Lead-Zinc Deposits of Cordillera Blanca and Northern Cordillera Huayhuash, Peru

GEOLOGICAL SURVEY BULLETIN 1017

Prepared in cooperation with the Ministerio de Fomento, Instituto Geológico del Perú, under the auspices of the Interdepartmental Committee on Scientific and Cultural Cooperation with the American Republics Department of State

GEOLOGIC INVESTIGATIONS IN THE AMERICAN REPUBLICS

LEAD-ZINC DEPOSITS OF CORDILLERA BLANCA AND NORTHERN CORDILLERA HUAYHUASH, PERU

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ABSTRACT

Base metal deposits in the central and southern Cordillera Blanca and the northern Cordillera Huayhuash comprise 6 mineral districts, 5 in the Departamento de Ancash and 1 in the neighboring Departamento de Huánuco. Although many of the deposits were prospected and some mined on a small scale during the Spanish Colonial period, most activity has taken place in the last hundred years. Concentrates were produced in 1948 and 1949 at the rate of about 1,000 tons annually, and the rate of production during several previous years was evidently about the same. Silver-bearing galena concentrate is the chief product. Sphalerite either is not mined or is discarded because its value has been too low to cover costs of production and transportation.

The sedimentary rock units of the region are Jurassic(?) marine quartzites and phyllites, Lower Neocomian fluviatile and brackish-water sandstones, shales, and coals, Barremian marine and nonmarine limestones, marls, shales, and tuffs, and Middle Cretaceous marine limestones. During a period of orogeny beginning at the end of the Cretaceous the sedimentary sequence was compressed, commonly forming upright folds, but also some recumbent folds, many small bedding-plane faults, and some large reverse faults. At or near the end of deformation the sedimentary rocks were intruded by a batholith of granodiorite. The sedimentary rocks are slightly metamorphosed on a regional scale as a result of folding and locally are more highly metamorphosed in zones bordering igneous bodies. During subsequent uplift of the Andean block the sedimentary rocks were dislocated along normal faults and intruded by igneous stocks, dikes, and sills. Deposition of base metals is thought to have accompanied or immediately followed this stage of igneous activity.

The most common sulfide minerals in the deposits are galena, sphalerite, and pyrite; chalcopyrite, tetrahedrite-tennantite, arsenopyrite, and stibnite may also be present. Silver occurs in galena, in the copper sulfides, or as free sulfides. The sulfide minerals are oxidized to shallow depths, and the upper parts of many veins have been secondarily enriched in silver. Common non-metallic gangue minerals in most deposits are quartz and carbonates; fluorite and barite are found in some deposits, and silicate minerals are found in contact deposits in calcareous rocks. Most deposits are fissure filling veins along small fault or shear zones, but a number are replacements of wall rock along small faults, certain sedimentary beds, or contact zones. The fissure filling veins occur in any type of country rock, sedimentary, metasedimentary, or igneous. Most replacement deposits are in calcareous rocks, but a few are in other rock types. Min-

eralogy and textures of the deposits indicate that nearly all are within the range of mesothermal-epithermal origin.

Mineralized faults and shear zones are from several hundred meters to more than a kilometer long and have vertical extents of at most a few hundred meters; they are generally from 0.5 to 1 meter wide. Ore shoots containing argentiferous galena occupy only a fraction of such structures, have sporadic distribution, and in most deposits are small and lenticular, with galena ranging in tenor from 5 to 80 percent. Replacement deposits have a wide range in size and are characterized by a low tenor of galena.

At most mines ore is mined selectively, crushed, and concentrated by hand. For this reason fissure-filling veins containing ore shoots with high tenor of galena are preferred by miners. Small concentrators in the Quebrada Honda-Vesuvio and the Pachapaqui districts treat ore from only a few deposits. The size of ore bodies in most deposits precludes larger scale mining or mechanizations of operations, and it is concluded that only minor expansion of production is possible under existing conditions.

The greatest deterrent to increased production is the high cost of transportation of concentrates by pack animals to roadheads. It is recommended that access roads be constructed to, or at least part way to, four of the mineral districts. With reduced transportation costs, miners could extract lower grade ore. Construction of small mills in other districts would also permit mining of lower grade ore.

Replacement deposits of lead-zinc sulfides in the Pacllón-Llamac and Pachapaqui districts and copper sulfides in the Antamina-Contonga district contain large reserves of possibly minable material. However, development of these deposits would require large investments in roads, concentrating plants, and mining machinery.

INTRODUCTION

GENERAL STATEMENT

The Andean mineral province, a major metallogenic area of the world, comprising thousands of ore deposits, covers an area including Peru, Bolivia, and northern Chile and Argentina. Metals present in quantity are copper, lead, zinc, silver, tin, and iron; those present in smaller but appreciable amounts include vanadium, tungsten, gold, antimony, arsenic, bismuth, and cadmium. In addition, a few deposits yield small amounts of manganese, cobalt, molybdenum, and mercury.

In Peru zinc, lead, copper, and silver are the principal metals extracted from many base metal sulfide deposits. Nearly all such deposits contain lead and zinc. Copper is not so widespread but provides the bulk of ore minerals in major deposits such as Toquepala and Quellaveco in southern Peru. Silver occurs in primary sulfide deposits associated with lead or copper minerals or in oxidized zones where primary sulfides of lead and copper have been leached. The deposits of the Departamento de Ancash are similar to many elsewhere in Peru, and although the emphasis in this report is on lead and zinc resources, silver occurs with lead in all deposits, and copper minerals are present in most.

Inasmuch as a great number of deposits throughout the Andean Cordillera in Peru consist mainly of lead and zinc ores, the government of that country suggested that such occurrences be studied systematically and sought assistance from the United States government in planning and executing this nationwide appraisal. A cooperative program was developed in 1946 between the Instituto Geológico del Perú, Ministerio de Fomento y Obras Públicas, and the Geological Survey, United States Department of the Interior. The contribution of the United States was sponsored by the Interdepartmental Committee on Scientific and Cultural Cooperation with the American Republics, United States Department of State.

The first area selected for comprehensive investigation was the Departamento de Ancash, the State north of the Departamento de Lima and west of the Departamento de Huánuco. In 1947 the deposits in the Cordillera Negra, the westernmost range in Ancash, were studied, and in 1948 and 1949 the work was extended to the central and southern Cordillera Blanca and northern Cordillera Huayhuash. This report summarizes information obtained from the 1948–49 investigations.

Mineral production from the Cordillera Blanca and northern Cordillera Huayhuash never has been large, and we conclude from our studies that only minor expansion is possible under existing conditions. Modest increases will be possible in several districts if access roads are built either partway to or directly to these mineralized areas. Construction of small mills or improvement of existing mill facilities also would stimulate production.

GEOGRAPHY OF THE REGION AND LOCATION OF DEPOSITS

GEOGRAPHY

The Departamento de Ancash extends from the Pacific Ocean eastward to its boundary with the Departamento de Huánuco; the boundary between these States follows the Cordillera Huayhuash in the south and the Río Marañon in the north. Huánuco in turn extends eastward to the Amazon Basin. All but one of the mineral districts described in this report are in the southeastern part of Ancash (fig. 1). One district in Huánuco lies along the southeast border of Ancash.

Most of Ancash and western Huánuco are in the Andean Cordillera, and are characterized by very rugged terrain. The only comparatively level areas are in the coastal regions, at a few places along the crest of the Cordillera Negra, and in narrow valley floors. Elsewhere slopes are steep and highly dissected and provide some of the most spectacular scenery in Peru. Peaks reach altitudes from 4,500 to 6,700 meters [1]

[1] All measurements in this report are expressed in the metric system. A table of conversion factors between the English and metric systems is appended (p. 162).

