Geologic Investigations in the American Republics 1950–53

GEOLOGICAL SURVEY BULLETIN 975

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1955

UNITED STATES DEPARTMENT OF THE INTERIOR

Douglas McKay, *Secretary*

GEOLOGICAL SURVEY

W. E. Wrather, *Director*

CONTENTS

[The letters in parentheses preceding the titles are those used to designate the separate chapters]

ILLUSTRATIONS

[All plates are in pocket]

Geology of the Huancavelica Quicksilver District Peru

y ROBERT G. YATES, DEAN F. KENT, *and* JAIME FERNANDEZ CONCHA

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EOLOGICAL SURVEY BULLETIN 975-A

'repared in cooperation with the Ainisteria de Fomento, Instituto Geológico del Perú, under the auspices f the Interdepartmental Committee on 'cientific and Cultural Cooperation)epartment of State

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GEOLOGY OF THE HUANCAVELICA QUICKSILVER DISTRICT, PERU

By ROBERT G. YATES, DEAN F. KENT, and JAIME FERNANDEZ CONCHA

ABSTRACT

The Huancavelica quicksilver district, the world's largest producer of quicksilver for over a century and a half, is in the Cordillera Occidental of south-central Peru. All the important mines of the district are in a north-trending belt about 1 mile (2 kilometers) wide and 5 miles (8 kilometers) long, but a few small mines and prospects are in north and south extensions of this main belt. During the Spanish colonial period the mines produced over 1,400,000 flasks of quicksilver, most of this coming from one mine, the Santa Bárbara. During the last hundred years little quicksilver has been produced, and in 1946 only one small mine was actively producing. It is not likely that the district will again become an important quicksilver-mining center unless new ore bodies are discovered or unless there prove to be unexhausted ore bodies in the inaccessible caved workings of the Santa Bárbara mine.

The Cordillera Occidental in central Peru is composed of Paleozoic, Mesozoic, and Tertiary sedimentary and volcanic rocks that have been folded, faulted, and intruded by various kinds of igneous rocks. In the Huancavelica district Jurassic limestones, Cretaceous sandstones, limestones, shales, and volcanic rocks, and Tertiary conglomerates, tuffs, and lavas constitute the sedimentary and volcanic rocks. Intruded into these are dacites and volcanic necks filled with pyroclastic material. The dominant structural feature is a north-trending anticline, which has a synclinal core bounded by high-angle reverse faults. Faulting accompanied and followed folding, and was itself followed by igneous intrusion and extrusion.

The quicksilver deposits are classified into three types: (1) deposits occurring in sandstone, (2) deposits occurring in limestone, and (3) deposits occurring in igneous rocks. Cinnabar is the principal ore mineral and occurs mainly as a filling between sand grains in the sandstone, in fractures and porous marly beds in the limestone, and as a filling in fractures in the igneous rocks. Other sulfide minerals are pyrite, arsenopyrite, realgar, and minor amounts of galena, sphalerite, and stibnite. Nonmetallic gangue minerals include quartz, calcite, barite, and hydrocarbons, none of which are abundant. The distribution of the ore bodies was controlled by the distribution of the more permeable sedimentary strata and of fracture openings. The cinnabar deposits are younger than the Tertiary volcanic rocks.

INTRODUCTION

LOCATION AND ACCESSIBILITY

The Huancavelica quicksilver district, which for a century and a half during the Spanish colonial period was the world's largest producer of quicksilver, is in the south-central part of Peru in the Department of Huancavelica (pl. 1). Although it is only 150 kilometers (93 miles) from the Pacific Ocean, it is in the Amazon drainage area because it is on the eastern side of the Cordillera Occidental, which constitutes the Continental Divide in this part of Peru (pl. 1). All the important quicksilver mines of the Huancavelica district are in a belt about 8 kilometers (5 miles) long and 2 kilometers (1 mile) wide that extends both north and south of the city of Huancavelica, the capital of the province and department of the same name. A few minor occurrences of quicksilver are located in north and south extensions of the belt, but these are not considered in the report.

Huancavelica, a city of about 9,000 inhabitants, is connected with Lima by both railroad and highway. Rail transportation from Lima is by way of the Ferrocarril Central del Perú (standard gage) to Huancayo, where a narrow-gage, Government-operated line continues to Huancavelica. Two days are required to cover a distance of 441 kilometers (273 miles). Huancavelica can be reached from Lima in 1 day, however, by driving southeastward on the Pan-American Highway down the coast to Pisco and from there eastward over the Cordillera to Huancavelica, a total distance of 541 kilometers (335 miles). An alternate automobile road, paralleling the railroad, is under construction, and all but 30 kilometers (19 miles) between Mejorada and Huancavelica has been completed. Both roads can be traveled throughout the year, except for short periods during the wet season when landslides or heavy snows make parts of them impassable. The mines are reached from Huancavelica either by road or by horse trail.

SURFACE FEATURES AND CLIMATE

The city of Huancavelica is in a particularly mountainous terrain in the valley of the Río Hicho, or Huancavelica River. The valley floor at Huancavelica is about 1 kilometer (0.6 mile) wide, but downstream it is very narrow and the river flows through a deep gorge that joins the gorge of the Mantaro River at Mejorada. The city, lying at altitudes of 3,650 to 3,700 meters (11,975 to 12,139 feet), is walled in on both north and south by precipitous mountain slopes that rise abruptly to merge with a more subdued upland topography, which in places reaches altitudes in excess of 5,000 meters (16,404 feet).

In this part of Peru there are two seasons: the wet season, from November through April, and the dry season, from May through

October. The wet season is slightly warmer than the dry, but because of the great number of sunless days it is locally called "winter." During the dry season nightly freezes are common, particularly above altitudes of 4,000 meters (13,123 feet), but after 10 o'clock in the morning sun temperatures are fairly high and any snow that may have fallen during sudden local storms soon melts. Most of the precipitation falls during January and February when heavy rains and snows are frequent. Any precipitation above 4,500 meters (14,764 feet), either in the wet or the dry season, is usually in the form of snow.

VEGETATION, AGRICULTURE, AND LABOR SUPPLY

The vegetation of the area about Huancavelica at altitudes above 4,500 meters (14,764 feet) is dominantly mosses and lichens; the vegetation below altitudes of 4,500 meters consists mainly of grasses. The raising of sheep, llamas, and alpacas on these grasslands is the principal industry of the area. A few trees, mostly introduced eucalyptus, grow in the valley of the Río Hicho, and cacti are seen on the northerly slopes up to altitudes of 4,000 meters (13,123 feet). The main agricultural crops are grain and potatoes; the grain is grown only in the valley, whereas potatoes are grown both in the valley and on terraced slopes up to altitudes of 4,300 meters (14,108 feet). All the land that is suitable for these crops is under cultivation.

The flocks and the potato crop, with the addition of a little imported corn, meagerly sustain the bulk of the population of Huancavelica. This population, dominantly Indian, furnishes the labor supply of the quicksilver mines. Except by Sr. Eulogio E. Fernandini, in his efforts to return the famous Santa Bárbara mine to production, this labor supply has been little drawn upon during the twentieth century.

FIELD WORK AND ACKNOWLEDGMENTS

The investigation that served as a basis for this report was made by the Geological Survey, United States Department of the Interior, and the Instituto Geológico del Perú, Ministerio de Fomento, in the months from August through December 1945. It formed a part of the program of cooperation among the American Republics sponsored by the Interdepartmental Committee on Cultural and Scientific Cooperation under the auspices of the United States Department of State.

The field work for the report was done during the months of September, October, and November 1945. The writers were accompanied by Ing. Rudolfo Flores Burneo during the first half of the field season and by Ing. Mariano Iberico Miranda and Albino Rondoño during the latter half. Juan Bendezú, of Huancavelica, acted as rodman. The work consisted of preparing a geologic and topographic

map of the district and geologic maps of almost all the accessible mine workings. The map of the district (pl. 1) was made on a scale of 1:10,000 with plane table and telescopic alidade, using as a base a triangulation net established by the field party. The maps of the mine workings were made on scales of 1:200, 1:400, and 1:500, using base maps surveyed by tape and Brunton compass. Responsibility for the individual phases of the work is shown on the various maps that illustrate this report.

The work would have been impossible without the wholehearted and thoughtful cooperation of Dr. Jorge A. Broggi, Director of the Instituto Geológico del Perú, and Carrel B. Larson, minerals attaché of the United States Embassy, Lima. Mr. Larson was of great assistance in the planning and execution of the field work. Dr. Broggi made available the personnel and resources of the Instituto Geológico and gave much of his personal time to the work. For all this the writers are sincerely grateful. The help of many other individuals, from both the United States Embassy in Lima and the Instituto Geológico, also is appreciated. Particular thanks are due Sr. Francisco Alvarado, chief draftsman of the Instituto Geológico, and his assistants.

The hospitality of Sr. Eulogio E. Fernandini, the owner of the Santa Bárbara mine, who provided living accommodations at Huancavelica, is deeply appreciated. Sr. Fernandini's representatives at Huancavelica, Sr. Eulogio Vergara, Sr. Jose Devescavi, and Tom Cahill, were accommodating in innumerable ways and directly and indirectly made possible the completion of the investigation in the allotted time.

SCOPE OF THE REPORT

The purpose of this investigation was primarily economic—to determine the extent, character, and economic potentialities of the quicksilver deposits. Although the Huancavelica mines have contributed little mercury to the world market during the past century, their impressive production history during the sixteenth, seventeenth, and eighteenth centuries and their decline in production only under impeditive circumstances have stimulated the belief that the district may again become an important source of mercury. The investigation was undertaken with the hope that a geological study of the district would either confirm or refute this belief. A conclusive answer to the question of whether or not the district is capable of again becoming an important producer of mercury, however, requires a background of first-hand data on the deeper mine workings, which unfortunately are inaccessible. The conclusions stated in this report are therefore based upon a study of the surface geology and the examination of accessible mine workings, as well as on a study of available records. Consequently the accuracy of the conclusions is in part dependent upon the accuracy of data sorted from available records and the interpretation of these data in the light of first-hand observations.

GEOLOGY

GEOLOGIC SETTING

The Cordillera Occidental in south-central Peru is composed of Paleozoic, Mesozoic, and Tertiary sedimentary and volcanic rocks that have been folded, faulted, and intruded by various kinds of igneous rocks. Details of the geology of the Cordillera are known only locally, but the pioneer work by Raimondi, Bravo, Lissón, Bowman, Steinmann, and others, as well as the later work of geologists of the Cerro de Pasco Copper Corp. (McLaughlin, 1924) and that of J. V. Harrison (1944), has firmly established the broad features outlined below.

The geologic history of the region is one of marine sedimentation and intermittent volcanic activity that was twice interrupted by major periods of mountain building. The oldest rocks exposed are dominantly shales and sandstones, of probable early Paleozoic age, that were highly folded and locally metamorphosed to phyllites and quartzites and subsequently eroded to a low rolling surface before the deposition of Carboniferous conglomerates, sandstones, and volcanics. Deposition, resulting in great accumulations of Triassic, Jurassic, and Cretaceous limestones, sandstones, shales, and volcanics, was uninterrupted (except by mild and local crustal disturbances) from the Carboniferous until the close of the Cretaceous. During Upper Cretaceous time, marine deposition was brought to a close and orogenic movements resulting in the great folds and faults of the region were initiated.

The Tertiary was a period of mountain building by folding and faulting, interrupted in its early stage by erosion and continental sedimentation and later amplified by igneous activity, which blanketed the region with volcanic flows and fragmental material and studded parts of it with volcanic cones. A late phase of the igneous activity was the intrusion of stocks of quartz monzonite and diorite, as well as smaller and shallower intrusions of various other kinds of igneous rocks. The formation of the metal deposits appears to be associated with these intrusions. After the cessation of igneous activity the folded Tertiary mountains were reduced to a region of low relief, which was subsequently uplifted in several stages to form the present Cordillera Occidental.

In central Peru, the Cordillera Occidental is a fairly simple, well-defined mountain range, following the general northwesterly strike of the sedimentary strata. In southern Peru it loses its simplicity by converging with several other ranges in what is termed a "knot." This knot is bounded on the south and southeast by a great volcanic field, which is part of the puna, or high plateau, of southern Peru. The topographic expression of the Cordillera Occidental in southern Peru includes a line of volcanic peaks along the southwestern margin of the puna.

The Huancavelica quicksilver district is just northwest of the point where the Cordillera joins the "knot." The dominant structural trend in the district is north, in contrast to the regional northwest trend of the Cordillera. Erosion has not exposed rocks older than Jurassic, nor are there any granitic intrusions either within or near the district. In other respects, the geology of the district is typical of the geology of the Cordillera Occidental. The quicksilver or cinnabar deposits are associated with faults and other fractures and are in Cretaceous sandstone and limestone, Jurassic limestone, and Tertiary volcanic rock.

