock is soft and easy to dig, and probably for that reason it has been extensively explored in a few places; no ore has been found in it. Breccia fragments that consist of halloysite rock are found with the ore; in this association the halloysite is commonly more or less stained with iron oxide, but even though surrounded by cinnabar the halloysite rock itself is generally quite barren.

The paragenesis of the minerals, as determined from their megascopic textural interrelations, shows that the alteration of the latite to halloysite preceded the metalization by cinnabar-bearing solutions. Thus the latite in the mineralized top of the dome was subjected to two kinds of alteration, first to halloysite and second by the ore-forming solutions. It is not known whether there were two separate waves of solutions or merely one wave of solutions that changed in character during the process, but these two kinds of alterations probably were accomplished by solutions of markedly different character.

Alteration to halloysite is accomplished by acid solutions. According to current theory cinnabar is deposited by alkaline solutions. No evidence has been found that any metacinnabar was formed at Canoas, although it must be admitted that as yet criteria have not been established by which to distinguish cinnabar that was deposited as cinnabar from cinnabar that inverted from metacinnabar. The absence of metacinnabar at Canoas and the absence in the halloysite of cinnabar that might have inverted from metacinnabar suggest that no metacinnabar was formed and that all the cinnabar at Canoas was deposited as cinnabar. Therefore it follows, if current theory is correct, that the cinnabar at Canoas was deposited by alkaline solutions.

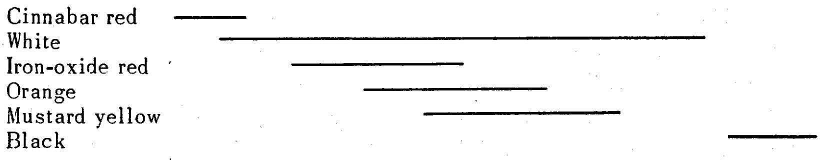
The cinnabar occurs chiefly associated with a soft clay mineral of the montmorillonite group, more or less stained with iron oxide, in narrow fractures and between breccia fragments of the altered latite. Montmorillonite is characteristically formed under alkaline conditions; hence its association with the cinnabar further vindicates the current theory that cinnabar is deposited under alkaline conditions.

Opal was the first material deposited by the metalizing solutions, as distinct from the halloysite-depositing acid solutions that preceded the ore-forming solutions. It is abundant throughout the mineralized zone and constitutes the main bulk of the rock mined and hence the bulk of the material now comprising the dumps. It is known at Canoas by the colloquial term "guija." It breaks with a conchoidal and hackly fracture like glass, has a peculiar shiny luster that gives it the appearance of being wet, and is of many colors.

The commonest color of the opal at Canoas is mustard yellow, but white opal is abundant; red, brown, and black varieties are found. The different colors are attributed to different impurities. The tint of some of the red opal is evidently due to disseminated cinnabar, but much of the red opal is of a different shade and is colored by iron oxide, as is also that which is brown or yellow. The black opal may owe its color to manganese oxide.

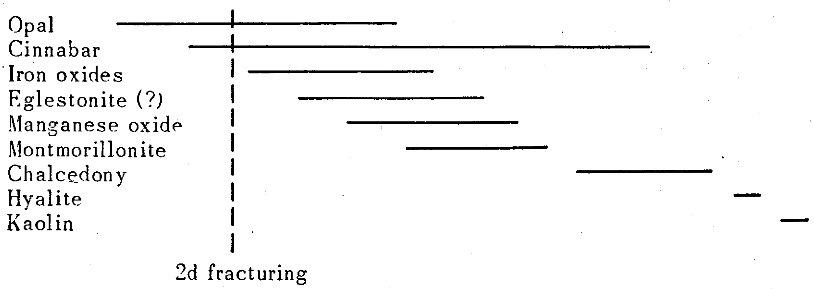
Opal of various colors may occasionally be found in which the colors grade into one another, but commonly the colors are separated as a result of brecciation of the opal of one color and recementing by opal of another color. Megascopic examination of the textural relations of the opals of different colors indicates that the following paragenesis exists among them:

Paragenesis of the color varieties of opal at Canoas



Megascopic examination of the textural interrelationships of the minerals in many ore specimens leads to the following table of mineral paragenesis:

Paragenesis of the minerals at Canoas



Where replacement by opal was intense the latite has been completely replaced by it. In some of this material the outlines of the replaced phenocrysts are still visible. Where the latite is incompletely replaced by opal, the ground mass has been replaced by it but the phenocrysts have not. In some of the white and mustard-yellow varieties, boxlike holes 2 to 3 mm long are found. Some are irregular in shape, but many of them are rectangular voids from which feldspar phenocrysts may have been leached.

Much of the mustard-yellow and white opal is massive, all of one color, and devoid of brecciation, but some of it is brecciated and most of the opal of other colors occupies fractures or fills the spaces between breccia fragments in earlier opal. The movement that brecciated the early-formed opal represents a second period of fracturing, distinct from the major fracturing that preceded the formation of the ore and that was connected with the tectonic doming of the latite, for the two periods of fracturing were separated in time by the period during which the halloysite alteration was accomplished.

Opal is invariably present where good ore occurs, but the converse is not necessarily true. Possibly the montmorillonite clay may offer a more reliable guide to ore.

The cinnabar at Canoas is very fine grained, and much of it may be colloidal in size. It is found disseminated in all the other minerals except (1) unaltered rock minerals of the fresh latite, (2) halloysite, (3) hyalite, and (4) the particular clay indicated in the table as kaolin.

In the richest ore the cinnabar forms botryoidal crusts, locally called "riñones" (kidneys). They have a concentric-layered structure parallel to the curved surfaces of the crusts. The individual layers are tinted different shades of red according to their content of cinnabar, which is evidently an extremely fine grained dissemination in chalcedony, for many of the layers show the radial fibrous structure of chalcedony and some are pure chalcedony. One typical specimen of high-grade riñón ore has a specific gravity of 6.3, indicating that the cinnabar is dispersed through the chalcedony that constitutes approximately 15 percent of the specimen by weight or 33 percent by volume. Although the cinnabar in the rich ore greatly predominates over the chalcedony in amount, the subordinate quantity of chalcedony is evidently able to exert a dominant influence in determining the structure of the mixture.

A similar relationship is known between other minerals and chalcedony, notably among the manganese minerals,[1] but it is not known whether the two minerals were deposited simultaneously or whether one replaced the other. The difference in cinnabar content in the different concentric layers of the riñón ore suggests contemporaneous deposition of the chalcedony and cinnabar of each successive layer, rather than formation of all the chalcedony followed by differential replacement by cinnabar.

The ore-formation process may have involved colloidal phenomena,[2] as indicated by the fine particle size of the cinnabar, much of which cannot be resolved with a microscope, as well as by the presence of opal and chalcedony.[3] The colloform shape also may be an indication of colloidal origin, but the mere shape, alone, is not proof of this.

Material that contains red cinnabar at Canoas turns black in a few minutes on exposure to the sun. For example, a stockpile of ore to be charged into a retort appears to consist of blackish, barren-looking rock and is seen to be ore only when the pieces are turned over, revealing the red cinnabar on the shaded sides. This change may be due, not to a change in the color of the cinnabar itself, but to a change from yellow to black on exposure to the sun of a mineral, possibly the mercury oxychloride eglestonite, that appears to be disseminated with the cinnabar. A few specimens of the opal, when broken open, are

[1] Fleischer, Michael, personal communication.

[2] Pollock, J. P., Colloidal deposition of cinnabar: Am. Inst. Min. Met. Eng. Tech. Pub. 1735, pp. 10, July 1944.

[3] Hitchen, C. S., The "solubility" of silica: Econ. Geology, vol. 40, pp. 361–365, 1945.

found to be tinted bright yellow, apparently by this same mineral, for they darken quickly on exposure to the sun.