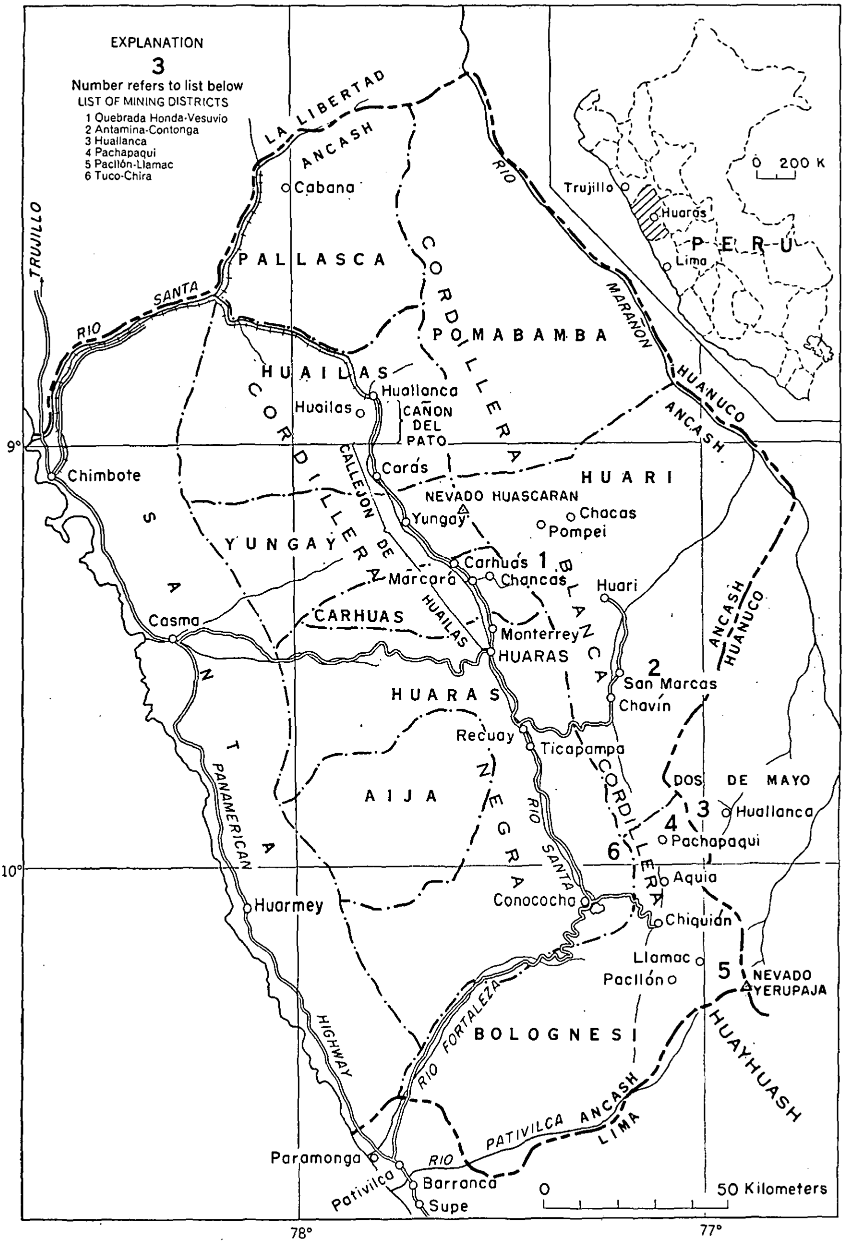


FIGURE 1.—Index map of the Departamento de Ancash, showing location of mining districts.

and include some of the highest in South America. Those in the Cordillera Blanca and Cordillera Huayhuash extending above 5,000 meters are covered with active mountain glaciers.

The three major mountain ranges of Ancash are the Cordillera Negra, which borders the Pacific Ocean, the Cordillera Blanca, which follows the medial part of the Departamento, and the Cordillera Huayhuash, which marks the southeastern border of the Departamento and extends southward along the boundary between the Departamentos de Lima and Pasco. The south end of the Cordillera Blanca and the north end of the Cordillera Huayhuash overlap by about 35 kilometers; the southern part of the Cordillera Blanca lies about 20 kilometers west of the Cordillera Huayhuash. Except for the offset and overlap the two ranges form a continuous mountain chain more than 300 kilometers long. The crest of the chain is 100 to 125 kilometers distant from the coast and is the continental divide in this part of Peru. The three ranges all trend about N. 30° W., more or less parallel to the coast.

All streams east of the continental divide in Ancash flow eastward into the Río Marañon, a major tributary of the Amazon River. West of the continental divide streams are comparatively short and flow directly into the Pacific Ocean. The more important of the westward-draining rivers are the Ríos Pativilca, Fortaleza, and Santa. The streams within the offset region between the Cordilleras Blanca and Huayhuash flow southward and form the Río Pativilca, or as it is known locally in its upper reaches, the Río Chiquián; this drainage system empties into the Pacific near the town of Pativilca. The Río Fortaleza heads in the southern part of the Cordillera Negra and flows southwest, reaching the Pacific just north of the mouth of the Río Pativilca.

The headwaters of the Río Santa are in the southern end of the Cordillera Blanca, between the watersheds of the Río Pativilca and the Río Fortaleza. The Río Santa flows northwest more than 150 kilometers, parallel to the coast and between the Cordilleras Blanca and Negra, then cuts westward through the Cordillera Negra and reaches the Pacific just north of Chimbote. Of the westward-flowing streams only the Río Santa carries appreciable amounts of water to the ocean.

Most population centers in Ancash are in the agricultural areas which follow the major river systems and lie at altitudes ranging from about 2,000 to 3,500 meters. A number of towns are on alluvial fans of rivers along the Pacific coast. In the mountains the largest agricultural area is along the middle reaches of the Río Santa and is known as the Callejón de Huaylas (Huaylas Corridor). Huarás, the capital of Ancash, is near the upper end of the Callejón de Huaylas at an altitude of about 3,000 meters; its population is about 20,000. Other principal towns of the Callejón de Huaylas, having populations of from 1,000 to 5,000, are Marcará, Carhuás, Yungay, Carás, and Huaylas north of Huarás, and Recuay and Ticapampa south of Huarás. At the upper end of the Santa Valley, just east of a pass in the Cordillera Negra, is the village of Conococha, a way-stop on the main highway. Below the agricultural belt and at the mouth of the

Cañón del Pato, where the Río Santa turns west towards the Pacific, are the towns of Huallanca and Hidroelectra. Huallanca is at the junction of the railroad from Chimbote and the road leading up the Santa Valley, and Hidroelectra, a comparatively new town about 2 kilometers to the south, is headquarters for the large hydroelectric development of the Corporación Peruana del Santa.

East of the Cordillera Blanca all towns and villages are small. The more important are Chiquián and Aquia in southeastern Ancash and Chavín, San Marcos, Huari, and Chacas in central Ancash. On the east slope of the Cordillera Huayhuash, in the Departamento de Huánuco, the only town of any size is Huallanca. Except for a few small towns on the west slope of the Cordillera Negra, the only concentrations of population in the coastal part of Ancash are at Chimbote, Casma, and Huarmey.

LOCATION AND ACCESSIBILITY OF MINING DISTRICTS

The six mining districts described in this report are in the higher parts of the Cordilleras Blanca and Huayhuash on both sides of the continental divide. They lie in an area about 60 kilometers wide and about 125 kilometers long, between latitudes 9°10′ S. and 10°20′ S. and longitudes 76°55′ W. and 77°25′ W. From north to south the districts are:

District	*Departamento*	*Province*
1. Quebrada Honda-Vesuvio	Ancash	Huari
2. Antamina-Contonga	Ancash	Huari
3. Huallanca	Huánuco	Dos de Mayo
4. Pachapaqui	Ancash	Bolognesi
5. Tuco-Chira	Ancash	Bolognesi
6. Pacllon-Llamac	Ancash	Bolognesi

The mines and prospects of the Quebrada Honda-Vesuvio district are in the central Cordillera Blanca, from 16 to 25 kilometers airline distance east and northeast of Chancos (fig. 2). Deposits in the Quebrada [2] Honda are west of the continental divide, and those in valleys to the north are east of the continental divide. The mines extend over a belt trending west of north for about 25 kilometers and range in altitude from 4,100 to 4,800 meters. From the roadhead above Chancos a trail leads up the Quebrada Honda to the deposits in the upper part of the valley, and a branch crossing the north wall of the valley leads via circuitous routes to mines and prospects east of the continental divide. Trail distances from Chancos are from more than 20 to nearly 50 kilometers.