ROCK UNITS

To facilitate regional correlations and to avoid ambiguity, most of the stratigraphic names used in this report are those that have been introduced into the literature by geologists of the Cerro de Pasco Copper Corp. (McLaughlin and Moses, 1945). However, some adjustment is necessary. In this report the Goyllarisquisga *formation* of McLaughlin and Moses is changed to the Goyllarisquisga *group* to include two cartographic units that are distinct and separable in the Huancavelica district. These units are given formational status and named the Gran Farallón sandstone and the Chayllatacana volcanics. Also included in the group is the Machay limestone.

PUCARA LIMESTONE

The Pucara limestone, the oldest formation in the district, is a fine-grained, medium-bedded, light-gray limestone, which on fossil evidence is assigned to the Jurassic period. The formation is dominantly fairly pure limestone, but it contains a few dolomitic beds and some shale, apparently near its upper limits. Nodules and irregular veins of gray to black chert are common. The formation crops out along the east and west borders of the mapped area (pl. 1) in the vicinity of Huancavelica, where it is in either fault or intrusive contact with other rocks. As only faulted segments of the formation are exposed in the Huancavelica area, its total thickness is unknown but undoubtedly is greater than 200 meters (656 feet), the thickness of the largest segment.

On the basis of lithology and fossils of early Jurassic (Lias) age, the limestone is correlated with the Pucara limestone of central Peru and is herein described under that name. Some beds of the Pucara limestone contain abundant fossils, representing a fauna rich in brachiopods, corals, and crinoids. All the fossils are silicified; consequently specimens weathered from the limestone are well preserved.

Relations between the Pucara limestone and the overlying Gran Farallón sandstone were not definitely determined. Gray and reddish shales, exposed at the lower portal of the Quichcahuayjo mine (Mina de la Quebrada de los Espinos), may be gradational between these two formations, or they may be a shaly facies within the Pucara limestone. There is no evidence to suggest that any important diastrophic movement occurred between the deposition of the Pucara limestone and that of the overlying Cretaceous strata.

Cinnabar occurs at several places in the Pucara limestone, but no substantial amount of quicksilver has been produced from these rocks.

GOYLLARISQUISGA GROUP

GRAN FARALLON SANDSTONE

The Gran Farallón sandstone, having been the host rock of the largest quicksilver deposit, is economically the most important formation in the district. It derives its name from the Gran Farallón, a bold, precipitous sandstone ridge that extends southward from Huancavelica to the Santa Bârbara mine. Although it is composed mainly of massive quartz sandstone, it includes minor amounts of shale and limestone. It is of early Cretaceous age.

What is here defined as the Gran Farallón sandstone is included by Berry and Singewald (1922) under the name "Gran Farallón limestone." As the Gran Farallón ridge is not composed of limestone and as the area that was mapped by Berry and Singewald as "Gran Farallón limestone" includes volcanic rocks, sandstone, and limestone in equal abundance, the name is not retained. Instead, the "Gran Farallón limestone" of Berry and Singewald is subdivided into three formations: the Gran Farallón sandstone, the Chayllatacana volcanics, and the Machay limestone. The name "Gran Farallón" in this report refers only to those beds, dominantly sandstone and only subordinately limestone, that underlie the Chayllatacana volcanics.

In general, the sandstone of the formation is light gray, medium-grained, massive, and cross-bedded. In some fresh exposures it is nearly white; in some weathered exposures it is brown, being stained by iron oxides. Although it is generally medium-grained, there are both fine- and coarse-grained facies and at least one thin pebble bed. The sandstone is composed of rounded quartz grains bound together by a siliceous cement. The degree of cementation varies greatly; in places the sandstone is very friable, readily crumbling under a light hammer blow, and in other places it approaches the hardness of quartzite. Cross bedding is common and characteristic. Silicified wood fragments are abundant, but no other fossils were observed. The sandstone in the upper part of the formation differs from that in the lower part by being purer and more strongly cemented, by having fewer but more pronounced intercalations of shale, and by having more abundant wood fragments and better-developed cross bedding.

Shale, although present in both the upper and lower parts of the formation, is more abundant in the lower part. The shale beds in the upper part, although rarely over a few meters thick, are fairly persistent and, because they weather more rapidly, give rise to deep slots in the face of the Gran Farallón. The topographic expression of the shale in the lower part of the formation is less pronounced. The sandstone here is more or less gradational into the shale and contains differing amounts of argillaceous material; thus they weather at approximately the same rate.

At least two limestone members occur in the lower half of the Gran Farallón sandstone; these are shown separately on the district map (pl. 1). The upper bed is about 10 meters thick and is a medium-bedded, light-gray limestone that resembles both the Pucara and Machay limestones. No fossils were found in this member. The lower limestone member is similar to the upper but is considerably thicker and contains fossil corals. The relationship of this lower member to the Gran Farallón sandstone is not entirely clear. It possibly may have closer affinities with the Pucara limestone.

Because of numerous faults, neither the base nor the thickness of the Gran Farallón sandstone could be determined. In the Huancavelica district the minimum thickness of the formation is at least 500 meters (1,640 feet).

The Gran Farallón sandstone is of early Cretaceous age. Although no diagnostic fossils have been found in the Huancavelica area, the formation can be readily correlated with the coal-bearing beds of the Goyllarisquisga district in the Department of Huanuca.

CHAYLLATACANA VOLCANICS

The Chayllatacana volcanics are basic lavas and tuffaceous shales with very minor amounts of conglomerate and limestone. They lie with apparent conformity above the Gran Farallón sandstone and below the Machay limestone. The thickness is in excess of 500 meters (1,640 feet), but because of numerous faults it cannot be accurately measured. Although no fossils were found in these rocks, they are regarded as of early or middle Cretaceous age.

These rocks are characteristically red or dark greenish red, and the soils derived from them are of similar colors. Under existing weathering conditions they decompose so rapidly that the only good exposures are in road or stream cuts. Even in these places, the lavas are so badly altered that they can only be described as quartz-free, dense to porphyritic volcanic rocks of basaltic or andesitic composition.

The bedded clastic rocks are tuffaceous shales and grits and a small amount of limestone conglomerate and sandstone. The shales and grits are well bedded and occur throughout the formation. Conglomerates, composed of limestone and some sandstone cobbles, occur as thin lenses, which may or may not be related to the same stratigraphic horizon. Sandstone is rare, being observed in only two places, where it closely resembles the Gran Farallón sandstone.

The only limestone regarded as a part of this formation occurs near coordinates 1000 S. and 170 E. (pl. 1). It is medium gray and well bedded. No fossils were found in it.

Marked differences in the kind and amount of material in the Chayllatacana volcanics in different parts of the district suggest that these rocks accumulated under local conditions that were constantly changing. According to Steinmann (1929, pp. 190–191), similar rocks—determined, from fossils in limestone intercalations, to be of early Cretaceous age—occur throughout the Peruvian Andes. Steinmann proposes calling these rocks the "formación andina de diabasas-meláfidos," which (freely translated from the Spanish to conform with North American petrographic usage) means "Andean altered basic volcanic rocks." Steinmann does not, however, restrict the term to Lower Cretaceous volcanic rocks, but applies it indiscriminately to all the Andean Mesozoic volcanic rocks; consequently the term, if used in this report, would only lead to confusion.

MACHAY LIMESTONE

The Machay limestone was the host rock of several economically important cinnabar deposits. This formation is composed largely of white to gray, fine-grained, medium-bedded limestone, which contains subordinate interbeds of marly limestone and red shale. It lies with probable conformity upon the Chayllatacana volcanics and is unconformably overlain by Tertiary rocks. Its minimum thickness is estimated as greater than 600 meters (1,968 feet). It contains fossils diagnostic of Cretaceous age.

The formation is roughly divisible into three units: (1) a lower unit of medium-bedded limestone with intercalated beds of greenish-gray, marly limestone; (2) a middle unit of thicker-bedded limestone, which contains only a few thin beds of marly limestone and shale; and (3) an upper unit of medium-bedded limestone with intercalated beds of red shale. Certain beds in all three units contain chert nodules. Divisions between limestone and marl and between limestone and shale are sharp.

The marly beds of the lower unit are important ore horizons. These beds, which particularly favored cinnabar deposition, enclosed the ore bodies of the Botija Punco and other mines.

Fossils from the Machay limestone were collected and described by Berry (Berry and Singewald, 1922, pp. 51–89, pls. 6–10). The forms, mostly pelecypods, gastropods, and echinoids, represent a very shallow clear water fauna, which, according to Berry, is unquestionably of late Cretaceous age. Steinmann (1929, p. 118), however, disagrees with this age assignment and places the enclosing strata in the Lower Cretaceous. The Cretaceous limestones at Huancavelica have been mapped by geologists of the Cerro de Pasco Copper Corp., who correlated them with the Machay limestone near Oroya, which, according to Lissón, is of early Cretaceous age. Fossils collected by the writers from the Botija Punco (Botija Puncu) locality of Berry and Singewald and numerous other localities in the Huancavelica district were identified by R. W. Imlay and C. Wythe Cook, of the U. S. Geological Survey, who assigned them to the Lower Cretaceous. Imlay's report on the mollusks is as follows:

> The collections from the Machay limestone and the Botija Punco limestone near Huancavelica, Peru, belong to the same fauna as described by Berry and Singewald in 1922 and assigned by Berry to Upper Cretaceous, probably upper Turonian or later. However, the collections do not contain any species that are definitely Upper Cretaceous and do contain several species that are characteristic of the upper part of the Lower Cretaceous. Among these are *Exogyra boussingaulti* D'Orbigny, *E. minos* (Coquand), *Neithea* cf. *N. occidentalis* Conrad (equals *N. quinquecostata* of authors), *Crasantella*? cf. *C. caudata* Gabb, *Isocardia* cf. *I. neocomiensis* D'Orbigny, and *Pholadomya ellipticaformis* Berry (equals *P. nodulifera* of authors). Most of these forms are widespread in northern South America and have been assigned generally to the Aptian. However, the possibility of a lower or middle Albian age is suggested by the occurrence of similar species in the Glen Rose and Edwards limestones of the southern United States

CASAPALCA FORMATION

The Casapalca formation, from which a little cinnabar has been mined, is composed of conglomerate and interbedded tuffaceous shale. It crops out in several places in the district but is most prominently exposed near the parish of Santa Bárbara. Here it unconformably overlies the Cretaceous rocks and its eroded surface is overlain by Tertiary tuffs and flows. The Casapalca formation probably is of early Tertiary age.

The Casapalca formation is dominantly conglomeratic but includes some red tuffaceous shales. A partial section of the formation is exposed in the Belén tunnel (pl. 2). This formation undoubtedly varies greatly in thickness, but the only place it could be measured was in the vicinity of Santa Bárbara, where it is about 120 meters (394 feet) thick.

The conglomerates of the Casapalca formation consist of subrounded to angular pebbles, cobbles, and boulders of limestone cemented in fine, calcareous sand and shale. In places the material is well sorted and the rock is bedded; in other places the material is unsorted and the rock is massive. The grade size ranges from pebbles 1 centimeter in diameter to boulders over 1 meter in diameter, but cobbles about the size of a man's fist are by far the most abundant. Many of the cobbles contain one or more concentric shells of chert, as well as chert nodules. Silicified fossils, similar to those found in the Pucara limestone, commonly occur in the cobbles and boulders.

As no fossils indigenous to the Casapalca formation were found, its age can be only approximated from structural relationships. It rests on the beveled edges of Cretaceous rocks; therefore it was deposited after these rocks were folded and eroded. It is overlain, perhaps unconformably, by Tertiary volcanic flows and tuffs; therefore it is older than these rocks. On the basis of the above relationships, an early Tertiary age is assigned to this formation and it is correlated with the Casapalca formation described by McLaughlin (1924, p. 611) from exposures near Yauli.

TERTIARY VOLCANICS

The Tertiary volcanic rocks are largely flows of rhyolite, basalt, and andesite and minor amounts of tuff. They rest unconformably upon the older rocks and, except for surficial deposits, are the youngest rocks in the district. They are folded and faulted, but not nearly as intensely as the Jurassic and Cretaceous rocks. Several deposits of cinnabar occur in the Tertiary volcanic rocks.

These rocks were not studied in detail, nor were particular varieties differentiated on the district map (pl. 1). The tuffs are most common along the Quebrada Santa Bárbara, below the Belén tunnel, where they are light cream to pale green and range from fine-grained varieties to moderately coarse grained varieties. The basaltic flows are not as abundant as the rhyolitic flows, which in the southern part of the district cover a large part of the mapped area (pl. 1). They are biotite rhyolites, white to light cream on fresh surfaces and reddish brown on weathered surfaces. Flow banding is common and locally well developed.

TERTIARY INTRUSIVE IGNEOUS ROCKS

Two kinds of intrusive igneous rocks occur in the area mapped (pl. 1); these are (1) breccias that show intrusive relationships to the surrounding rocks and (2) intrusions of dacite. The breccia intrusions form the largest rock exposures and occur in three separate areas in the central part of the district. The intrusions of dacite consist of two small plugs in the southern part of the area and an irregular dikelike intrusion near the Santa Bárbara mine.