The iron oxides, and the manganese oxide that is presumed to account for the black color of some of the opal, appear to play no other part in the mineralogy than to act as pigments.

Some barren chalcedony continued to form subsequent to the cinnabar as a botryoidal coating, and grown on it in a few places are smaller botryoidal encrustations of still later, colorless, transparent hyalite. A clay mineral of the kaolin group, possibly saponite or beidellite, is found as the last mineral to form in cavities and in fractures in a few places. When fresh it is like soft, brown grease, but on drying it loses its plasticity and becomes a hard, brown, waxy-looking substance with a wrinkled surface and desiccation cracks. Like montmorillonite it is characteristically formed under alkaline conditions, and therefore its presence suggests that such conditions continued to the end of the mineralization.

STRUCTURE

The structure of the Canoas quicksilver deposits is not readily discernible. The significant features are obscured by the profusion of meaningless detail, the entire surface of the mined area is covered with dumps 1 to 10 m thick, the shallow mine workings are mostly caved and inaccessible, and the deeper mine workings are not sufficiently extensive or abundant to make the significant large structures obvious. However, the distribution, trend, and inclination of the stopes reveal major zones, or lodes, in which the fracturing, alteration, and mineralization effects are more intense than elsewhere.

The structural feature of primary importance is the latite dome, in the top of which all the ore is localized. Second in importance are the lodes that traverse the fractured and brecciated top of the latite dome. The individual fractures and breccia opening are of third-order importance, and it is this last group that presents the profusion of meaningless detail. The really significant structures that give an understanding of the distribution of the ore, and provide a key to further exploration for ore, are the lodes of the second category.

The individual fractures in which the ore is found range in size from small joints to large faults. Many of them are no more than 1 or 2 mm wide; some are 1 or 2 cm wide. Although some of the gouge zones are several tens of centimeters thick, they rarely contain much ore, probably because of the impermeability of the fault gouge. These fractures of diverse sizes appear to be oriented in all possible directions, and detailed mapping fails to reveal any significant pat-

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tern among them. They are so numerous in the upper part of the mineralized zone that they constitute a stockwork.

In many places where the fracturing is abundant, the movement has given rise to breccia consisting of angular fragments of altered country rock that range from a few millimeters to several tens of centimeters in size but are commonly a few centimeters. The openings between the breccia fragments range from a millimeter or so to several centimeters across but are commonly 1 to 3 cm.

The stockwork zone spreads throughout the mineralized area at the top of the dome like the head of a mushroom, but instead of having a single stem, it merges downward into six major zones of fracturing. These are the lodes. Each of them has a different strike and dip, and each is a zone several meters thick in which the effects of fracturing, brecciation, alteration, and mineralization are more intense than in the adjoining latite. The margins of these lodes are nebulous, because they grade into less highly deformed and altered country rock.

The San Antonio lode, judging from the trend and inclination of the workings of the San Antonio mine (pl. 9), which is situated in it, strikes N. 69° W. and dips 45° SW. Although it is a questionable procedure to assign such a precise strike and dip to so indeterminate a feature as a lode at Canoas, the figures do have value as close approximations. This lode was not encountered in the Jesús mine west along the strike from the San Antonio mine workings, and if it did not pinch out it was probably cut off by a fault. If so, the fault may be the one, striking N. 75° W. and dipping 70° SW., that is found just south of the Jesús shaft on the 40-m level of the Jesús mine.

North of the San Antonio and Jesús mines is La Cruz mine, in which can be seen the San Antonito lode, striking N. 50° W. and dipping 75° SW. This attitude is clearly shown by the disposition of the principal stopes of La Cruz mine. The westward-striking San Agustín lode, which dips 80° N., also can be seen in La Cruz mine.

The western workings of La Cruz mine, particularly where they are well exposed in the 40-m level, follow the San Agustín lode for about 60 m and then crosscut southwestward through a large stope in La Purísima lode, which strikes N. 26° W. and dips 62° SW., in the northern part of the San Alfredo mine.