The Antamina-Contonga district is in a northern ramification of the Cordillera Huayhuash about 10 kilometers east of San Marcos. The district has two centers of mineralization, the larger in the upper

[2] Quebrada, defined by the dictionary as a ravine or gorge, is applied in Peru to all but the very largest valleys.

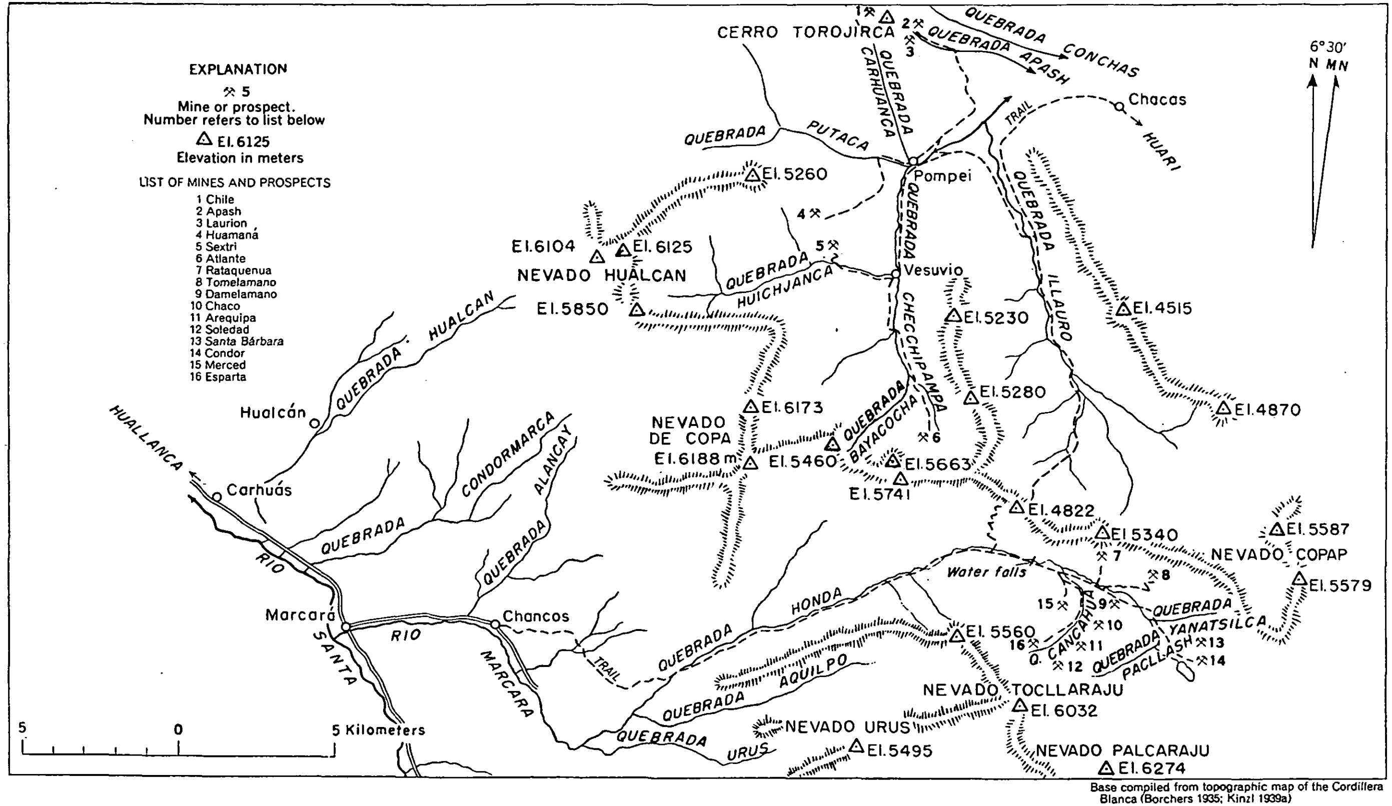


FIGURE 2.—Index map of the Quebrada Honda-Vesuvio mining district, showing location of mines and prospects.

part of the Quebrada Antamina and the smaller, about 5 kilometers to the north, at the head of Quebrada Pajush. Deposits range from about 4,200 to 4,700 meters in altitude. One branch of the trail from San Marcos goes directly up the Quebrada Pajush to Contonga, and the other goes southeast before ascending the Quebrada Antamina. Both areas are about 15 kilometers by trail from San Marcos (fig. 3).

Four districts form a group in southeastern Ancash and Huánuco. The Huallanca district is near the north end of the Cordillera Huayhuash and on its eastern slope. Most deposits occur in an area 12

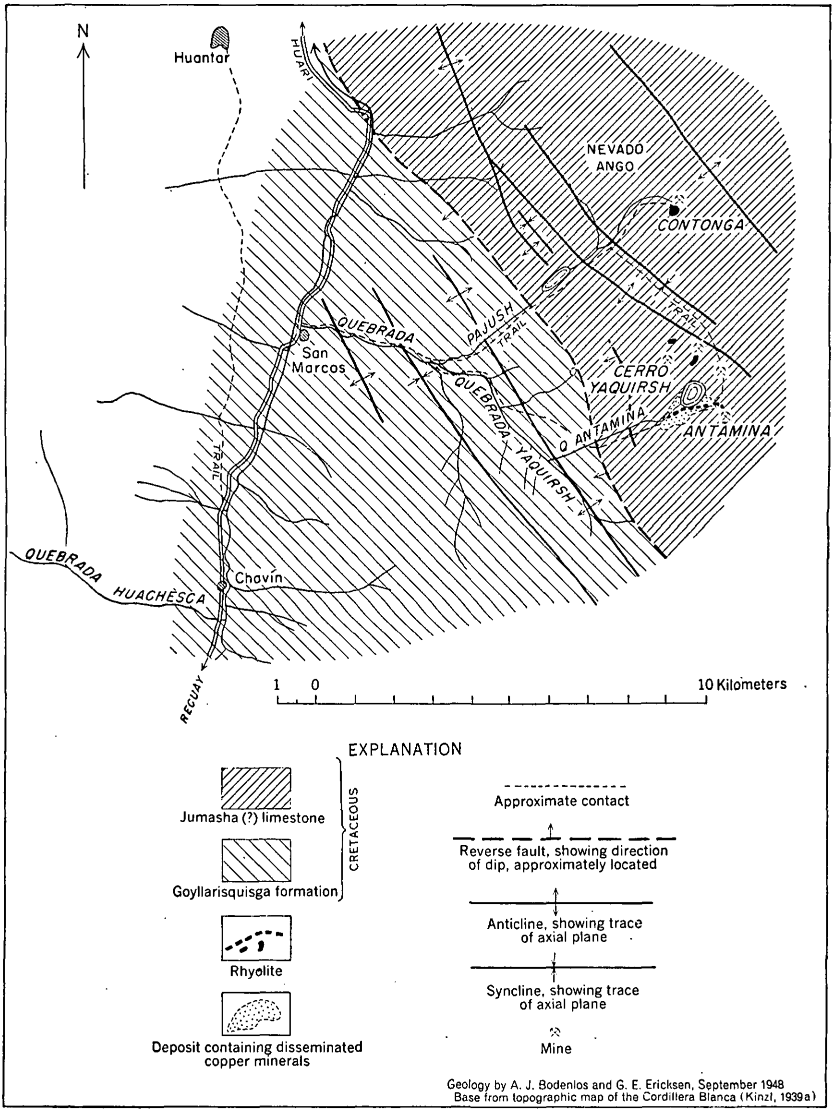


FIGURE 3.—Geologic sketch map of the San Marcos area.

kilometers east-west by 11 kilometers north-south to the west of Huallanca (fig. 4). Mines of the Pachapaqui district are west of the continental divide east and north of Pachapaqui, a small town about 20 kilometers southwest of Huallanca. The main group of deposits is from 4 to 7 kilometers east of the town and extends along the slope of the Cordillera for about 6 kilometers. A smaller group of deposits is found 6 to 9 kilometers north of the town (fig. 5).