The character of the breccia intrusions was not thoroughly understood during the progress of field mapping; consequently altered sedimentary rocks along their peripheries were not separated from the intrusions proper. As a result their sizes are exaggerated and their shapes distorted on the map (pl. 1). These rocks are a coarse to very fine breccia composed of altered igneous and sedimentary material. Where not stained by hydrous iron oxides they are white to cream-colored. In thin section, under high magnification, the fine-textured rock that forms the matrix for the coarser material is a typical tuff of undeterminable rhyolitic or dacitic composition. It is composed of angular fragments of glass, crystals, and aphanitic igneous material. Intrusive relationships with the surrounding sedimentary rocks suggest that these igneous rocks occur in the necks of former volcanoes, whose last activity was of an explosive nature. The two plugs to the south are similar in character.

Rock alteration along the peripheries of the intrusions consisted of silicification of the tuffs and the sandstones and limestones. The introduction of large amounts of iron sulfide, since altered to limonite, causes the weathered rocks to be stained various shades of brown. Small exposures of similarly altered rocks elsewhere in the district suggest a relationship between them and these intrusions. In and near the altered rocks are numerous small veins of galena with a little sphalerite in a barite gangue. These are structurally related to the breccia intrusions but have no apparent relationship to the cinnabar deposits. The volcanic vents likewise have no apparent structural relationship to the cinnabar deposits.

The dacite intrusive in the vicinity of the Santa Bárbara mine is so badly weathered that specimens unaltered enough for identification were obtained with difficulty. This rock is probably that described by Umlauff (1904) as an andesite, but phenocrysts of quartz observable in both hand specimens and thin sections preclude the use of this name. Microscopic examination further revealed a groundmass of oligoclase laths; consequently the rock can be best described as a dacite. The intrusives to the south have a similar composition but also contain well-formed phenocrysts of biotite, whereas the ferromagnesian minerals in the intrusive near the Santa Bárbara mine are altered beyond the limits of determination.

The intrusions of dacite occurred after the faulting and before the cinnabar mineralization. Both the two small plugs and the dikelike intrusion near the Santa Bárbara mine are intruded along faults, and as they show no displacement by fault movement, they were intruded after the fault movement occurred. As Umlauff (1904) describes cinnabar occurring in the igneous rock in the Santa Bárbara mine, and as cinnabar was observed by the writers along the contact of the dacite and intruded limestone in the open pits east of the Santa Bárbara mine, the cinnabar mineralization occurred after the intrusion of the dacite.

QUATERNARY GLACIAL MORAINE

Deposits of unsorted rubble, definitely glacial in origin, cover some of the valleys and slopes in the southern part of the mapped area (pl. 1). Outcrops of sandstone, limestone, and volcanic rocks are locally smoothly polished and sharply striated. Glacial striae occur as low as 4,270 meters (14,009 feet) in altitude and morainal material as low as 4,200 meters (13,780 feet) in altitude. The moraines are composed of angular blocks, some as great as 10 meters (33 feet) in diameter, derived from outcrops of sedimentary and volcanic rocks similar to those in the district. These glacial deposits are probably remnants of much more extensive moraines that have been almost entirely removed by erosion. Much of the area above 4,200 meters (13,780 feet) has the characteristic subdued topography that is attributed to extensive glaciation.

UNDIFFERENTIATED QUATERNARY ALLUVIUM

All extensive deposits of fluvial gravel and sand, landslide debris, or talus are shown on the district map (pl. 1). The smaller deposits are not shown unless they are in areas where interpretation of the bedrock geology is critical.

Deposits of Recent fluvial gravel and sand were mapped only in the valley of the Río Hicho, where they occur on the south side of the river underneath the town of Huancavelica and on the north side of the river as two small conical hills that cap the travertine deposits. Fluvial deposits may underlie the travertine, but this relationship was not observed in the area mapped. Deposits of landslide debris and talus, or combinations of both, occur in ravines and at the bases of steep slopes.

TRAVERTINE DEPOSITS

The floor of the Río Hicho in the vicinity of Huancavelica is covered by deposits of travertine that extend downstream for several kilometers east of the town. At the east edge of the mapped area (pl. 1) the deposits are over 70 meters (230 feet) thick; 1 kilometer farther east, they are over 150 meters (492 feet) thick. The travertine is a well-bedded, white to yellow-brown rock that is used extensively in the locality as a building stone. It is composed almost wholly of calcium carbonate and appears to be free from fluvial material. The attitude of its bedding planes indicates that it was deposited from springs that had their orifices on both sides of the valley. It is of Recent age and is still being deposited in a few places. It is associated with at least two hot springs; therefore it seems reasonable to postulate that it was deposited from hydrothermal waters.

STRUCTURE

GENERAL STATEMENT

The structure of the Huancavelica district is complex. The dominant structure may be described as a north-trending, tightly folded anticline that has been so thoroughly sliced into fault-bounded segments that its identity is preserved only on its flanks. Subordinate structures include faulted northeast-trending folds and north-south faults. The most reasonable interpretation of the structural history suggests the initial development of open folds, followed by the closing and contemporaneous faulting of these folds.

The anticline trends north through the northern and central parts of the district. In the central part of the district, near the Tesoro Orccjo mine, its east limb bends westward to terminate against a north-south fault, thus forming half a nose. The western counterpart of this half-nose either was never formed or was destroyed by faults trending north and N. 20° W. that "cut the rocks" in the vicinity of the Santa Bárbara mine. These faults at the nose of the anticline extend northward along the edges of the core and along the west flank of the anticline, where they further complicate its structure. Along the planes of these faults, the east and west limbs of the anticline were pushed upward and toward each other, whereas the core was bowed into a syncline as it was pushed downward. The net result of these various movements is an anticline with a faulted synclinal core composed of rocks younger than those that immediately flank it. This complexly folded and faulted structure occupies the northern two-thirds of the mapped area (pl. 1) and is hereafter referred to as the Huancavelica anticline.

The southern third of the mapped area is divided into two minor structural units by the southern extension of the fault zone that cuts the nose of the Huancavelica anticline. East of the fault zone, the Cretaceous rocks are folded into tight, northeast-trending synclines and anticlines that are cut by reverse strike faults, which dip steeply to the southeast. West of the fault zone, the structures in the Cretaceous rocks are largely buried beneath Tertiary volcanic rocks that, although folded and faulted, are not deformed to the degree or pattern of the Cretaceous rocks to the west.

In describing the structural features of this complexly folded and faulted area it is difficult to separate the features formed by folding from those formed by faulting. The major structure, the Huancavelica anticline, is so much the result of both fold and fault movements that its description under either heading would be misleading, as well as inconsistent. To avoid needless repetition, the skeletal description of the Huancavelica anticline here given will not be repeated, but will merely be amplified in the following two sections with pertinent structural details.

FOLDS

The core of the Huancavelica anticline is a northeast-pitching syncline of downfaulted Machay limestone and Chayllatacana volcanics. This syncline can be traced northwestward, from its head at the Santa Bárbara mine, for 1⅓ kilometers (0.83 mile); it then appears to terminate against the conglomerates of the Casapalca formation. Its symmetry is destroyed by a rhyolitic intrusion and by several cross faults and strike faults. Its northeast pitch is anomalous to the south pitch of the enclosing structure, whose general northerly trend is likewise different from that of the northeast trend of the axis of the syncline.

An interesting and puzzling feature of this syncline is a circular area of intensely crushed Gran Farallón sandstone enclosed by relatively unfaulted Machay limestone. It is a short distance northeast of the brocal of the Santa Bárbara mine (near coordinates 800 N. and 0 E., pl. 1). The contact of the sandstone with the enclosing limestone could only be observed along its eastern edge, where it is a fault contact; elsewhere the contacts are covered by mine dumps and detrital material. This circular area has the characteristics of a breccia pipe but is not well enough exposed to determine definitely its mode of origin.

The folded rocks south and southeast of the Tesoro Orccjo mine form two well-defined synclines and a crumpled anticline. They are separated from each other by faults. Their axes trend northeast and pitch to the northeast. The outcropping rocks of the synclines are Machay limestone and Chayllatacana volcanics; outcrops on the anticline are Gran Farallón sandstone. The northwesternmost fold is a minor syncline that has been almost destroyed by erosion and the two faults that bound it (see pl. 1, particularly geologic cross section *D-D′*). It is asymmetric; its northwest limb dips more steeply than its southeast limb. Immediately southeast of it is a prominent closely folded syncline that has a reversed, and more pronounced, asymmetry; locally its southeast limb is overturned. The crumpled anticline lies southeast of the two synclines and is only partly exposed. Its southeastern half is covered by Tertiary lava flows, and its northwest limb is composed of several minor folds, the component limbs of which dip more steeply to the northwest than to the southeast. The anticline probably is more complex than it appears to be on the district map or geologic cross section *F-F'* (pl. 1), but because of the massive character of the sandstone only the major complexities could be mapped.

Several other folds are shown on the geologic map of the district (pl. 1), but they are of such a minor nature that their description is not justified. Local warps and crenulations are common to the rocks of the district, but there was no time available for the mapping of these features, data on which might be useful in interpreting the larger structures.

FAULTS

Although faults are more numerous than folds in the Huancavelica district, they are not nearly as evident to the observer. There are good reasons for their lack of prominence. Most of the major faults are strike faults; therefore they are not as apparent as faults that produce marked offsets and abrupt terminations of beds. Fault movements produced zones of sheared and crushed rock, which eroded to topographic lows that now are largely covered with detrital material. Some faults placed rocks of great resistance to weathering against rocks of little resistance; thus, as erosion proceeded, scarps were formed and the faults now lie under talus that accumulated at the bases of the scarps.

For these reasons, many of the faults in the Huancavelica district could not be observed directly, but were mapped on the basis of stratigraphic and indirect structural evidence. They all appear to be high-angle reverse faults, formed complementary to the folding, and can be roughly classified as transverse faults that cross the strike of the enclosing beds and strike faults that parallel, or nearly parallel, the strike of the enclosing beds. On the district map (pl. 1) the transverse faults are located with fair accuracy, but the strike faults are only approximately located. Because the strike and transverse faults grade into each other, the individual faults described below are taken up geographically instead of by structural type.

As previously mentioned, the Huancavelica anticline is faulted on both flanks, as well as internally. On its west flank are three principal zones of faulting, one east and one west of the Gran Farallón and one west of the Botija Punco mine hill. The fault east of the Gran Farallón has a steep westerly dip and trends, from the Santa Bárbara mine, N. 10° E. to the Huancavelica valley, where it disappears under alluvium. Its maximum displacement is equal to or greater than the thickness of the Chayllatacana volcanics, as these rocks locally are completely cut out. Near the southern end of the Gran Farallón it is offset by several tear faults. It joins the faults that lie west of the Gran Farallón near the brocal of the Santa Bárbara mine. The fault immediately west of the Gran Farallón that is shown cutting the Chayllatacana volcanics on plate 1 is not exposed, but its presence is interpreted from stratigraphic evidence. It trends about N. 10° W. and dips steeply to the west. In the valley west of the Botija Punco mine hill three faults whose relationship is puzzling thrust blocks of Chayllatacana volcanics up over blocks of Machay limestone. Two of these faults trend northwest, and the third, against which the others terminate, trends north; all dip in a westerly direction. To the north and northwest they are cut out by an intrusion of rhyolite. Northwest of the rhyolite intrusion are two other faults that also are older than the rhyolite intrusion.

The east-dipping faults along which the east flank of the Huancavelica anticline is thrust up on the core of the anticline have a combined displacement greater than those on the west flank. In the lower part of the valley of the Quebrada de los Espinos, Pucara limestone is separated from Machay limestone by only a thin sliver of Gran Farallón sandstone. At the head of the valley of the Quebrada de los Espinos the faults disappear under alluvium.

Faults that are the southern equivalents of those in the valley of the Quebrada de los Espinos occur to the north of the Tesoro Orccjo mine. Following the swing of the nose of the anticline they trend northeast. To the northeast they are cut out by a rhyolitic intrusion; to the southwest they converge with a south-trending fault that extends into the southern end of the district.

The north-south fault zone that extends through the southern third of the district is in actuality a southern extension of the faults that converge at the nose of the Huancavelica anticline. This fault zone is composed of two parallel faults. In general the west fault is the boundary between the Tertiary volcanic rocks and the Cretaceous Chayllatacana volcanics, although most of the movement on this fault took place before the deposition of the Tertiary volcanics.

Three northeast-southwest faults separate the folds in the eastern part of the southern third of the district. The two that bound the small syncline southeast of the nose of the Huancavelica anticline were mapped from stratigraphic evidence. They converge to the northeast. The third fault cuts off and locally overturns the southeast flank of the larger syncline. These faults were overthrust to the northwest, as were those on the west flank of the Huancavelica anticline. At the east edge of the mapped area between coordinates 350 S. and 1000 N. (pl. 1), the northeasterly structures are offset by a fault that in general trends north. On this fault, movement was dominantly strike-slip, with rocks on the east side moving northward with respect to those on the west side.