The principal lode of the San Alfredo mine is La Providencia, which strikes N. 12° E. and dips 77° E. Southward La Providencia lode is seen in the workings known as "winze 48," in which the San José lode also occurs, striking N. 75° W. and dipping 70° S. Eastward along the San José lode is the Santa Catarina mine, situated where the southern extension of La Purísima lode crosses the San José lode.

Many of the principal mines at Canoas are located at lode intersections. La Cruz mine is at the intersection of the San Antonito and

San Agustín lodes; the most productive parts of the San Alfredo mine are in the vicinity of the intersection of La Purísima and La Providencia lodes; the collar of winze 48 is at the intersection of La Providencia lode and the San José lode; and the Santa Catarina mine is at the intersection of the San José lode and La Purísima. Northwestward rich ore was mined in shallow workings where the San Antonito lode and La Purísima intersect, and southeastward rich ore was found early in 1944 where the San Antonito and San Antonio lodes intersect outside the property owned by the Compañía Minera Metalúrgica, S. A. Conversely, little ore has been found in the Jesús mine, which is not at a lode intersection.

In summary, the ore was deposited close to the surface, in fractures and breccia openings in a stockwork and six major lodes that form its roots, in the top of a tectonic dome of latite. The influence of the six major lodes is reflected in the irregular surficial outline of the ore-bearing zone as shown on plate 10. Much of the latite was altered to halloysite by acid solutions and was then invaded by alkaline mineralizing solutions which deposited, possibly under colloidal conditions, abundant opal and some montmorillonite, chalcedony, and cinnabar, together with small quantities of a yellow mineral, possibly eglestonite. A second period of fracturing occurred during this alkaline mineralization. The region was inundated by rhyolite flows that did not quite overtop the latite dome, and because no cinnabar has been found in the rhyolite it is probable that this inundation occurred after the deposition of the ore.

Most of the quicksilver produced at Canoas has come from the near-surface stockwork ore, but a considerable quantity has come from ore shoots as much as 40 or 50 m below the surface, particularly those in the intersections of the six major lodes. Little ore has been found deeper than 50 m, but it should be noted that almost no scientifically guided search has been made for deeper ore. A little ore was found in a short crosscut northward from La Cruz shaft at a depth of 82 m; hence cinnabar persists at least to that depth at Canoas. The 75-m level in La Cruz mine failed to find the downward extension of the San Agustín lode, but exploration was probably inadequate. As none of the other lode intersections have been explored at depth, it cannot be said with finality that no ore occurs there. However, the general stockwork-with-roots form of the deposit suggests that even though ore is found, particularly at the lode intersections, by adequate deeper exploration, the quantity probably will be small as compared with that already extracted from the virtually exhausted upper parts of the deposits.

MINING

All the mining at Canoas has been carried on within a northwestward-trending area about 400 m long and 250 m wide (pl. 10). Within this small area the gambusinos have dug about a thousand holes called "pozos." The word "pozo," commonly meaning "a well," is extensively used in Mexico as a mining term in reference to irregular holes that extend downward from the surface. A pozo may be described as too small to be an open-cut, too deep to be a prospect pit, too steep to be an adit, and too irregular and out of plumb to be a shaft. The steepest parts are equipped with ladders, commonly the notched poles called "chicken ladders," and some of the less steep parts may have crude, rock-hewn steps. Some typical examples are shown on plate 11.

Over 600 pozos that were visible in 1944 are plotted on plate 3. An estimated 400 additional pozos are buried under the dumps. Each pozo is a hole 1 to 2 m in diameter, generally surrounded by a dry wall to keep the dumps from falling into it. Some pozos open into stopes half a meter below the surface; others continue downward as narrow, steep, irregular, winding passageways with here and there a short crosscut or a small stope. As each pozo is made without plan or survey control and is diverted to follow any likely-looking fracture encountered, few of them fail to connect eventually with other pozos, and it is said that at one time it was possible at Canoas to enter any pozo and come out of any other pozo, provided you knew the way—which would be no mean feat!