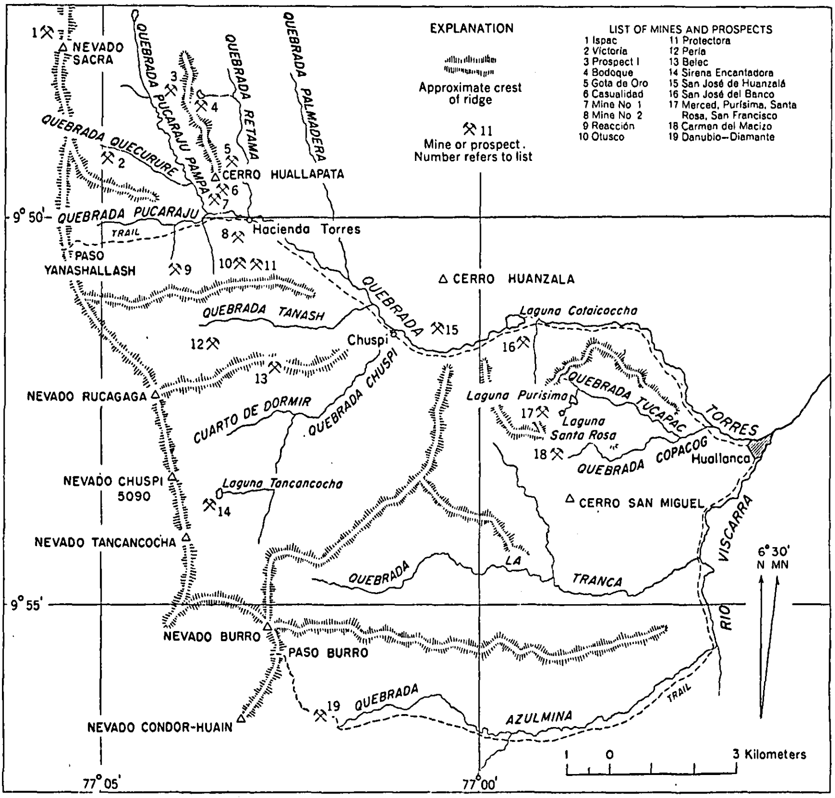
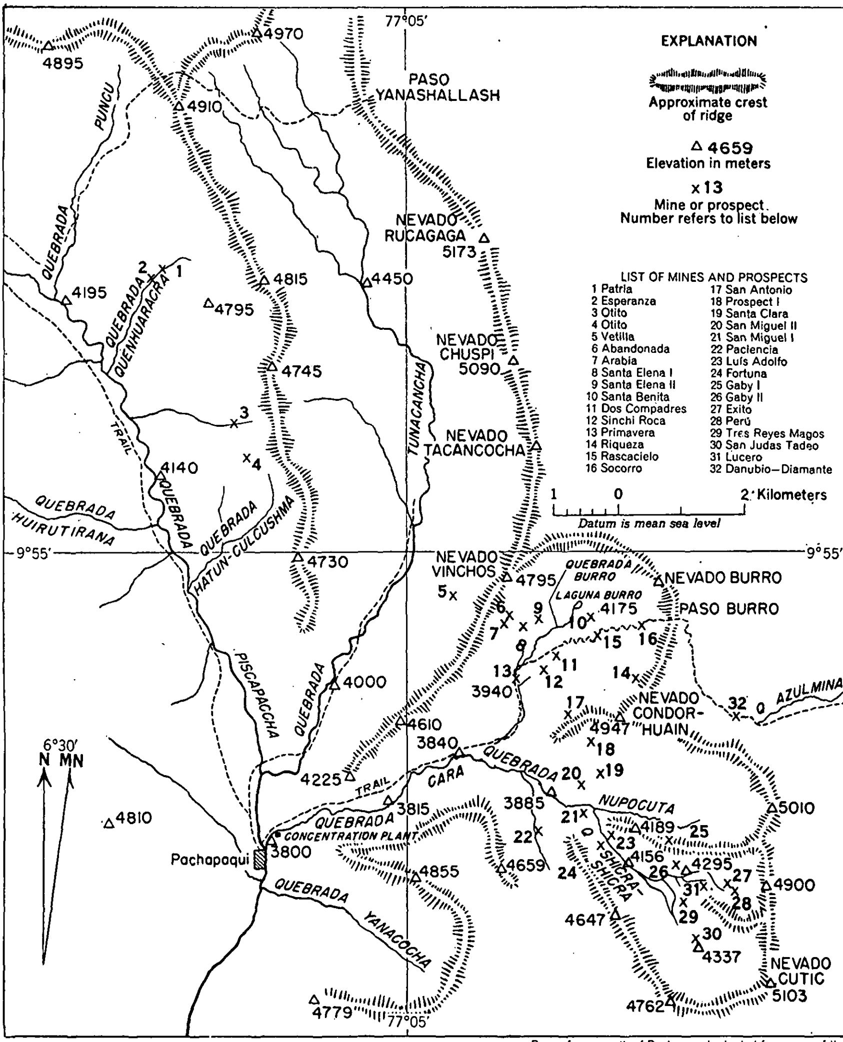


FIGURE 4.—Index map of the Huallanca mining district, showing location of mines and prospects.

The Pacllón-Llamac district, also west of the crest of the Cordillera Huayhuash, is about 35 kilometers south of Pachapaqui. The deposits are in an area about 2 by 3 kilometers and lie from 8 to 10 kilometers east of the village of Llamac (fig. 6).

The Tuco-Chira district is at the southern end of the Cordillera Blanca about 12 kilometers west of Pachapaqui. All deposits but one are on the west slope of the Cordillera. The deposits are in an area about 5 by 6 kilometers, and the southernmost is 14 kilometers northeast of the village of Conococha and 16 kilometers northwest of the town of Chiquián (fig. 7). Most of the deposits in these southern districts are between the altitudes of 4,000 and 5,000 meters.



Base of area north of Pachapaqui adapted from map of the Cordillera Blanca (Kinzl, 1939a). Area east of Pachapaqui (Quebrada Cara and tributary valleys) mapped by plane table triangulation by G. E. Erickson and A. J. Indacochea, July 1940

FIGURE 5.—Index map of the Pachapaqui mining district, showing location of mines and prospects.

The trail from the roadhead at Chiquián to Pachapaqui extends northward along the Río Pativilca, a trail distance of about 35 kilometers. Two other trails continue northeastward through Paso Burro (Burro Pass) and Paso Yanashallash across the Cordillera Huayhuash to Huallanca, an additional distance of about 30 kilometers. The Pacllón-Llamac district is accessible from Chiquián by a 30 to 35 kilometer trail extending southeastward along the Río Pativilca and then eastward in Quebrada Llamac to Hacienda Palca near the north side of the district. A narrow mountain road about 18 kilometers long