ORE DEPOSITS

HISTORY AND PRODUCTION

The history of the quicksilver mines of Huancavelica is long and colorful. It is essentially the history of the Santa Bárbara mine, which contributed the great bulk of the production. The cinnabar deposits were known to the Incas long before the arrival of the Spaniards, who, according to one legend, were informed of the deposits as early as 1532. Another, more plausible legend has it that an Indian, Nahuincopa, made known the presence of the deposits to his master, Amador Cabrera, in either 1564 or 1566. It is certain, however, that Cabrera was in possession of the deposits and worked them until 1570, when they were appropriated by the Spanish Crown.

The Crown owned and operated the deposits until the proclamation of Peruvian independence in 1821. Spain valued the mines of Huancavelica very highly, considering them "the greatest jewel in the Crown." The mines furnished a plentiful supply of mercury for treating, not only the silver ores of Peru, Chile, and Bolivia, but also those of Mexico. Consequently they contributed large sums to the royal coffers and, in addition, made it unnecessary to ship mercury from the mines of Almadén, Spain, to the Western Hemisphere, thus reserving this supply for trade in Europe.

Although the Crown owned the mines until the end of the colonial era, it did not directly administer operations except for brief periods. Direct administration lasted until 1577, when Don Francisco de Toledo, the fifth viceroy of Peru, contracted with the Gremio de Mineros, a miners' guild, to operate the mines. Many similar contracts followed, lasting from 25 to 30 years; the Gremio de Mineros, financed by the Crown, was required to turn over its entire production of mercury at a fixed price and was consequently in debt to the Crown. The last contract terminated in 1782, when the mines were again directly administered.

The Gremio de Mineros was responsible to various royal governors and superintendents, who knew nothing of mining. In fact, the difficulties and problems of mining under both direct administration by the Crown and management by the Gremio de Mineros were numerous and similar. The administrators appointed by the Crown were anxious to make a good record, as were those of the guild, who were anxious to reduce their indebtedness. Consequently, there was no long-range policy of development, and the mines were continuously being exploited for the benefit of the immediate operators with no regard for safety or the future of the mines. In the Santa Bárbara mine, the practice of removing pillars of rich ore whenever the ore bodies decreased in grade led to numerous disastrous cavings. Notable among these cavings were those of Santo Domingo de Cochapata, Capillita, Hoyo Negro, San Jacinto, Brocal Santa Rita, and Marroquin. The loss of life in these disasters was enormous; the collapse of Santo Domingo de Cochapata buried over a hundred Indians, and the most catastrophic caving, that of Marroquin in 1786, took the lives of over 200. After the last major collapse, in 1806, much of the Santa Bárbara mine was caved from top to bottom and has remained so ever since.

After the Marroquin caving the King of Spain was well aware that reforms were badly needed. Accordingly, in 1790, Baron Nordenflicht was sent to Huancavelica to investigate conditions there. Recommendations made by Nordenflicht were approved by the King but were disregarded by the administrator, Count Ruiz de Castilla, who permitted the reworking of the dumps and the pillars of previously exploited zones within the mine, which temporarily increased the production. About this time, also, the viceroy decreed that all subjects within 10 leagues of Huancavelica must work in the mines. In order to stimulate the discovery of new deposits, finders of mines were enfranchised to work them, although the titles were retained by the Crown. This led to the discovery of several smaller mines, which contributed an important share of the production during the last years of the eighteenth century and the early years of the nineteenth century.

In 1821, when the newly proclaimed Peruvian Republic took over the Huancavelica quicksilver mines, it found them almost as much of a liability as an asset. Most of the workings were caved, the mines were stripped of all the better ore, and expensive, urgently needed repairs were wanting. Funds were not available for improving conditions, and because of political unrest during the first years of independence, the mines were practically abandoned to a few snipers and small lease holders. Silver mining in Peru made the quicksilver mines indispensable; therefore, from 1821 to 1850, the industry was maintained—though on a rapidly decreasing scale, with all the inefficient practices of the colonial period.

In 1836 a company was formed by Don Demetrio Olavegoya, under the sanction of the Government, to work the Santa Bárbara property. This company was soon dissolved and replaced by another, which fared no better. These and still other companies that followed held only the Santa Bárbara mine and not the smaller properties that were then in active production. Finally, in 1901, the Santa Bárbara property was opened to denouncement under the Peruvian mining laws. No parties

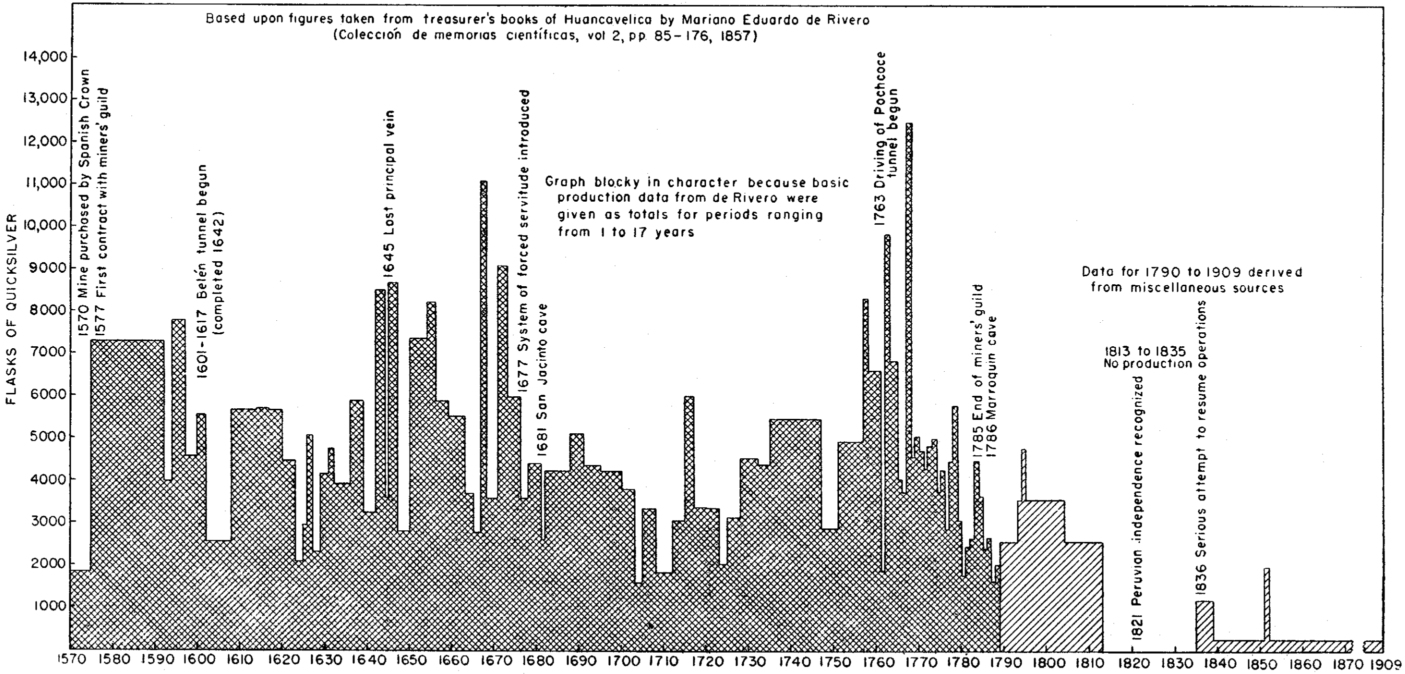


Figure 1.—Graph showing the production history of the Santa Bárbara mine, Huancavelica quicksilver district, Peru.

with sufficient capital appeared to undertake the rehabilitation of the district until 1915, when E. E. Fernandini obtained control of the Santa Bárbara mine.

In 1946 Fernandini still controlled the Santa Bárbara mine and adjacent properties and had done extensive development work, including the installation of a hydroelectric plant and two Gould-type rotary furnaces with a 250-ton capacity for treating the ore. The old main adit, the Belén tunnel, was reopened, but it has since caved and in 1946 had not been completely reopened. A new adit, the Socavón Fernandini, was driven below the old workings, which, incidentally, did not extend to the depths shown by old descriptions. In 1945, however, this new tunnel was inaccessible because of caving near the portal. Fernandini has apparently abandoned exploratory work from this lower level and is planning to extract the fill from the old caved stopes above the Belén tunnel level. The only production of quicksilver by Fernandini up to the present time has been on an experimental scale.

The Huancavelica mining district is credited with a total production of quicksilver that exceeds the output of any other district in the Western Hemisphere. Most of the quicksilver was produced from the Santa Bárbara mine during the 220-year period from 1571 to 1790. The district has produced only a negligible quantity of quicksilver during the past hundred years.

The archives of the Santa Bárbara mine have been lost, but figures taken from the treasurer's books of Huancavelica by Mariano Eduardo de Rivero (1857) give the production from 1571 to 1790 as 1,040,069 quintales (1,369,038 flasks of 76 pounds each) of quicksilver. All figures from 1790 on are largely estimates based upon very few records. These estimates, added to the recorded production, give the total production of 1,470,000 flasks of quicksilver shown graphically on figure 1.

GEOLOGY

The quicksilver deposits of Huancavelica are located along a narrow belt less than 3 kilometers wide that extends for many miles both north and south of the town of Huancavelica. Almost all the production, however, was derived from the relatively small area in the immediate vicinity of Huancavelica that is shown on plate 1, and almost all this production came from the Santa Bárbara mine, with only minor production from the adjacent Botija Punco, Pucacapa, and San Roque mines.

MINERALS

Cinnabar was the principal ore mineral, with a minor amount of native mercury and possibly some metacinnabar. Sulfide minerals that are closely associated spatially are pyrite, arsenopyrite, realgar, orpiment, and stibnite. Less closely associated sulfides are galena and sphalerite. Associated nonmetallic minerals are quartz, calcite, barite, and hydrocarbons.

Cinnabar was the only mercury mineral observed by the writers, except for very small amounts of native mercury. It was certainly the only abundant ore mineral, although native mercury was widely distributed throughout the district. Cinnabar that Arana reported as resembling ruby silver may be metacinnabar. Some of the cinnabar occurs as a powder, but much of it occurs in minute, bright-red crystals. It fills fractures and coats fracture surfaces and other openings; some replaces the country rocks, whether sandstone or limestone. According to old reports and the observation of the writers, it most commonly occurs in sandstone as a filling interstitial to the quartz grains, but locally it replaces the siliceous cement and even the quartz grains of the sandstone. Thin sections of sandstone ore from the Santa Bárbara mine exhibit cinnabar replacing crushed and pulverized sandstone along fracture planes, as well as replacing unfractured quartz grains. Replacement of the sandstone probably accounts for the "bunches" of almost pure cinnabar that have been described as occurring in the district.

Pyrite is a common mineral, not only in the quicksilver deposits, but throughout the district. Its occurrence is similar to that of the cinnabar, both in fracture openings and as replacements of country rock. Large masses of limonite containing casts of what formerly were pyrite cubes are abundant, particularly along the contacts of the intrusive breccias with the limestone.

Arsenopyrite, realgar, and orpiment are commonly associated with the cinnabar. The arsenopyrite was found in the lower levels of the Santa Bárbara mine in much greater abundance than cinnabar and can be seen on the waste dumps from these inaccessible levels. The presence of abundant realgar and rarer orpiment in oxidized surface rocks suggests that these minerals may have been derived from the oxidation of arsenopyrite.

Other sulfide minerals that occur associated with the cinnabar are stibnite, galena, and sphalerite. Stibnite was observed in small veinlets in the sandstone in association with galena and sphalerite. Most of the galena and sphalerite occur independently of the cinnabar in barite veins near the contact of the intrusive breccia with limestone.

Nonmetallic gangue minerals, exclusive of the rock-forming minerals, are not abundant. A little calcite, quartz, barite, and hydrocarbons occur with the ore. The quartz is uncommon in deposits in sandstone and the calcite in deposits in limestone. The barite appears to be more closely related to the galena than to the cinnabar.

Heavy black oils and tars are found in all types of deposits. These locally fill all the available rock openings and ooze and drip from the rocks. The hydrocarbons are more commonly present, however, as a dark stain in the sandstone, which occurs only in or near sandstone that has been mineralized.

TYPES OF QUICKSILVER DEPOSITS

The deposits may be classified, according to the rocks in which they occur, in the following groups: (1) deposits occurring in sandstone, (2) deposits occurring in limestone, and (3) deposits occurring in igneous rocks. Although this classification is intended chiefly for convenience in description, it is also of genetic importance, because the type of host rock primarily determines the structural control of the ore deposits. The location of the deposits in sandstone was controlled by more permeable sandstone beds and fractures, the location of the deposits in limestone by marly beds and cross fractures, and the location of the deposits in igneous rock by fractures.