If a gambusino sank a "wildcat" pozo and found ore, a fact that could hardly be concealed when he began to operate his retort, other gambusinos would immediately begin to sink pozos all around his; a pozo-sinking race would ensue, each trying to get as much of the discoverer's ore as possible before he extracted it all. The workings in places were so close together that some men were killed underground by blasts in nearby pozos. Where two workings broke into each other, trespass and many other problems arose.

In an attempt to solve these numerous problems the gambusinos organized a local union, headed by a committee which negotiated agreements with the Compañía Minera Metalúrgica, S. A., settled disputes, and enforced rules and safety regulations. Of course it was against the rule to mine ore from another man's pozo, even if it could be entered by an underground route; nevertheless it was customary for at least two men, in partnership, to work alternate shifts in any pozo in ore; otherwise a face in ore had a way of advancing by itself while the owner was at home sleeping.

Most of the mineralized ground at the top of the latite dome was owned by the Compañía Minera Metalúrgica, S. A., but except for La Cruz mine, shaft 120, and winze 48 it was all open to the gambusinos on application through the union. A gambusino could apply for permission to work a place of his own choice or could ask to be assigned to a place chosen by the company. In return for working within the company-owned ground, the gambusino was supposed to deliver all his ore to the concrete floor of the company patio, where it was officially quartered, the company retaining one-quarter as royalty and the gambusino resacking and taking home his three-quarters.

A good example of pozo operations at Canoas is afforded by the history of pozo 116, in which ore was discovered late in 1943. Several old pozos nearby were immediately reopened, and some of the gambusinos working in the northwestern part of the San Alfredo mine quickly drove a drift over to get under the ore body of pozo 116. They mined the ore body from below, and the gambusinos in the surrounding pozos mined it from all sides and on top. The stope in pozo 116 was ultimately about 8 m long, 4 m wide, and 5 m high, and the owner was mining the interior of a shell almost surrounded by open space. It is also interesting to note that from a stope of this size the one-quarter royalty received by the company amounted to 1.1 tons of ore.

The average depth of the pozos within the ore-bearing zone is about 20 m. Few of them are less than 15 m deep, and perhaps a third of them exceed 20 m in depth but are not deeper than 40 m. Many of these 40-m pozos connect with the 40-m level in the mines. A few pozos exceed 50 m in depth, but probably none of them exceeds 60 m. Calculations based upon the number, depth, and general form of the pozos, as well as calculations based upon the estimated volume of the dumps, indicate that approximately 15 percent of the total rock of the mineralized zone to a depth of 20 m has been mined. Since the discovery of quicksilver at Canoas about 900,000 tons of rock has been mined, yielding about 30,000 flasks of quicksilver. This indicates an average tenor, before sorting, of about 1 kg of recovered quicksilver per metric ton of rock mined.

Below the pozo workings are the more formal mine workings. They are developed most extensively at a depth of about 40 m below the surface. Some workings in the San Alfredo mine extend deeper, and the very lowest workings are near the bottom of La Cruz shaft, which is 85 m deep. However, these more formal mine workings are not extensive, and probably ten times as many tons of rock and ore, and about ten times as much quicksilver, has been produced from the gambusino pozos as from the more formal mine workings.

SAN ANTONIO MINE

The San Antonio shaft, of unknown but probably shallow depth, is caved. Although the workings to the west of it, along the San

Antonio lode, are called the San Antonio mine, they are in reality merely the result of the coalescence of many pozos and the stopes and subsidiary workings from them. Many of them are more or less caved, and they were nearly all filled with gob until 1943, when the Compañía Minera Metalúrgica, S. A., cleaned some of them out to a depth of about 20 m below the surface. How much deeper these old workings may extend down the southerly dip of the San Antonio lode is not known. The workings shown on the mine map (pl. 9) are those along an underground traverse from the Jesús mine to a caved stope that can be entered from the surface near the San Antonio shaft. Filled workings incline downward to the south, and partly caved stopes, pozos, and irregular holes incline upward to the north, broken through to the surface in many places. One such break-through appeared early in 1944 in the floor near one of the retorts in the company patio and served as a convenient, and seemingly unfillable, receptacle for the discharged calcines. Detailed mapping of the San Antonio mine was not attempted, for the ore is exhausted and the mine abandoned.