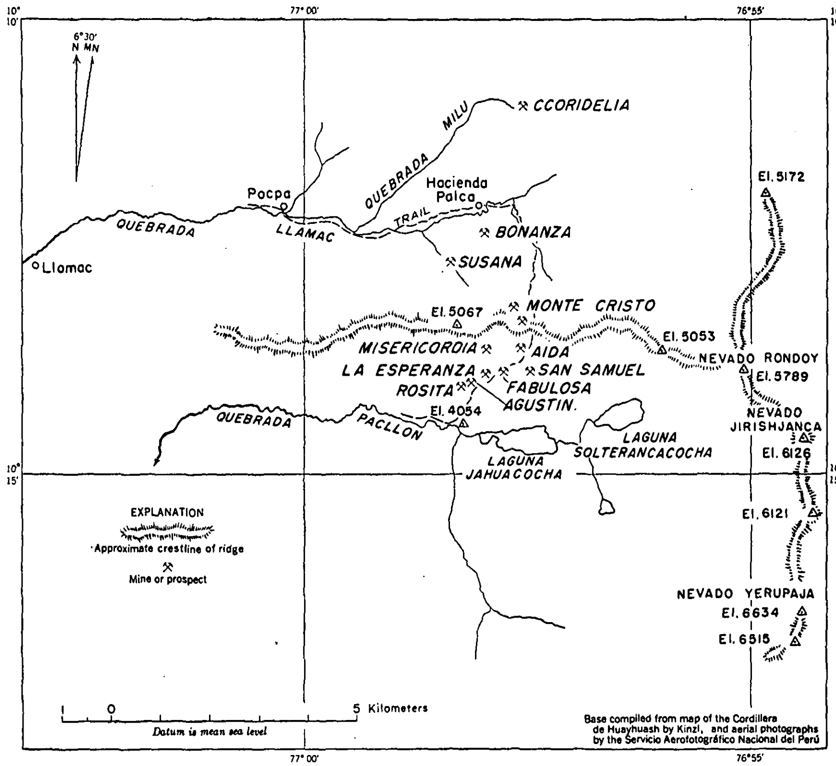


FIGURE 6.—Index map of the Pacllón-Llamac mining district, showing location of mines and prospects.

connects the Tuco-Chira district to the Conococha-Chiquián road at Hacienda Mojón, about 12 kilometers by road east of Conococha.

CLIMATE AND VEGETATION

Although the entire region lies within 10° 20′ of the Equator, the high altitudes influence the climate to such an extent that in many respects it is more typical of a cold temperate zone than of the tropics. During the winter months of June to October there is very little precipitation; the days are warm, but the temperatures at night drop to near freezing or a few degrees below freezing. The summer months of December to April are characterized by a tropical type of rainy season with rainstorms in afternoon and evening at the lower altitudes and snowstorms at altitudes above 4,000 meters. Night time temperatures during the rainy season are generally higher than during the dry season.

Above 4,000 meters the temperature drops to the freezing point or below at night, and only the hardiest of grasses, shrubs, and trees can survive. In such areas a coarse pampa grass thrives in marshy land on hillslopes and in valleys, and a type of bunch grass called by the

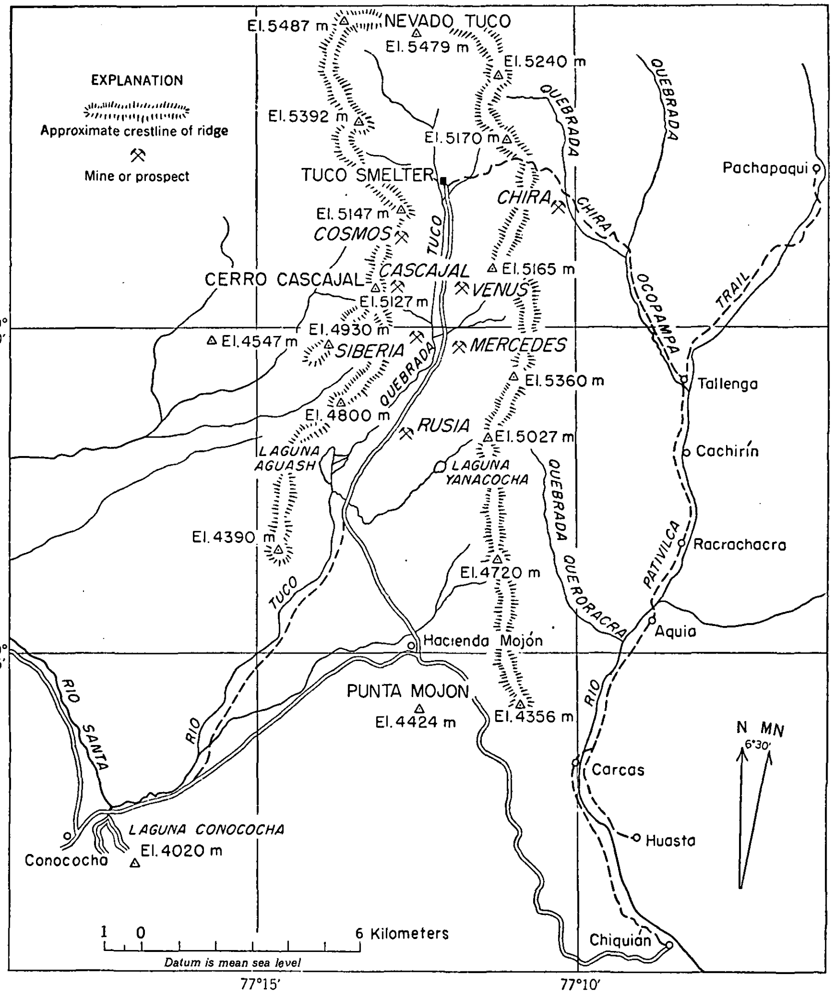


FIGURE 7.—Index map of the Tuco-Chira mining district, showing location of mines and prospects.

Quechua name ichu grows on drier ground. Protected hillslopes along narrow valleys commonly support growths of crooked broadleaf evergreen trees (quinual), which grow to a maximum height of about 5 meters. In nonglacial areas above 5,000 meters vegetation consists largely of sparse growths of mosses and scattered bunches of ichu.

Areas between altitudes of 4,000 and 5,000 meters are sparsely settled by Indians whose main source of livelihood is the raising of sheep and cattle or small-scale mining. The main agricultural products exported are wool, hides, cheese, and meat. The Indian women are adept at spinning raw wool into yarn and weaving cloth for their families' clothing. Indian huts are constructed of adobe bricks, chunks of sod, or large rocks haphazardly chinked with mud, and have thatched roofs of bunch grass.

Indians living in areas below 4,000 meters are generally more prosperous because here land can be cultivated and crops of grain, corn, potatoes, and alfalfa can be grown during the rainy season. In some localities fields are irrigated, and certain crops can be grown all year. From 2,500 to 4,000 meters eucalyptus is planted to supply timber for construction and fuel. In addition, the areas of lower altitudes support a wide variety of natural shrubs, grasses, cacti, and trees, which become progressively more tropical toward sea level.

WATER SUPPLY AND TIMBER

Most ores are mined and sorted by hand, and therefore not much water is needed other than for camp use and for hand jigs. An adequate supply of water is available near most mines should mechanization be considered. The major streams in all the districts have moderately large volumes of water the year around, and, in addition, the many lakes form catchment and storage basins. Water for beneficiation plants is insufficient at a number of mines, especially at those near ridge crests and on higher peaks. Even in such areas, streams or lakes are within a few kilometers of the deposits. In the Vesuvio area, for example, a 2-kilometer aerial tram was built from one mine to a mill in the valley below.

A minimum of timbering is required in underground workings because most deposits are either veins or replacements following narrow and comparatively steep zones and because wall rock alteration is either limited or not intense. Stulls are used here and there in open stopes, short stretches of drift may be timbered and lagged, and some man-ways and ore chutes are cribbed. Local quinual trees generally furnish adequate mine timber, but at times eucalyptus is hauled in from the nearest agricultural area for permanent timber installations.

TRANSPORTATION ROUTES

Central Ancash may be reached over two roads and a railroad, all of which branch from the Pan-American Highway, the major coastal road of Peru. The more important of the two roads branches at Paramonga, just north of Pativilca, 190 kilometers from Lima. It follows the valley of the Río Fortaleza, crosses the Cordillera Negra 126 kilometers from Pativilca, and then continues 184 kilometers along the valley of the Río Santa to Huallanca. The second road leaves the coastal highway at Casma, a small town 150 kilometers north of Pativilca, crosses the Cordillera Negra, and joins the Santa Valley road at Huarás. This road, 135 kilometers long, is in poor condition and follows an extremely tortuous route.

From the port of Chimbote, 420 kilometers north of Lima, the railroad extends up the lower part of the valley of the Río Santa to Huallanca, a distance of 133 kilometers. At Huallanca the railhead meets the northern termination of the Santa Valley road.