QUICKSILVER DEPOSITS IN SANDSTONE

The quicksilver deposits in sandstone were economically the most important in the Huancavelica district. Included under this type of deposit are the ore bodies of the famous Santa Bârbara mine, those of the Tesoro Orccjo and Tacna y Arica mines, and those of several smaller mines and prospects. The deeper workings of the Santa Bârbara mine are inaccessible; therefore information based on direct observation of the deposits in sandstone comes mainly from the accessible near-surface workings of the Santa Bârbara mine and the superficial workings of the smaller mines. This is unfortunate, because the Santa Bârbara ore bodies were the only ones that were extensive and were mined to any appreciable depth.

Cinnabar occurs in the Gran Farallón sandstone mainly as intergranular disseminations that, in the aggregate, are roughly tabular in form. The shape and orientation of the ore bodies depend upon the fractures that controlled them and upon the thickness and attitude of the enclosing porous sandstone beds. Cinnabar and other sulfide minerals replace the sandstone and fill fracture openings to some extent, but most of the metallic sulfide is distributed in pore spaces between the grains of quartz sand.

Fractures appear to have been the loci for dissemination; cinnabar is most abundant near the fractures and proportionately less abundant away from the fractures. Pockets and shoots of rich ore probably were characterized by closely spaced parallel fractures or by ramifying fractures. The better ore appears to have been deposited in the more loosely cemented sandstone. Because cementation of the sandstone varies between beds and also within beds, the ore bodies tend to be irregular in form, with numerous inclusions of barren rock representing more tightly cemented sandstone. Locally the ore bodies are bounded sharply by beds of shale.

Little is known of the maximum vertical extent of the cinnabar deposits in sandstone. In the smaller mines, most ore shoots appear to have bottomed within 50 meters (164 feet) of the surface. Stopes in the Santa Bárbara mine are accessible only to corresponding depths but are undoubtedly much deeper. The best evidence indicates that ore was mined in the Santa Bárbara mine through a vertical distance of about 300 meters, but it is doubtful if individual stopes were much more than 100 meters long.

QUICKSILVER DEPOSITS IN LIMESTONE

Deposits of cinnabar in limestone are economically the second most important type of deposit. They occur in both the Machay and Pucara limestones at numerous localities within the district. The Botija Punco, San Roque, and Quichcahuayjo (Quebrada de los Espinos) mines exemplify this type of deposit. Unfortunately the production records fail to separate the production of individual mines; therefore it is not possible to compare statistically the production from the deposits in limestone with the production from those in sandstone. However, the deposits in limestone contributed a small but substantial quantity of the quicksilver produced in the district.

Cinnabar occurs in irregular tabular bodies concordant to the bedding of the limestone and in veins that are transverse to the bedding. In contrast to the cinnabar in sandstone, the cinnabar in limestone largely fills fracture openings. Beds of marly limestone near the base of the Machay limestone were particularly favorable for the deposition of cinnabar, and most of the ore bodies in limestone are in these beds. Lithologically the Pucara limestone lacks the variation in porosity from bed to bed that characterizes the productive part of the Machay limestone. Consequently the smaller and less numerous ore bodies in the Pucara limestone are more closely controlled by fractures than by lithology.

In the Botija Punco mine the ore bodies occurred in beds of marly limestone, but as the ore bodies are completely mined out, the character of the ore can be inferred only from the physical character of the host beds. The marly limestone is a soft, porous rock that has a greater porosity than the beds of purer limestone with which it is interbedded. Consequently it appears probable that the ore was a highly irregular network of small veinlets of cinnabar with occasional nodulelike pockets of cinnabar where the rock was replaced by the cinnabar. Richer ore shoots in the limestone occurred where transverse fractures crossed favorable beds.

Cinnabar was mined at greatest depth from limestone in the Botija Punco mine, where ore was stoped 80 meters (265 feet) below the surface. These ore shoots appear to have bottomed at this depth. Most ore shoots were much smaller, averaging no more than 25 meters (82 feet) in stope depth.

Cinnabar was mined from the limestone conglomerate of the Casapalca formation, but it was so completely removed by mining that its mode of occurrence could not be observed. It probably occurred as fillings in fracture openings, since the deposits were located along fractures.

QUICKSILVER DEPOSITS IN IGNEOUS ROCKS

The quicksilver deposits in igneous rocks occur in the southern part of the district, where the Tertiary lavas cover the older rocks. The best example of a deposit of this type is the Dewey, or Santa Bárbara III, mine, which in 1945 was the only actively producing quicksilver mine in the district. Here cinnabar occurs in biotite rhyolite in a fracture zone near a limestone contact. Cinnabar-bearing rhyolite and basalt have been prospected in numerous places in the southern part of the district, but no other commercial deposits have been discovered.

The occurrences were controlled by fracture zones and thus have veinlike forms. Crystalline cinnabar associated with pyrite coats the fracture faces and to a minor extent impregnates altered rock away from the fractures. The ore body at the Dewey mine has a maximum width of 10 meters (33 feet), is over 70 meters (230 feet) long, and has been worked to a depth of 80 meters (262 feet).

According to Umlauff (1904, p. 35), cinnabar occurs in the Santa Bárbara mine along contacts of intrusive andesite and impregnates the andesite for short distances away from the contacts. The writers did not find any intrusive andesite in or near the Santa Bárbara mine, but Umlauff probably refers to the intrusive dacite shown on the district map (pl. 1). Although no cinnabar was seen in this rock, it is explored by several prospect pits, which probably were in metalized rock. The only cinnabar in igneous rock seen by the writers was a specimen from the mine dumps, which was too badly altered to determine whether it was dacite or a basaltic lava from the Chayllatacana.

STRUCTURAL CONTROL

The problem of structural control, in particular the structural control of individual ore bodies, is economically the most important geologic problem in the district. Undiscovered ore bodies are most likely to be found in areas that contain structures similar to those that control the mined ore bodies.

The classification of the quicksilver deposits according to rock type is also a classification of the structural control of the ore bodies, although it is not a very systematic classification. Natural variations between the permeability of various rock types and their various reactions to earth stresses will largely determine the location of passageways that may be traversed by ascending ore-forming solutions. The control of the individual ore bodies, as well as the location of the mines, is therefore mainly a function of the original, or primary, permeability of the host rocks and the secondary permeability induced by rock deformation. On the other hand, the over-all structural control of the district is not concerned with the location of permeable passageways, but instead is concerned with the location and extent of the deeper source of the ore-forming solutions.

In the sandstone and the limestones the ore bodies are commonly roughly concordant with the bedding. Ore bodies that parallel the bedding in the sandstone are in more permeable beds, which are either coarser-grained or less well cemented. The ore bodies that parallel the bedding of the limestones were found in marly beds that had a greater permeability than adjacent beds of purer limestone. In both the limestones and the sandstone, fractures served as feeder channelways into permeable rocks; consequently the structural control is often a combination of primary and secondary permeability. The rich shoots of many ore bodies occurred where fractures crossed favorable stratigraphic horizons.

As the permeability of the igneous rocks was relatively low and uniform, the ore-forming solutions followed along fracture openings when traversing these rocks. Breccia zones were particularly favorable for ore formation. Contacts between intrusive and sedimentary rocks, in particular those that have been fractured since intrusion, also are favorable locations for ore bodies.

ORE RESERVES

It was not possible to make any reasonable estimate of either indicated or inferred ore reserves. In 1946 there was only one small mine in operation, and even here no ore was being developed in advance of mining. The other small mines had been abandoned with no ore remaining in the working faces. The possibility always exists, however, that there may be projections of the exploited ore bodies, as well as adjacent undiscovered ore bodies, but such possibilities cannot be considered as even reserves of inferred ore. The accessible parts of the Santa Bárbara mine contain caved material, certain parts of which may be considered as low-grade ore estimated to contain about 2 pounds of mercury to the ton. The great bulk of the caved material at the surface and in the shallow accessible workings is almost barren of cinnabar and cannot be considered as ore. The potential ore reserves of the district would be in the lower workings of the Santa Bârbara mine, where some of the caved fill is probably ore. It is also quite possible that new ore bodies may be discovered through exploration directed from these lower workings.

As pointed out in a previous section of this report, one cannot make any truly sound prediction of the future of the district without a first-hand knowledge of the deeper parts of the Santa Bârbara mine, which were inaccessible at the time of the investigation. If the lower levels of the mine were reopened, it seems very possible that a thorough study of the geology of these levels would lead to the discovery of ore bodies unknown during the colonial period. The structural controls of the ore bodies in the accessible parts of the mine are clear, and similar favorable unexplored structures may exist in the lower levels. Any program of exploration should first consider the exploration of the rocks adjacent to the workings of the lower part of the Santa Bârbara mine. This seems the most favorable area in the district.

Most of the other small mines and prospects do not warrant any extensive exploration. A few places favorable to the accumulation of ore are pointed out under the descriptions of individual mines, but the past of the district was the past of the Santa Bârbara mine and it appears just as likely that the future of the district will be the future of the area around the Santa Bârbara mine.

MINE DESCRIPTIONS

Prospects, as well as mines, are included under the following descriptions. In general, a property is called a mine if it has a recorded or inferred production and a prospect if it has no known or inferred production. Inferred production is based upon the size of the workings and the presence of dumps of burned ore. Naturally distinctions based upon such evidence are not infallible; for example, a small surface pit may represent a small mined-out pocket of ore, or it may represent a faint showing that was prospected without developing any ore whatsoever. The presence or absence of burned-ore dumps also can be misleading; ore was carried by llama from the producing mines to numerous small retorts that in some cases were located far from the source of the ore. The writers believe, however, that the distinctions that have been made between mines and prospects are valid.

The descriptions of the mines and prospects are arranged in major groups according to their geologic occurrence. Arrangement within the major groups is according to size and relative economic importance. The host rock in which the ore was found is the basis for the three major groups: (1) mines and prospects in sandstone, (2) mines and prospects in limestone, and (3) mines and prospects in igneous rocks.

MINES AND PROSPECTS IN SANDSTONE

SANTA BARBARA MINE

The Santa Bárbara mine, named after the hill in which it is located, is at the south end of the Gran Farallón 2 kilometers (1.24 miles) south of Huancavelica, from which it can be reached by a surfaced automobile road. The several small adjacent mines have been worked in conjunction with the Santa Bárbara mine, but these are independent workings that are in geologically different deposits. When the mine was transferred to the Spanish Crown in 1570, it was described as being 80 Spanish varas (222 feet) long, 40 varas (111 feet) wide, and 60 varas (166 feet) deep. A survey made in 1763 describes the mine as having more or less the same area but an increased depth that had only doubled its size in almost 200 years. This survey must be in error, or else only a part of the main workings was regarded as the Santa Bárbara mine, because a map drawn by Don Pedro Subiela and dated 1775 shows the mine as having a maximum length of 540 meters (1,772 feet) and a maximum width of 100 meters (328 feet). The surface depression that marks the limits of the open-cut and caved workings is 480 meters (1,575 feet) long and has a maximum width of 100 meters (328 feet). This depression, however, extends 120 meters (394 feet) farther north than the workings shown by Subiela; consequently, according to Subiela's map, the underground workings extend 180 meters (590 feet) beyond the south end of the depression.

The mine workings extend in a northerly direction. They were originally worked from open-cuts by inclined spiral stairways, but the deposits were later worked from four adits. The most famous and important adit is the Belén tunnel, which was completed in 1642. It was driven eastward to intersect the southern workings of the mine. In 1918, when the Fernandini company began to clean out this badly caved adit, it was open for only 280 meters (919 feet). Gastelumendi, the engineer in charge of the reopening, reported (1917) that it proceeded in a fairly straight line for 508 meters (1,667 feet), after which it began to descend abruptly, following a sinuous course for 126 meters (413 feet) to a point where a slope was encountered 33 meters (108 feet) below the floor of the adit. In 1945 the adit was open for a distance of 384 meters (1,260 feet). It was surveyed and its geology mapped (pl. 2). Another adit, the Socavón de Chayllatacana, was driven southeastward; it intersects the stopes about 40 meters (132 feet) below the outcrop. The adit of San Javier was driven from the east and intersected the stopes at a distance of 56 meters (185 feet) below the outcrop. The San Nicolás, the fourth adit, also was driven from the east but at a higher elevation. In 1945 all these adits, except the Belén, were caved at their portals. Sr. Fernandini began in 1916 to drive a new adit 370 meters (1,215 feet) lower than the outcrop of the deposit. It was necessary to raise from this adit (the Fernandini tunnel), which also was inaccessible in 1945, to connect with the old workings.

The maximum depth of the old workings is unknown; however, it is very doubtful if they extend more than 300 meters (985 feet) below the outcrop. Subiela's map shows stopes below the Belén level, but as no elevations are given it is not possible to determine the depth of these stopes.

Before the adits were completed, the mine was worked by a complex series of spiral inclines and stairways. Shaft mining was never attempted. The ore was brought up the stairways and spiral inclines on the backs of Indian laborers to the surface and transported on the backs of llamas to the numerous retorts where the mercury was extracted. The retorts, or hornos, were primitive masonry furnaces constructed from local stone; no metal was used in their construction. They consisted of a chamber for heating the ore with a fuel of llama dung and chambers for condensing the mercury vapors driven off from the cinnabar ore in the heating chamber. Much of that part of Huancavelica north of the river is built upon burned-ore dumps from the old hornos.