JESUS MINE

The upper part of the Jesús mine is a shaft that passes through near-surface stopes by virtue of a rectangular, chimneylike structure of masonry built at some unknown date. Adjacent to the shaft, at a depth of 18 m below the surface, is a level connecting eastward to the workings of the San Antonio mine and formerly connecting south-westward to the stopes of the Santa Catarina mine. Apparently little or no ore was discovered in these workings. Three meters lower, at a depth of 21 m below the surface, a drift from La Cruz mine connects with the Jesús shaft. This drift is in barren latite, more or less altered to halloysite, and apparently no ore was found in it except immediately at the Jesús shaft.

The Jesús shaft was extended to a depth of 42 m, probably in 1942, and exploration drifts at that depth extended southeastward and southwestward without any discovery of ore. A little cinnabar was found in a raise 15 m southeast of the Jesús shaft which may have been the downward extension of the San Antonio vein, but it was explored upward for only 5 m. The workings to the southwest on the 42-m level were abandoned when ore was not found beneath the old Santa Catarina stopes, but as the plunge of the junction of La Purísima lode and the San José lode, which probably determined the localization of any large amount of ore in this vicinity, is to the south-west, this exploration was stopped at least 20 m before reaching the likely location of the ore. The Jesús mine is not at a recognizable lode intersection, and little ore has been found in it except near the surface in the old stopes through which the Jesús shaft was constructed. This ore was evidently in the upper part of La Purísima lode, which dips 62° SW., thus explaining why exploration vertically downward not only failed to bring about the discovery of more ore, but lost what ore there was.

LA CRUZ MINE

La Cruz mine consists of several distinct parts. They center around La Cruz shaft, 85 m deep, which is the deepest shaft at Canoas. An old shaft, called La Esperanza, lies 20 m northeast of La Cruz shaft and extends downward only to the adit level 15 m below the surface. When the Herreshoff furnace was installed in 1942, a crusher was mounted in a pit between La Cruz and La Esperanza shafts so that ore hoisted through La Cruz could be crushed and dumped into La Esperanza as an ore bin from which it was drawn into cars on the adit level and trammed out of the adit to a trestle that led to the Herreshoff furnace. The adit level appears to have been driven many years ago, possibly under the management of Mr. Walker (p. 51). Ore was not found in it, and it is too shallow to be of much use.

La Cruz shaft was probably originally a pozo, and from it large stopes extended southeastward along the San Antonito lode and northwestward in the intersection of the San Antonito and San Augustín lodes. When Mr. Moll took over the management of the property in 1941, these stopes and La Cruz shaft were largely filled with gob. The gob was removed, disclosing that much of La Cruz shaft had been enlarged into a stope. The shaft was sunk deeper from the bottom of the stope at a point plumbed below the orifice at the surface, and hoisting was reestablished through the stopes with the aid of cable-guides. A manway of ladders was established by a devious route through parts of old pozos, stopes, and winzes, and a program of exploration for new ore was undertaken.

Small showings of ore in narrow fractures were found in many places near the shaft, but no larger ore body was discovered. At a depth of 75 m below the shaft collar a new major-development level was established, but the exploration program was no more than well started when the Compañía Minera Metalúrgica, S. A., suspended operations early in April 1944 coincident with the collapse of the price of mercury.