Roads branching eastward from the Santa Valley road lead to towns or inns whence trails continue to the various mining districts. The southernmost extends from Conococha to Chiquián, a distance of 31 kilometers; from Chiquián trails lead to 3 and a road to 1 of the 4 southern districts. From Recuay a road leads 126 kilometers northeast to Huari. At San Marcos, 87 kilometers northeast of Recuay, trails branch eastward to the Antamina-Contonga district. A 5-kilometer branch road extends between Marcará and Chancos; trails continue beyond the roadhead just above Chancos to the Quebrada Honda-Vesuvio district as well as to the towns of Chacas and Huari. The accompanying table lists road and railroad distances from shipping points to the towns and ports along the coast. Distances to Huarás are included, as some ore is sent to dealers there before being shipped to the coast.

Distances, in kilometers, from shipping points in Departamento de Ancash to junctions and ports

Town	Route						
	Río Santa—Río Fortaleza road				Río Santa road—railroad		
	Pativilca	Supe	Lima	Chimbote	Huarás	Huallanca	Chimbote
Chiquián	158	174	347	390	114	224	357
Conococha	127	143	316	359	83	193	326
San Marcos	271	288	460	503	111	221	354
Recuay	184	201	374	416	24	134	267
Marcará	235	251	425	467	25	85	218
Huarás	210	226	400	442		110	243

Because of the long truck haul along the coast, little ore is sent to Lima for export from the port of Callao, although modern facilities there permit dockside loading. Most ore shipped to the south is sent to the shallow-water port of Supe, 16 kilometers south of the Pativilca turnoff, where it is transferred to lighters for loading. Ore sent to Chimbote is trucked out either via Pativilca and then north along the coast, or north along the Santa Valley road to Huallanca, where it is transferred to the railroad. Chimbote, one of the best ports in Peru, has a moderately well protected harbor and new dockside loading facilities.

PREVIOUS GEOLOGIC WORK

Previous geologic reports present only reconnaissance studies of the regional geology, mineral deposits, physiography, and glaciology. No reports cover completely any of the mining districts herein described, although a large number of deposits are mentioned in comparatively old papers. Recent but unpublished descriptions of many mines and prospects are in mining company files.

One of the earliest reports, by Raimondi (1873), describes the general geology, mineralogy, and mining activity of several areas in the Cordillera Blanca. A comprehensive report by Steinmann (1930) on the geology of Peru includes discussions of the structural geology, stratigraphy, and mineral deposits of several regions in southern Ancash.[3] Velarde (1908) and Miller and Singewald (1919) briefly described mines and mineral production in the Vesuvio and Antamina areas and in the Huallanca district. The only detailed mine report is that of Dueñas (1904) which covers the deposits of the Vesuvio area. A few short papers deal with minerals and mines in southeastern Ancash and southwestern Huánuco: Comstock (1879) reported on tetrahedrite from Huallanca; Dunstan (1909) briefly summarized the mining industry in the province of Bolognesi; and Garbin (1904) gave descriptions of some minerals of the Huallanca district.

Among papers discussing the glaciology of the area are those of Borchers (1935), Kinzl (1942), Heim (1947), and Szepessy Schaurek (1949). Topographic and glaciologic maps of the Cordillera Blanca and northern Cordillera Huayhuash (scale 1: 100,000) were published by Borchers (1935a, 1935b) and by Kinzl (1939a, 1939b). A mudflow at Chavín was described by Indacochea and Iberico (1947), and its origin was discussed by Spann (1947).

FIELD WORK AND ACKNOWLEDGMENTS

This report is based on the reconnaissance examination of more than 100 lead, zinc, silver, copper, and antimony mines and prospects in central and southern Ancash and in southwestern Huánuco. The districts in the central Cordillera Blanca were studied by Bodenlos and Ericksen in August and September 1948, and those in the southern Cordillera Blanca and Cordillera Huayhuash by Ericksen from July to October 1949. Brief descriptions of several deposits in the Huallanca district, examined by F. S. Simons in 1952, are also included. Dr. Angel Indacochea and Sr. Ulrich Petersen, geologists of the Instituto Geológico del Perú, ably assisted the Geological Survey personnel during both 1948 and 1949.

Most of the deposits are one to two days journey by trail from the nearest roadhead, so that it was necessary to transport men and equipment by pack mules and saddle horses. In those districts having a large number of deposits the parties worked from centrally located base camps.

In the central Cordillera Blanca, regional geology was mapped on air photos and on the base maps of Borchers (1935a) and Kinzl (1939a). District geology in various areas was mapped with plane table and telescopic alidade on scales ranging from 1: 10,000 to

[3] Steinmann's book on the geology of Peru originally was written in German and published in 1929. The Spanish translation was published in the following year; all page references in this paper are to the Spanish edition.

1:25,000. Deposits were mapped with plane table or compass and tape on scales 1:1,000, 1:2,000, or 1:5,000 and underground workings with compass and tape on scale 1:500 or 1:1,000. The underground maps included in this report show geology as mapped or projected to floor level. Only principal workings are shown; stopes are omitted. Bases for the underground maps of several mines were graciously furnished by mining companies as follows: the Atlante mine, Empresa Minera Vesuvio; the Huamaná mine, Empresa Minera Pompei; and the Huanzalá mine, Compañía Minera Santa Bárbara. The Compañía Minera Santa Bárbara also furnished a topographic map of part of the Huallanca district, and the Northern Perú Mining and Smelting Company gave general information about the Pacllón-Llamac district. Officials of Mauricio Hochschild y Cia. permitted study of company reports on the central Cordillera Blanca region and the Pachapaqui and Tuco-Chira districts.

All bearings are given relative to true north, using an assumed magnetic declination of 6° 30′ east of north. Altitudes of most mines were established by airplane-type altimeters and generally can be considered correct only to the nearest 150 meters; these altitude measurements have been rounded to the nearest 10 meters. Altitude measurements to the nearest meter were taken from published maps or from company surveys or were established by mapping in relation to a single aneroid station. The relative reliability of altitude measurements in given areas is indicated in district descriptions.

The field investigations were made possible only through the assistance and cooperation of many governmental and mining company officials and technologists as well as private mine owners, local miners, ranchers, merchants, camp hands, and guides. Grateful acknowledgment is made to all those listed below as well as to those whose names are not included. Their information and suggestions were invaluable and permitted acquisition of maximum data in the shortest possible time. We also wish to express our gratitude for the courteous hospitality tendered us by many residents of the region.

The foremost among those to whom heartfelt thanks are given is Ing. Jorge A. Broggi, Director of the Instituto Nacional de Investigación y Fomento Mineros and of the Instituto Geológico del Perú. Not only was the cooperative work between the Instituto Geológico del Perú and the Geological Survey first suggested by him, but he also worked tirelessly to assure the success of the cooperative program. From the smallest detail to major planning Ing. Broggi's energy and wisdom were indispensable to us, and through him all facilities of the Instituto Geológico were put at our disposal.

In addition to the field assistance of Dr. Indacochea and Sr. Petersen, special credit is given to the following members of the Instituto Geológico del Perú: Sr. Petersen for assistance in compiling the bibliography and in mineralogic studies, Srta. Rosalvina Rivera for paleontologic compilations, and Sr. Dante Brambilla for assistance in compilation of index maps.

In Lima all officials of the Dirección de Minas and the Ministerio de Fomento y Obras Públicas were most cooperative, as were the Prefects and Sub Prefects in the Departamento de Ancash. In Huarás the Secretary to the Prefect, Sr. Eudoro Holguín, capably handled our official transactions.

Also of inestimable help to us was Mr. Carrel B. Larson, Minerals Attaché of the United States Embassy in Lima. In addition to expediting our official business, Mr. Larson provided us with abundant background data on Andean mineralization and mining, gleaned from his extensive travels and research in Peru.

In addition to acknowledgments to mining companies for technical information as listed above, thanks are given to Mauricio Hochschild y Cia. for the use as field headquarters of the staff house at their hydroelectric plant near Huarás. Sr. Alberto López, manager of the Hochschild ore buying depot at Huarás, Sr. William Brameld, manager of the Empresa Minera Pompei, Ing. Francisco Gadivia and Ing. Giovanni Rossón, managers of the Empresa Minera Vesuvio, and Ing. Eugenio DeRoet, manager of the Compañía Minera Santa Bárbara, all extended every courtesy to us.