In 1945 less than 5 percent of the workings of the Santa Bárbara mine were accessible. These were shallow stopes entered from the Carlos III and Guadalupe portals and stopes opened by caving in the ground immediately north of the Carlos III portal. These stopes are probably comparable in size to those in the inaccessible part of the mine; the largest is a little more than 50 meters (164 feet) long. Generally they are irregularly tabular in form with pipelike projections. Some ore bodies were only 1 meter thick; others were more than 10 meters (33 feet) thick; and still others were probably 20 meters (66 feet) or more thick. The inclination of the ore bodies ranges from almost horizontal to vertical, but in the aggregate the deposit dips steeply toward the west.

The stopes in the southern part of the mine were not as abundant, large, or ramifying as those in the northern and central parts of the mine. South of the point where the Belén tunnel joins the main workings are two stoped areas that are isolated by what is apparently barren ground. The area north of the Belén tunnel junction is an almost continuous area of stopes. However, the deeper workings appear to have been in the southern part of the mine.

921853—51——3

According to Umlauff (1904, p. 43), the average grade of the ore is believed to have been about 2 percent. As it is not possible even to approximate the volume of stoped ore, one cannot check this estimate by calculating the grade of ore from the total production. No volume of ore approximating this richness can be seen in the mine workings, but that is to be expected because during the many years the mine was abandoned the workings were stripped by high-graders. The relatively small waste dumps emphasize the fact that all cinnabar-bearing rock, regardless of grade, was treated in the furnaces. With the enforced servitude of the Indians, operation costs must have been small; consequently almost any grade of ore could be profitably mined. It seems likely that during the times when high-grade ore was temporarily unavailable the abundant supply of slave labor was employed in mining ore that could not be mined under present operating costs.

The Santa Bárbara quicksilver deposit is located at the southern termination of the Gran Farallón sandstone within a "V" formed by two intersecting faults that dip to the west. At the surface the northern workings are in sandstone and the southern workings are in Chayllatacana volcanics and shales. The east side of the "V" is bounded by a fault that trends N. 22° E. and the west side by a fault that trends north. The interior of the "V" is divided into a number of smaller blocks by faults striking northeast and northwest (pl. 1). Two of the faults within the "V" intersect to form a smaller "V" and in so doing form the boundary between the Gran Farallón sandstone and the Chayllatacana volcanics. The faults bounding this small "V" dip away from it; therefore the Gran Farallón sandstone has a southward plunge under the volcanics. Accordingly the workings at the end of the Belén tunnel, 215 meters below the surface, are in sandstone. The faults bounding the larger and outer "V" terminate in a dacite intrusion at the surface. The southernmost underground workings of the mine may be in dacite.

The character of the ore has been described elsewhere in this report.

TESORO ORCCJO MINE

The Tesoro Orccjo mine is on Tesoro Orccjo hill, from which it receives its name. This hill, on the east limb of the Huancavelica anticline, is composed of Gran Farallón sandstone. The mine includes two groups of trenches, open-cuts, and shallow underground workings. The first group is located near coordinates 50 N. and 470 E. (pl. 1) and the second group near coordinates 250 N. and 1000 E. In 1945 the property was inactive, although it had been active only a few years before. A considerable quantity of ore has been mined, but as no records were kept it is not possible to give even a rough estimate of the amount.

The first group of workings includes an open-cut, 14 meters (46 feet) by 10 meters (33 feet) in size, and some superficial underground workings. (See fig. 2.) These workings are in a white, fine-grained, friable sandstone, which has well-defined beds that range from 0.4 meter (1 foot) to 0.7 meter (2 feet) in thickness. The beds strike approximately east and have an average dip of about 60° S. They are cut by a series of parallel fractures, which likewise strike east but dip about 40° N., a direction almost normal to the bedding planes of the sandstone. Thin films of cinnabar along some of the fractures in the walls of the workings indicate that the ore that was mined occurred in a similar manner. In addition to these east-striking fractures, a few strike north to northwest and dip to the east.

Three small trenches are included in the first group of workings. These also are in fractured sandstone, but the fractures are unoriented instead of systematically arranged.

The second group of workings consists of five short irregular adits, horizontal or inclined, whose portals are located within a vertical range of 20 meters (66 feet). The general trend and inclination of these workings indicate that they were driven along mineralized

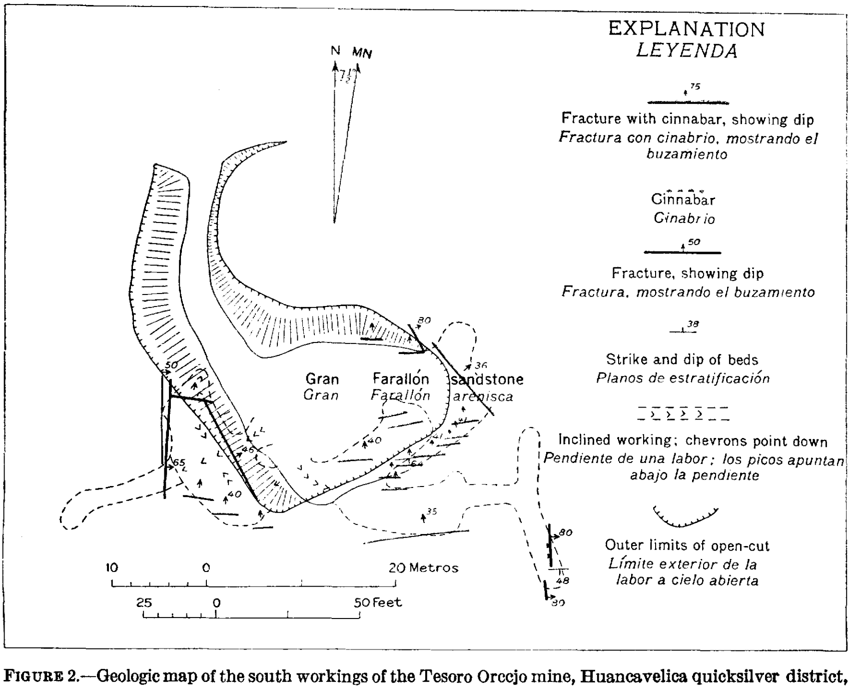
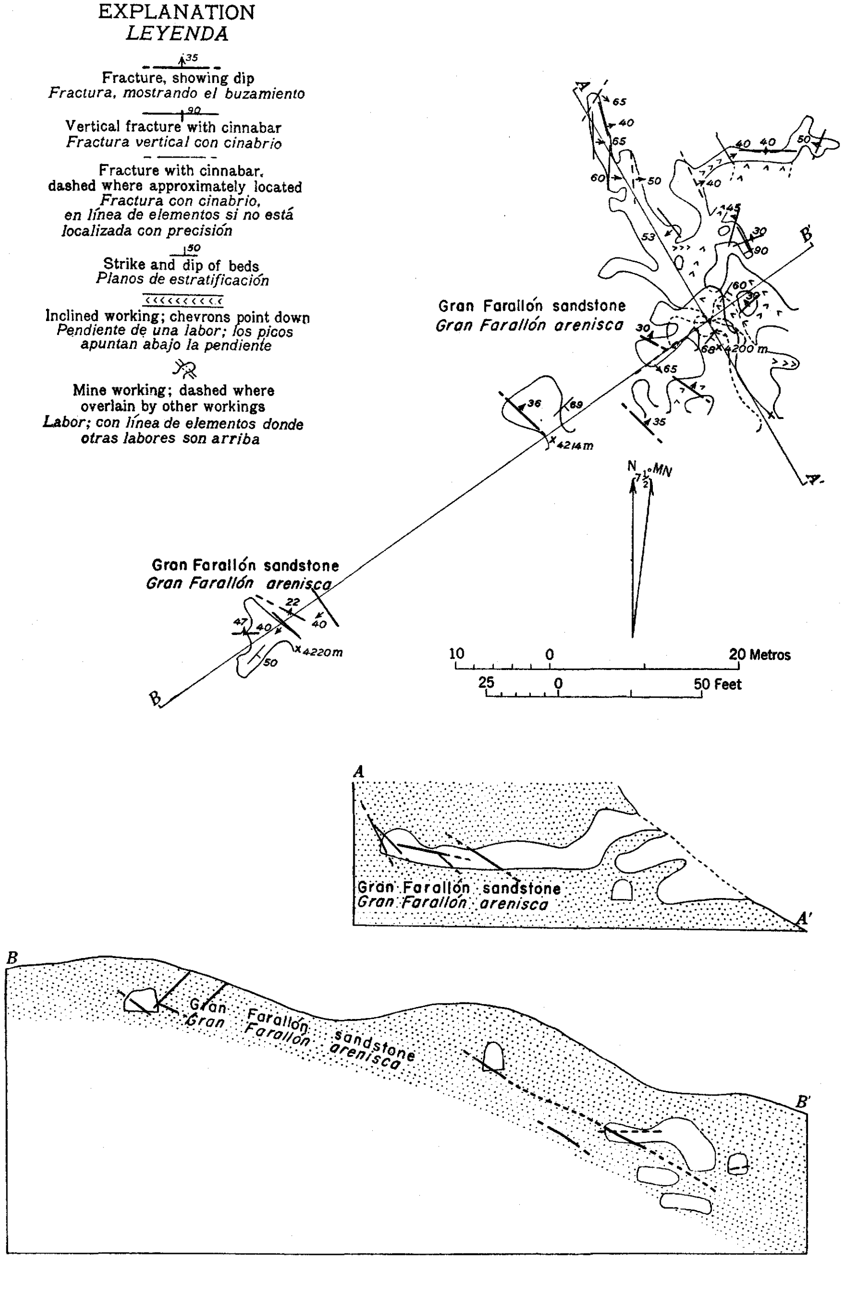


FIGURE 2.—Geologic map of the south workings of the Tesoro Orccjo mine, Huancavelica quicksilver district, Peru.



By Jaime Fernandez Concha and Rodolfo Flores Burneo
Por Jaime Fernandez Concha y Rodolfo Flores Burneo

FIGURE 3.—Geologic map and sections of the north workings of the Tesoro Orccjo mine, Huancavelica quicksilver district, Peru.

fractures striking northwest and dipping to the northeast. Figure 3 shows the shape, extent, and geology of these workings. The cinnabar seen along the fractures in the walls suggests that the rocks in this area were more strongly mineralized than those in the first group and that there are greater possibilities of finding more ore in this area. It is very doubtful, however, if ore bodies like those of the Santa Bárbara mine will ever be developed here, because major geologic structures like those that control the ore at Santa Bárbara are lacking.

JARAMPA MINE

The Jarampa mine is near coordinates 2200 S. and 200 E. (pl. 1) in the Gran Farallón sandstone that crops out in the extreme southeastern part of the area studied. It consists of an open-cut, about 30 meters (98 feet) by 8 meters (26 feet) in size, with an average depth of about 10 meters (33 feet). Connected with this open-cut, which trends N. 25° E., are several underground stopes, the largest of which is toward the south. Toward the north of the open-cut is a shaft connected with what are apparently fairly extensive underground workings; these were inaccessible to the field party.

All the workings are along two parallel faults, following the N. 20° E. strike of the sandstone, that truncate the west-dipping beds with dips of about 50° SE. The mineralization was apparently controlled by these faults, and the ore probably occurred along them and in associated fractures. Cinnabar, however, was seen only along a few cross fractures at the northern end of the workings. The sandstone in which the workings occur is locally bleached and iron-stained and coated with iron sulfates, which suggests that the unoxidized ore is high in pyrite.

Near this mine are two hornos and several moderately large dumps of burned ore.

MINE AT COORDINATES 2400 S. AND 550 E.

As the writers were unable to learn the correct name of this mine, it is here identified by its location on the district map (pl. 1). It is about 400 meters (1,312 feet) southeast of the Jarampa mine.

The lower workings were flooded during 1945, and for this reason their form, extent, and geology cannot be described. The accessible workings consist of two small trenches, from the lowest of which extends an incline that opens up into a small, almost circular stope. On the walls of this stope can be seen many unoriented fractures that are mineralized with cinnabar. These mineralized fractures apparently interlaced to form an ore body, which possibly has been explored on a lower level.

From the size of the burned-ore dumps it appears that this small mine may have produced considerable quicksilver.