The largest stopes around La Cruz shaft are above the so-called "40-m level," which is actually 32.6 m below the shaft collar. Here some large stopes extend northwestward from the shaft, connecting upward to shallower stopes above and also sloping downward to the northwest and west. These stopes are clearly in the junction of two lodes—San Antonito and San Augustín lodes. The strike and dip of the San Antonito lode are apparent from the shape of the stopes higher up, particularly those southeast of the shaft, as well as from the shape of the stopes around the 40-m level. The San Augustín lode, because it strikes west, accounts for the western extensions of these stopes.

West of the shaft the 40-m level consists of a remarkable tubular rock pipe practically surrounded on top, sides, and bottom by stopes in the San Augustín lode. Along both sides of this rock-pipe drift are many short crosscuts and windowlike holes from which one may look out, up, and down into the stopes surrounding the thin-walled drift. The San Augustín lode can here be seen to consist of a number of more highly fractured parallel zones a few centimeters to a meter thick separated by less highly fractured zones of about equal thickness. The whole lode is about 10 m wide, strikes west, and dips about 80° N. This rock-pipe drift and attendant stopes end 60 m west of La Cruz shaft, and a crosscut 3 m higher leads in a southwesterly direction to La Purísima stope and the workings of the San Alfredo mine.

SAN ALFREDO MINE

The ramifications of the so-called "40-m level" of the San Alfredo mine are the most widespread of any at Canoas, probably because this was the first mine that was turned over to the gambusinos by the Compañía Minera Metalúrgica, S. A.

The 40-m level of the San Alfredo mine is accessible through the crosscut from the western end of the drift in La Cruz mine that follows the San Augustín lode on the 40-m level. This crosscut passes through the principal stope on La Purísima lode. The stope enlarges upward and connects with many pozos. The bottom of La Purísima stope is filled with gob and its depth is not known, but the shape and attitude of the stope and the exceptionally well defined footwall surface show clearly the strike and dip of La Purísima lode.

The bottoms of pozos, or pozo stopes, can be seen in many places in the back throughout the 40-m level of the San Alfredo mine, but little ore has been found on the 40-m level itself or in the few explorations at greater depth. A few small stringers or subsidiary veins have been followed by the gambusinos. A good example is afforded by the pozolike burrow that extends northwestward beginning at a place 30 m west of the San Alfredo shaft at coordinates 166 E. and 289 N. This burrow follows an irregular cinnabar-bearing fracture that strikes generally west and dips moderately to the north. The ore-bearing fracture ranges in width from very narrow to as much as 2 cm.

WINZE 48

Winze 48 is not a true winze but is called by that name locally. Its collar is built on stulls and gob about 15 m below the surface of the ground in an irregular stope. The stope is connected to the surface by several pozos and cave-ins. The stope extends downward irregularly on both the west and north sides of the winze for several meters. The winze is vertical and passes through latite and sandstone (pp. 56–57) to a depth of 51.8 m below the collar. At the bottom a northwestward-trending crosscut traverses sandstone striking N. 25° E. and dipping 18° NW. for 7 m, then crosses a fault which here dips 40° NW., and continues for a few meters in barren latite. Subsidiary drifts to the southwest and northeast explore the vicinity of the fault, which is revealed in the northeast heading to be a northward-trending fault dipping 68° W. The short crosscut that extends southeastward from the bottom of the winze is in sandstone striking east and dipping 10° N. No ore was found at depth in winze 48 because the workings failed to reach far enough southeast to test the possibilities of the junction of La Providencia lode and the San José lode at this depth.

SANTA CATARINA MINE

The Santa Catarina mine has long been abandoned and is largely caved and partly filled with gob. Irregular stopes about 10 m wide could be entered to a depth of 20 m in early 1944, but they revealed nothing of particular interest. The localization of a relatively large and rich ore shoot at this place was evidently determined by the intersection here of La Purísima lode and the San José lode. The workings formerly connected to the Jesús mine and also to an old northwest stope, long since caved, between the Santa Catarina and San Alfredo shafts. This old stope was said to have contained one of the richest ore bodies found at Canoas, so rich in fact that it was called the "Salón Rojo." If the location was correctly reported, the Salón Rojo was apparently in an ore shoot in La Purísima vein.