The stratigraphy in this paper has been revised according to more recent work by V. E. Benavides, who in 1951 and 1952 studied the Cretaceous rocks of central and northern Peru. Mr. Benavides has most graciously permitted our use of his revision in age and correlation of stratigraphic units in Ancash, prior to publication of his results (Ph. D. thesis, manuscript in preparation, Columbia University, New York).

Our camp staff in both years, Srs. Policarpo Caballero, Ambrosio Rosales, and Manuel Pérez, efficiently handled our packing and also served as rodmen when needed.

GEOLOGY

Rock units in the area herein described are mainly marine strata of late Mesozoic age and batholithic rocks. Smaller intrusive masses, including stocks, sills, and dikes, thought to be younger than the batholithic rocks, are common in most mineralized areas. The sedimentary rocks have been intensely folded and to a lesser extent faulted. Sedimentary rocks were unaffected or only slightly metamorphosed during folding, but some thermal metamorphism occurred in their contact zones with igneous bodies. Unconsolidated till and outwash deposits of Pleistocene and Recent glaciation partly mantle all older rocks. In several localities travertine is being deposited from active hot springs. Tertiary volcanic rocks do not crop out within any of the six mining districts but are present along the route leading from the Santa Valley to the southern mineralized areas.

STRATIGRAPHY

The complexity of structure and scarcity of fossils made it impossible to work out fully the stratigraphic relations between mineral districts in the brief time available for field studies, but it is probable that all sedimentary rocks in the region are of Late Jurassic and Early and Middle Cretaceous ages. The correlations made here are based on general lithologic similarities to a few sections described by Steinmann and others as well as unpublished revisions by V. E. Benavides, and on several fossil identifications by R. W. Imlay of the Geological Survey.

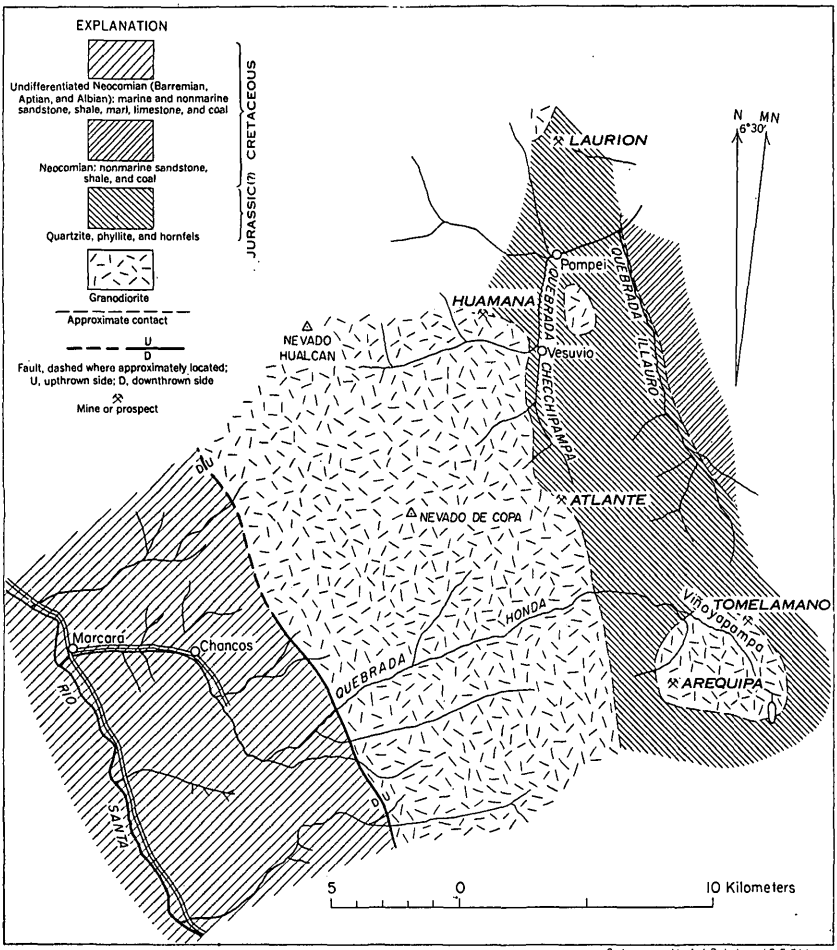
For a general description of the paleogeography of Peru during the Jurassic and Cretaceous, the reader is referred to the papers by Weaver (1940), Kummel (1948), and Huff (1949).

JURASSIC(?) ROCKS

The oldest sedimentary rocks in the region crop out east of the batholithic core of the Cordillera Blanca in the Quebrada Honda-Vesuvio mining district (fig. 8). These rocks include a thick sequence of quartzites, shales, low-grade phyllites, and andalusite- and zoisite-bearing hornfels. Massive-bedded dark-gray quartzites, dark-gray and blue-gray shales, and gray phyllites compose the bulk of the rocks; cream and white quartzites occur in places. Zoisite- and andalusite-bearing hornfels are not as abundant and occur for the most part close to the contact with the batholith. (See p. 39.) Foliation planes in phyllites are commonly macaceous. In the area we studied there is little development of secondary foliation, so it is thought that metamorphism was induced primarily by contact rather than by dynamic effects. Weathered surfaces of these rocks are dark, and areas underlain by them have a marked somber appearance. Many craggy peaks in this part of the Cordillera Blanca consist of quartzitic parts of the sequence.

Raimondi (1873, p. 283) and Dueñas (1904, p. 37) stated that shales and quartzites are bleached near the contact with the batholith, a phenomenon which we did not see. Raimondi also commented on the bleaching and alteration of country rock near hydrothermal veins, a feature common to many veins that we examined. These authors and also Boit (1926, p. 53) noted the development of andalusite-bearing rocks near the contact with the main intrusive mass.

The strata in the Quebrada Honda-Vesuvio district are isoclinally folded, so that considerable detailed mapping would be necessary to determine the thickness of the sequence. These rocks underlie a belt



Geology mapped by A. J. Bodenlos and G. E. Ericksen, August 1948. Base from topographic maps of the Cordillera Blanca (Borchers 1935; Kinzl, 1939a)

FIGURE 8.—Geologic sketch map of the Quebrada Honda-Vesuvio mining district.

about 5 kilometers wide in the upper Quebrada Honda and can be traced from the southeast end of the district northward about 25 kilometers to the Laurión and Apash mines. According to Raimondi and Dueñas, comparable strata are exposed in the Cajavilca district about 7 kilometers north of the Laurión mine, and farther north Boit found similar rocks east of the divide at Quebrada Llanganuco.

These rocks were assigned to the Tithonian (Portlandian) stage of the Jurassic by Steinmann (1930, p. 83–84) and are so shown on the Geologic Map of South America (1950). Steinmann wrote (p. 84):

> The first occurrence described is at Huayanca (Huallanca, Departamento de Huánuco) where ammonites appear together with some lamellibranchs. From here the Tithonian can be followed to the Cordillera Blanca and its northern continuation to the valley of the Río Chicama (in northern Peru). In the vicinity of the granite masses of the Cordillera Blanca the sendiments are altered by

contact metamorphism and converted to andalusite schists . . . (translation by the present authors).

At Huallanca these rocks seem to be present only in the area north of town and do not crop out in the mining district to the southwest.

The general geographic location of the Quebrada Honda-Vesuvio district suggests that these rocks could correspond to strata of Tithonian age cropping out both to the north and to the south. Furthermore, at least part of the sequence contrasts in color with overlying Lower Cretaceous clastics; Raimondi and Dueñas well before Steinmann noted this lithologic difference. We found no fossils in the district, presumably because they have been destroyed by metamorphism, and therefore we consider the Jurassic age of the sequence questionable.