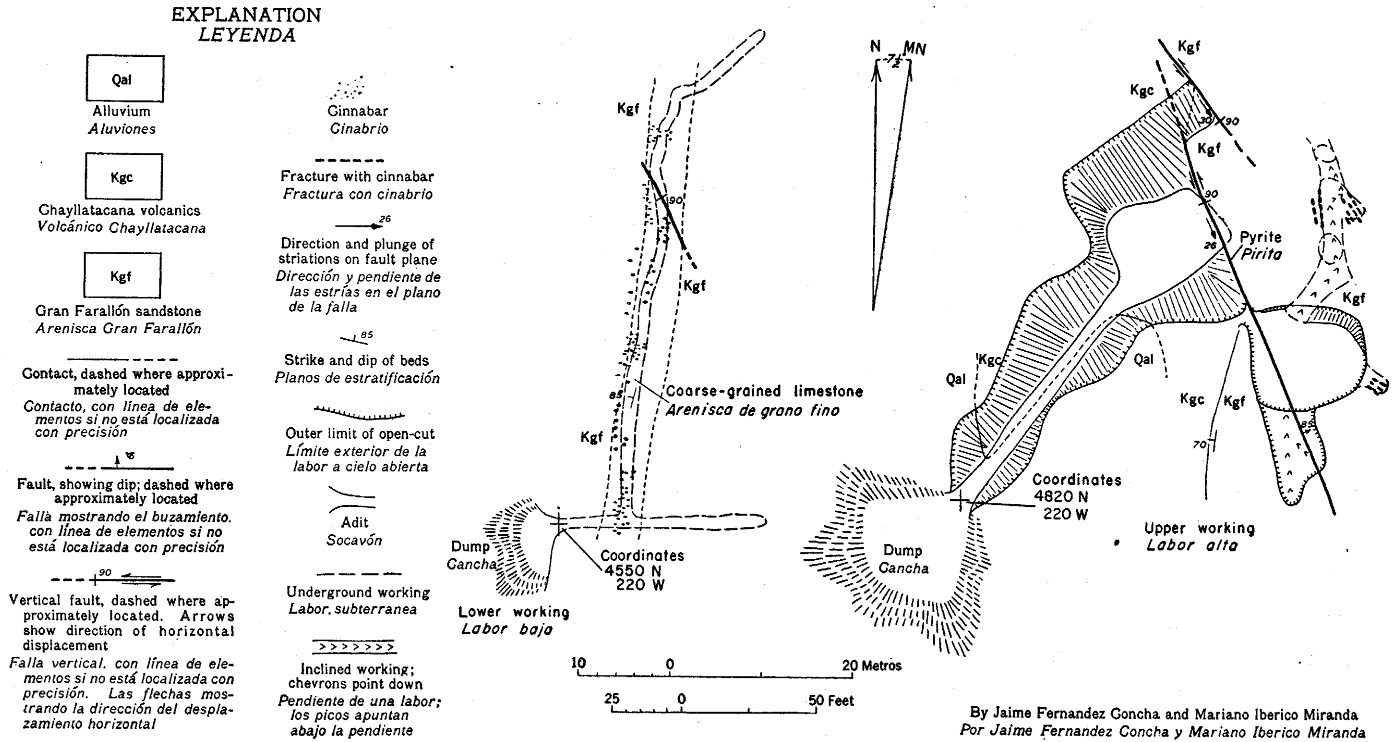


Figure 4.—Geologic map of the Tacna y Arica mines, Huancavelica quicksilver district, Peru.

TACNA Y ARICA MINES

The Tacna y Arica mines are north of the Río Hicho near the northern limit of the mapped area (pl. 1). They consist of two small workings about 300 meters (984 feet) apart. The southern and lower working is a short adit located near coordinates 4550 N. and 250 W. (p. 1). There was no activity at either of these workings in 1945.

The lower working is an adit (fig. 4) that was driven for 25 meters (82 feet) eastward into the face of an almost vertical cliff of Gran Farallón sandstone. Eight meters (26 feet) from the portal a drift was driven northward along a bed of coarse-grained sandstone that contains disseminated cinnabar. The drift follows this bed for 48 meters (157 feet); then it turns northeast to continue for about 10 meters (33 feet) and terminate in a face of barren, fine-grained sandstone. The best concentration of cinnabar is near a vertical fault that crosses the drift with a strike of N. 35° W.

As the distribution of the cinnabar is apparently related to both the coarse-textured sandstone and the fault, these features should be considered in any future exploration. A drift extended to the southeast along the fault might cross other sandstone beds that were favorable to mineralizing solutions.

The upper workings (fig. 4) consist of two open-cuts and a spiral incline, the lower part of which is flooded. One open-cut is in Gran Farallón sandstone, and the other is in the volcanic rocks of the Chayllatacana, which are separated from the sandstone in the northeast end of the cut by a vertical fault with a northwest trend.

The ore extracted from these open-cuts was apparently burned in hornos located at the burned-ore dumps that are about halfway between the upper and lower workings.

MINES AND PROSPECTS IN LIMESTONE

BOTIJA PUNCO MINE

The Botija Punco mine is named after the hill in which it is located. It is about 500 meters (1,640 feet) north of the Santa Bárbara mine and west of the Gran Farallón. Originally this mine was worked in conjunction with the Santa Bárbara mine, but in 1945 it was held under a separate denouncement. The Botija Punco mine has been worked up to recent years.

The Botija Punco mine consists of three parallel groups of open-cuts (pl. 3), from which descend inclined underground stopes. The open-cuts range from only a few meters to over 30 meters (98 feet) in depth.

At the base of the hill and about 85 meters (279 feet) below the top, an adit was driven eastward to explore the ground below the exploited ore bodies. This, the Chayllatacana adit (not to be confused with the adit of the same name at the Santa Bárbara mine), was accessible in 1945 for about 160 meters (525 feet) from its portal. The adit doubtless extends farther, but a cave at the 160-meter point prevented the measuring of the distance to its face. It is open under two groups of open-cuts, but the third, or eastern, group of open-cuts is above its caved part.

The workings of the Botija Punco mine are entirely in the Machay limestone, and the three groups of open-cuts are in marly parts of the limestone. In the vicinity of the mine the limestone strikes about N. 10° E. and has dips of 50° to 70° W. Besides the three marly horizons just mentioned there are several others, but these are much thinner and apparently were not mineralized. The limestone is crossed by numerous joints with an easterly trend and vertical or near-vertical dips. Although practically no cinnabar was seen in the mine workings, the ore appears to have been concentrated in the places where the joints were most closely spaced.

The limestone block in which the mine is located is bounded on the west by Chayllatacana volcanics in apparent conformable relations; on the south and east it is bounded by a reverse fault, which separates it from the Chayllatacana volcanics; and to the north the unity of the block is lost in an intrusion of rhyolite. Because of these relations the Botija Punco mine has a structural setting somewhat similar to that of the Santa Bárbara mine; that is, the block of Machay limestone terminates to the south in a "V" that is similar to the "V" termination of the Gran Farallón sandstone at the Santa Bárbara mine.

This southern termination of the limestone block may be more complicated than it seems on plate 1. South of the mine exposures are poor, and it is possible that the limestone may be broken by east- or northeast-trending faults similar to those a little farther south (pl. 1).

The three ore horizons can be conveniently described as mantas, although their steeply inclined attitude is contrary to the common usage of this term. Hereafter the ore horizons will be referred to as the eastern, middle, and western mantas.

The eastern manta, which has a stope width of 20 to 50 meters (66 to 164 feet), is the widest and contains the most extensive workings. The open-cuts in this manta extend over a surface distance of about 150 meters (492 feet). The middle manta is the longest, as well as the narrowest, of the three. It has been mined by unconnected workings over a surface distance of about 230 meters (755 feet). Its stope width ranges from 5 to 10 meters (16 to 33 feet). The western manta is about as long as the eastern manta but was less extensively mined. Its stope width ranges from 5 meters (16 feet) at its northern end to a maximum of about 20 meters (66 feet) near its southern end.

At its southern end it has a bulbous expansion that extends westward for 60 meters (197 feet) across the strike of the beds, but this expansion is mostly in nonmarly limestone and should not be considered as part of the manta proper. There is a similar enlargement at the southern end of the eastern manta. The eastern manta includes at least three closely spaced marly limestone horizons that are separated by nonmarly limestone. In places all of these marly layers were mineralized; in other places only one or two horizons were mineralized. At the south end of the manta all three were mineralized, as well as the intervening layers of nonmarly limestone, which was probably more highly fractured than at most other places.

The shape of the stopes that extend downward from all three mantas (pl. 3) illustrates the erratic distribution of the cinnabar. Within a distance of a few meters the stopes range in both width and height from 1 to 8 meters (3 to 26 feet) and are more or less sinuous as they extend downward. When one considers the primitive mining methods that were used in extracting the ore and the fact that very little cinnabar remains in the walls of the stopes, it seems reasonable to believe that the walls of the stopes essentially represent the limits of the mineralized rock and that the stopes represent the shapes of the ore shoots within the mantas.

The maximum depth of the mine workings was not determined. Winzes that were inaccessible to the writers extended downward to unknown depths from the stopes of all three mantas. Workings in the middle and western mantas did not, however, extend to the level of the Chayllatacana adit. Those of the eastern manta may have reached this level, but as the adit was caved at a place west of the point where the eastern manta would project, this could not be verified.

Mineralization did, however, extend as deep as the Chayllatacana adit, although perhaps not continuously from the surface. On this level the middle manta was stoped for a length of about 50 meters (164 feet) and for an average width of about 5 meters (16 feet). These stopes extended a few meters below this level and continued upward for an unmeasured distance. The western manta can be recognized on the Chayllatacana level, and a short drift to the north indicates that cinnabar was found here, but none was seen by the writers.

The Botija Punco mine was probably the second-largest producer of quicksilver in the Huancavelica district. It is not possible to give even an approximate figure for its total production, because during its productive years its output was included with that of the Santa Bârbara mine. A conservative guess is that its total production is not more than 5 percent of that of the Santa Bârbara mine.

921853—51——4

Although no ore was seen in the Botija Punco mine, the possibilities of this area are not exhausted. The ore controls are clean-cut; the ore occurred in the marly zones of the limestone in roughly tabular bodies in places where cross fractures had formed the more open structures. Ore shoots that were mined near the surface show that there was no horizontal continuity to the ore; instead, they indicate that the individual ore bodies were separated along the strike of the ore zone by barren rock. There is no reason to believe that a similar relation does not exist in a vertical direction, with undiscovered ore bodies lying below those that have been exploited. The apparently isolated ore body that was mined from the middle manta on the Chayllatacana level adds weight to this belief. With the possible exception of the eastern manta, the Chayllatacana level has been only superficially explored. Future exploration should begin on this level and could be done by drifting along the marly limestone of the mantas as far north as the surface workings extend and as far south as the fault that bounds the Machay limestone.

At the surface the fault that bounds the Machay limestone was not mineralized to any appreciable extent, but it may be on the Chayllatacana level. Fractured limestone along it should be a favorable host for ore. If this structure was not too open and the rising mineralizing solutions had access to it, it seems possible that the largest ore bodies in this area may have formed along it.

SAN ROQUE MINE

The San Roque mine is about 400 meters (1,312 feet) southwest of the Santa Bárbara mine (pl. 1). Although it was worked in conjunction with the Santa Bárbara mine, the workings of the two are not connected, nor is there any similarity between the geology of the two mines. There is, however, a similarity between the geology of the San Roque mine and that of the Pucacapa and Faltriquera mines, which are located nearby.

The San Roque mine, as well as the Pucacapa and Faltriquera, is in an upfaulted block of Machay limestone that is bounded by the limestone conglomerates of the Casapalca formation. Adjacent to this fault block of limestone the conglomerates of the Casapalca unconformably overlie the Machay limestone; the conglomerates and limestone have the same northwesterly strike, but the conglomerates have a steeper, southwesterly dip. The ore occurred in the same marly beds as in the Botija Punco mine, and possibly it is in the same stratigraphic horizon as the western manta of the Botija Punco. If so, there may be two other ore horizons below the one that has been exploited.

The mine workings consist of a large, shallow open-cut (only partly shown on pl. 4) and fairly extensive subsurface stoped ground. The open-cut represents in general an eastward extension of the stoped area. It is difficult to tell much about the form of the ore bodies, but in the western part of the mine, where the workings are under ground, the stoped ground in general is on one principal irregular, inclined plane that has an aggregate northwesterly strike and an average dip of 15° SW. The plan of the stopes (pl. 4) shows that the exploited ore was in two principal zones that trend almost at right angles to each other from the open-cut, at which they converge. The larger and more irregular stoped area in general trends N. 70° W. and the other S. 20° W. The shape of both stopes is very irregular, with many constrictions and enlargements, which range in width from less than 1 meter (3 feet) to over 20 meters (67 feet). A few secondary stopes projecting from the main stope are even more irregular in shape.

As the Machay limestone has a fairly uniform strike of N. 25° W. and a dip of about 30° SW., it is obvious that the stopes are only roughly concordant with the bedding planes of the limestone. In places the agreement is perfect, but in other places there is a marked discordance between the dip of the limestone and that of the stopes, which may be horizontal in contrast to the 30° dip of the limestone. This contrasts with the concordance between stope and bedding-plane attitudes in the Botija Punco mine and suggests that other structures exerted a controlling influence over the ore bodies. Low-angle shears similar to those in the Belén tunnel and Santa Bárbara stopes, although not observed, may be present; if so, they could account for the discordance.