SHAFT 120

Shaft 120 in the northwestern part of the mined zone was made by straightening and deepening a pozo that had been assigned the number 120. At a depth of 50.2 m below the shaft collar exploratory workings were extended both northward and southward. The original purpose of opening shaft 120 was to explore northward and northeastward to try to find the downward extension of an exceptionally large and rich ore body that had been so badly mined near the surface by the gambusinos that their workings had caved irreparably and the ore body had been lost. No ore was found in this direction because the workings were stopped before they had extended far enough to reach the likely location of this ore shoot, which was evidently localized by the intersection of La Purísima lode and the San Antonito lode. Exploration southward, however, resulted in the discovery of ore in the downward extension of La Purísima lode, but this discovery was made only shortly before the Compañía Minera Metalúrgica, S. A., suspended operations entirely in April 1944.

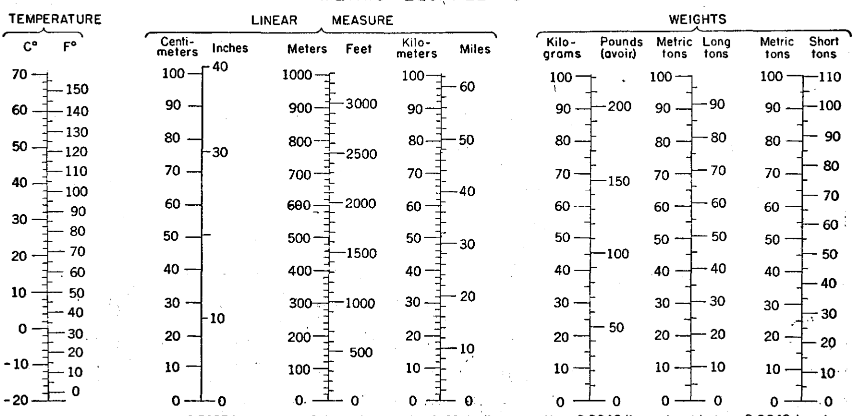
ORE RESERVES AND FUTURE OF CANOAS

In common with most other quicksilver deposits, Canoas has no blocked-out ore reserve. The upper part of the deposit has been so thoroughly gutted by the gambusinos that it is virtually exhausted. However, what is gob to a gambusino may be ore to a steam shovel, and it is likely that adequate sampling of the dumps and fills and the unmined ground left by the gambusinos might reveal sufficient contained quicksilver to make possible mining at a profit by efficient large-scale methods during a period of high mercury price. The reserves of such material probably amount to about a million tons per 5 m of depth.

Adequate exploration below the 40-m level might result in the discovery of ore, particularly in the downward extension of the lode intersections, but because of the stockwork-with-roots form of the deposit the total yield of quicksilver would almost certainly be only a fraction of the 30,000 flasks that have probably been produced already. It may be pointed out that the known ore-bearing zone is north of the actual top of the latite dome, which, as indicated by the contours on the base of the rhyolite (pl. 8), is under the village of Canoas and has not yet been explored.

Lastly, it may be reemphasized that scientific prospecting by the method of studying the structures in the rhyolite as explained in this report might lead to the discovery of other similar deposits.

METRIC EQUIVALENTS



1 cm. = 0.3937 in.
1 in. = 2.5400 cm.
1 m. = 3.2808 ft.
1 ft. = 0.3048 m.
1 km. = 0.6214 mile
1 mile = 1.6093 km.
1 sq. m. (m2) = 1.20 sq. yd.
1 hectare (100x100m.) = 2.47 acres
1 cu. m. (m3) = 1.31 cu. yd.
1 kg. = 2.2046 lb.
1 lb. = 0.4536 kg.
1 metric ton = 0.9842 long ton
1 metric ton = 1.1023 short tons
1 metric ton = 2,205 lb.
1 long ton = 1.0161 metric ton
1 short ton = 0.9072 metric ton

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