Besides being much flatter, the ore bodies of the San Roque mine differed in shape from those of the Botija Punco. The latter had their longest dimension along the strike of the enclosing limestone, whereas those of the San Roque had their longest dimension down the dip.

The ore was probably similar to that of the Botija Punco mine, occurring as fillings of cinnabar along fractures. The fractures have an average trend of N. 75° E. and a vertical or near-vertical dip. Many of these fractures are in the walls of the stope, and there is a little cinnabar along some of them. The best concentration of cinnabar seen was at the south end of the stope that is cut by section line *D-D′* of plate 4.

Although there is little metalized rock in the San Roque mine that could be economically mined at the present time, it is possible that other ore horizons could be discovered underlying the exploited one and that the exploited ore body could be extended down its dip.

If, as suggested, the exploited ore horizon is the same as that of the western manta of the Botija Punco mine, there are beneath it at least two more zones of marly limestone that were structurally favorable for the deposition of cinnabar. If they are spaced at the same intervals as at the Botija Punco they would lie at depths of approximately 50 meters (164 feet) and 100 meters (328 feet) below the exploited ore body. According to this assumed correlation of ore horizons, the middle horizon should intersect the Casapalca formation at its unconformity with the Machay limestone in the vicinity of the two open-cuts in the Casapalca formation between the San Roque and the Santa Bárbara mines. In fact, the ore that was removed from these pits may have been the surface expression of mineralization in underlying limestone. The conglomerate at the southwest pit is at least 12 meters (39 feet) thick. The Machay limestone that borders the west edge of the depressed area of the Santa Bárbara mine (see pl. 1) is mineralized and has been mined to a slight extent. This may be the equivalent of the eastern manta of the Botija Punco. The mapping of more detailed stratigraphic units and structure in the vicinity of the Botija Punco, Santa Bárbara, and San Roque mines would probably determine the correlations between the marly-limestone horizons.

The possibility that the present mine workings do not reach the down-dip limit of the metalized rock seems valid to the writers. Some stopes have cinnabar in their lower faces. The deeper terminations of the workings are with only a few minor exceptions stope faces and not the faces of exploratory drifts and crosscuts. From the appearance of the mine, work terminated when constrictions in the ore bodies made it unprofitable to continue operations. Such must also have been the situation at various times in the past, if one is to judge from the shape of the ore body that has been mined.

FALTRIQUERA MINE

The Faltriquera mine is almost adjacent to the San Roque mine, lying only a few meters to the southwest. This mine, which was not mapped, is of moderate size but not as large as the San Roque. It is in the Machay limestone, and its ore body is probably in the same ore horizon as that of the San Roque.

PUCACAPA MINE

The Pucacapa mine is a little over 100 meters (328 feet) north of the principal open-cut of the San Roque mine. The workings are not extensive, and the ore occurs under geological conditions similar to those at the San Roque.

The mine consists of an open-cut, 30 meters (98 feet) by 20 meters (67 feet) in size, connected with an irregular winding stope that extends about 55 meters (180 feet) to the southwest and another parallel stope that is entered by an inclined adit, located a few meters north and uphill from the open-cut (pl. 5).

A normal fault that dips steeply to the southwest and trends northwest cuts diagonally across the open-cut, separating the conglomerates of the Casapalca formation from the Machay limestone to the northeast. The stoped ground is principally northeast of this fault in the limestone. The average strike of the limestone is similar to that of the San Roque mine, N. 25° W., but the dip is steeper and ranges from 50° to 60°. Apparently the ore occurred as cinnabar-filled fractures that crossed the bedding in a northeasterly direction.

MINAYA MINE

The Minaya mine is located about 300 meters (984 feet) south of the Santa Bárbara mine. It consists of a number of open-cuts, shallow trenches, and small inclined adits distributed over a horizontal distance of about 200 meters (656 feet) along the contact between the Machay limestone and intrusive dacite. The workings, which trend northeast, are all fairly shallow; apparently only a little ore was mined.

The limestone, which strikes N. 10° E. to N. 20° E. and dips steeply to the west, was the host rock for almost, if not all, the ore. Although no cinnabar was seen, it probably occurred along fractures. Although the ore apparently did not occur on the contact or in the dacite to any extent, the contact was probably the structure that controlled the distribution of the mineralized rock.

QUICHCAHUAYJO MINE

The Quichcahuayjo mine (Mina de la Quebrada de los Espinos) is at coordinates 2700 N. and 1300 E. (pl. 1) on the east slope of the ravine known as Quichcahuayjo, from which it takes its name. The mine consists of six small stoped areas, all trending east, that are distributed in a horizontal distance of 80 meters (262 feet) and through a vertical distance of 60 meters (196 feet). (See pl. 6.) The stopes are narrow and extremely irregular and range in length from 10 to 30 meters (33 to 98 feet).

The mine workings are on the west flank of an anticline of Pucara limestone. The limestone in general strikes north, and its dip ranges from 20° to 30° W. The stopes are located in zones of east-trending cross fractures that range in dip from vertical to 60° W. All the limestone in this area is similarly jointed, but it is only where the fractures are closely spaced that cinnabar was found. The cinnabar occurs as coatings and fillings in the fracture openings. The fractures are short and shallow and cannot be projected from one level to another. The thin shale partings that occur in the limestone probably acted as incompetent buffers that prevented the fracture cracks from developing across bedding planes.

The uppermost working is an open-cut 12 meters (39 feet) long, 9 meters (30 feet) wide, and 7 meters (23 feet) deep at its back, from which at least 700 tons of rock have been removed. It appears to have been crossed by numerous mineralizing fractures. This is by far the largest body of ore that was taken from the mine.

The lowermost stopes are accessible by means of a horizontal adit, which is so crooked that its 100-meter (328-foot) length is equivalent to a straight-line distance of 68 meters (223 feet).

MINES AND PROSPECTS IN IGNEOUS ROCKS

PROSPECTS NEAR COORDINATES 2000 S. AND 300 W.

The unnamed prospects located near coordinates 2000 S. and 300 W. (pl. 1) consist of several shallow trenches. The trenches were dug in a flow-banded rhyolite, and they follow closely spaced fractures trending N. 65° W. and N. 70° E. Although only a few traces of cinnabar can be seen on these fractures, they apparently controlled the mineralization. Besides the cinnabar there were minor amounts of realgar and galena and abundant iron sulfide. A little ore was burned from these workings, but not enough to justify calling them a mine.

PROSPECTS NEAR COORDINATES 2500 S. AND 200 E.

The unnamed prospects located near coordinates 2500 S. and 200 E. (pl. 1) consist of several shallow trenches (fig. 5). The trenches are distributed along three different groups of fractures in flow-banded basalt. The fractures strike approximately east and dip 50° to 60° S. The mineralized rock is similar to that at the prospects described in the preceding paragraph.

SANTA BARBARA III MINE

The Santa Bárbara III (Dewey) mine, located at the extreme south of the mapped area (pl. 1) near coordinates 3000 S. and 300 W., is the only mine in the Huancavelica district that was in production in 1945. This mine is located along a vertical fault that trends N. 40° W. and separates Machay limestone from rhyolite on the southwest. The brecciated rock along the fault has been mineralized with pyrite and cinnabar.

The ore body was exploited by an open-cut 40 meters (131 feet) long, 10 meters (33 feet) wide, and about 40 meters (131 feet) deep. The bottom of the cut is reached by a horizontal adit.

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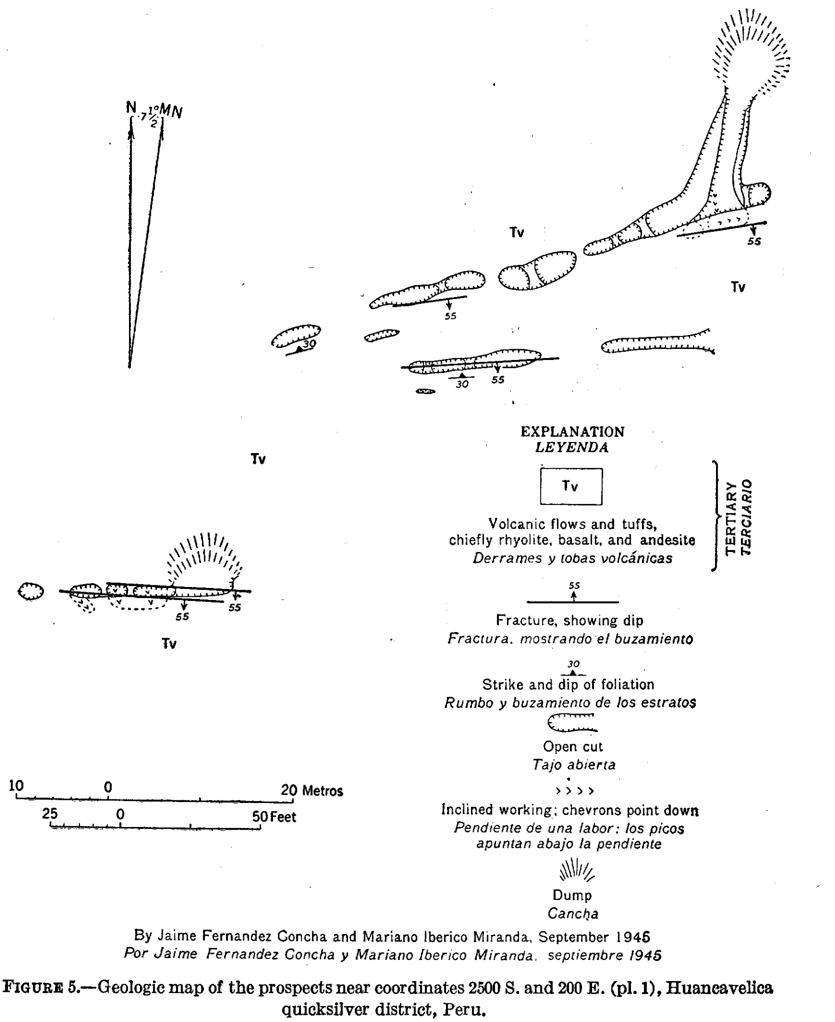
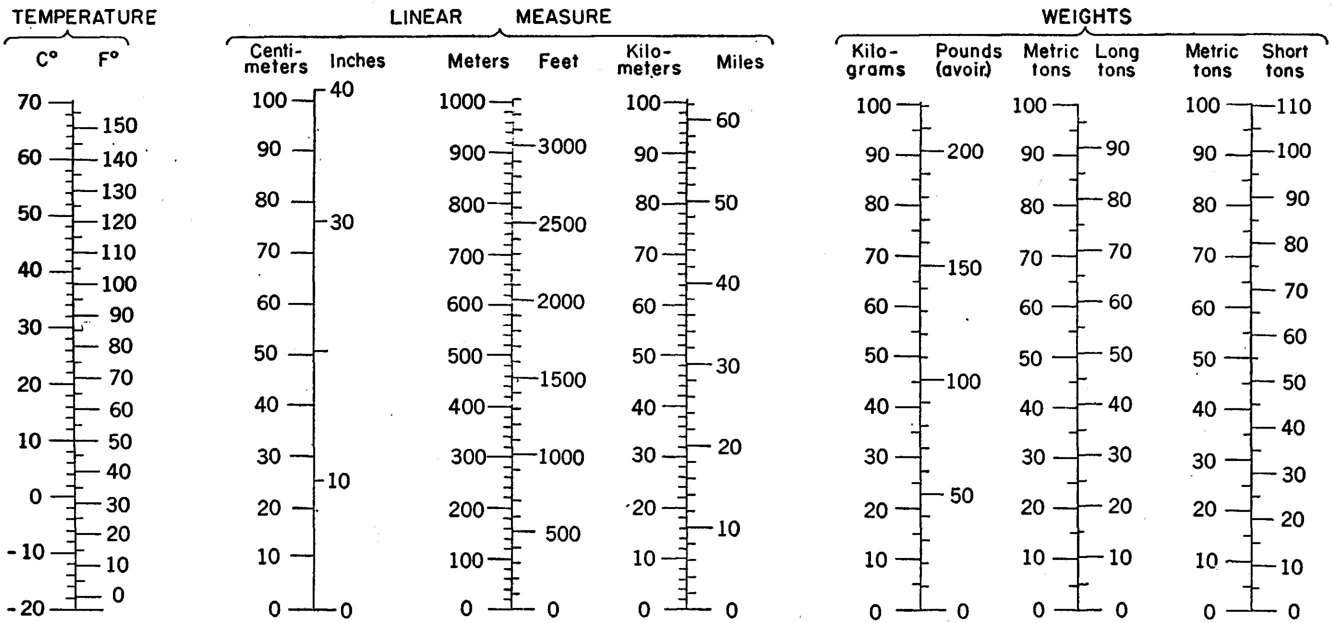


FIGURE 5.—Geologic map of the prospects near coordinates 2500 S. and 200 E. (pl. 1), Huancavelica quicksilver district, Peru.

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

INDEX