Review of the literature indicates why we hesitate to assign all these rocks to Jurassic. Although abundant fossils of Tithonian age have been found, especially in northeastern Ancash (Welter, 1913; Boit, 1926, p. 62; Knechtel, Richards, and Rathbun, 1947), there is no record that the strata actually have been walked out from fossiliferous areas to metamorphosed areas. Secondly, although Steinmann and, more recently, Huff (1949, p. 9) considered the Tithonian in northern Peru to be of marine origin, Steinmann noted that coals may occur in association with green and red shales in the Tithonian sequence. In northern Ancash Singewald (*in* Knechtel, Richards, and Rathbun, 1947, p. 24–25) found thin coal beds in Tithonian strata. As the overlying rocks of earliest Cretaceous age in that area are of fluviatile and brackish-water origin and contain coal beds, the boundary between the rocks of the two periods might be difficult to establish even by detailed stratigraphic work.

Boit (1926, p. 62) stated,

In the shale formation fossils of the Portlandian have been seen, comprising in its upper part Valanginian species.

Singewald found blue-black shales, not only of Tithonian age but also as young as middle Albian, in the Aco-Cabaña area of northeastern Ancash (Knechtel, Richards, and Rathbun, 1947, p. 15, 23). In our investigation of the Tuco-Chira district we found strata of Cretaceous age converted to hornfels rather similar in appearance to the metasedimentary rocks in the Quebrada Honda-Vesuvio district.

We therefore conclude that rocks of comparable lithology occur in both the uppermost part of the Jurassic and the lowermost part of the Cretaceous. Although most of the darker strata of marine origin seem to be of Jurassic age, the Jurassic system may include rocks of fluviatile and brackish-water origin, and the Cretaceous in places may include rocks that resemble the marine Jurassic strata. Apparently Boit and Steinmann have taken the boundary of metamorphism as the dividing line where paleontologic evidence is not available. We use the same division in this report but reserve judgment on the definite age of the metamorphosed rocks.

CRETACEOUS SYSTEM

Other than the quartzites, shales, and metasediments of possible Jurassic age, all sedimentary rocks in the Cordillera Blanca and northern Cordillera Huayhuash are of Cretaceous age. Inasmuch as the nomenclature of Cretaceous rocks in Peru is that used in Europe, the following table, with equivalents used in the United States, is given for reference:

Divisions of the Cretaceous Period

<table>
<tr><th colspan="4" rowspan="2">In Peru [1]</th><th colspan="5">In the United States [2]</th></tr>
<tr><th colspan="3">Western interior</th><th colspan="2">Gulf coast</th></tr>
<tr><td rowspan="5">Upper Cretaceous</td><td colspan="2" rowspan="5">Senonian</td><td>Danian [3]</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>Maestrichtian</td><td rowspan="6">Upper Cretaceous</td><td rowspan="2">Montana gp.</td><td>Fox Hills ss.</td><td rowspan="6">Gulf series</td><td>Navarro group</td></tr>
<tr><td>Campanian</td><td>Pierre shale</td><td rowspan="2">Taylor group</td></tr>
<tr><td>Santonian</td><td rowspan="3">Colorado group</td><td rowspan="2">Niobrara chalk</td></tr>
<tr><td>Coniacian</td><td>Austin chalk</td></tr>
<tr><td colspan="3" rowspan="3">Middle Cretaceous</td><td>Turonian</td><td>Benton shale</td><td>Eagle Ford shale</td></tr>
<tr><td>Cenomanian</td><td colspan="2">Dakota ss.</td><td>Woodbine formation</td></tr>
<tr><td>Albian</td><td rowspan="6">Lower Cretaceous</td><td colspan="2">Purgatoire fm.</td><td rowspan="2">Coman-che series</td><td>Washita group
Freeridcksburg group</td></tr>
<tr><td rowspan="4">Lower Cretaceous</td><td rowspan="4">Neocomian</td><td rowspan="2">Upper</td><td>Aptian</td><td colspan="2" rowspan="5">No deposits</td><td>Trinity group</td></tr>
<tr><td>Barremian</td><td colspan="2" rowspan="4">(base concealed)</td></tr>
<tr><td rowspan="2">Lower</td><td>Hauterivian</td></tr>
<tr><td>Valanginian</td></tr>
<tr><td colspan="3"></td><td>Berriasian [4]</td></tr>
</table>

[1] After Steinmann, (1930).
[2] Simplified from C. O. Dunbar and others (1942).
[3] The Danian is not included in the Cretaceous by Dunbar.
[4] The Berriasian is not included in the Cretaceous by Steinmann.

The threefold division of the Cretaceous system used by Steinmann is followed in this report. Fossils collected during our study are representative of his lower and middle parts of the system.

The broad outlines of stratigraphy in central and northern Peru have been established, but sections of the Cretaceous rocks differ in these two regions. The area described in this report lies between them, and although it had the benefit of some study by Steinmann (1930), the work lacks sufficient detail to permit ready correlation of his units with those found in central Peru. More recently V. E. Benavides (Ph. D. thesis, manuscript in preparation, Columbia University, New York) correlated the Cretaceous strata of northern Peru with those of central Peru. This work included correction of Steinmann's correlations in Ancash, which Benavides graciously has permitted us to use. In the following description the nomenclature of the rock units is that of Steinmann and of previously published geological literature on central Peru, but units are reclassified with regards to age on the basis of determinations by Benavides.

Three main rock units comprise the bulk of the Cretaceous system of central Peru: The Goyllarisquisga formation, the Machay limestone, and the Jumasha limestone. The equivalents of these formations continue northward from central Peru into Ancash, but in the latter area overlie a sequence of sandstone, shale, and coal, as well as a younger sequence of limestone and shale.

The Goyllarisquisga formation (Jenks, 1951, p. 211), formerly known as the Goyllarisquisga-Jatunhuasi sandstone (McLaughlin, 1924, p. 605-607) and described by Harrison (1943, p. 9) as the Lower Cretaceous sandstone series, was named after the coal district northwest of Cerro de Pasco. McLaughlin noted that the formation is 700 to 900 meters thick and consists principally of quartz sandstone, in part somewhat conglomeratic, and that it also includes thick sequences of black and red shale as well as lesser coal beds. He further stated that similar strata occur at Oyón in northern Departamento de Lima, whence they can be traced northward into the Departamento de Ancash.

Throughout most of the western ranges in central Peru, a sequence of limestones from 600 to 700 meters thick forms a prominent unit in the Cretaceous rocks. This sequence was given formational status by McLaughlin (1924, p. 608–609), who named it the Machay limestone from a locality near Goyllarisquisga. McLaughlin divided the formation into two members: the Chulec, a thin-bedded light-gray limestone, which he considered to be of Aptian age; and the Pariatambo, a darker and partly bituminous limestone, which he considered to be of Albian age.

Overlying the Machay is the Jumasha limestone, described by McLaughlin (p. 609) as a uniform light-gray limestone which generally is more massive-bedded than the Machay. The Jumasha limestone was determined by McLaughlin to be possibly of Senonian age.

Limestones overlying the Goyllarisquisga were not subdivided by Harrison (1943, p. 9–11) who referred to them only as the Middle Cretaceous limestone series. He did note that the base consists of yellow-brown and rust-colored limestones overlain by an alternating sequence of partly bituminous limestone, marl, and shale. The oldest fossils collected by Harrison are of Albian age, the youngest of Cenomanian age, so evidently his series includes beds younger than the Machay.

Steinmann's column for Ancash and northwestern Huánuco includes lower Neocomian sandstone, shale, and coal; a Barremian sequence of three units consisting of a lower limestone, a middle heterogeneous group of sandstone, shale, limestone, marl, and tuff, and an upper limestone; and limestones of Aptian and Albian age. He correlated the lower Neocomian clastic sequence with the Goyllarisquisga formation, the limestones of Aptian and Albian age with the Machay limestone, and placed the Barremian sequence between them.

Recent work by Benavides in Ancash has resulted in substantial revision of age determinations of the various units as well as revision of several of Steinmann's correlations. The lower Neocomian sandstone, shale, and coal sequence is restricted by Benavides to the infra-Valanginian, and the lower limestone unit of the Barremian sequence of Steinmann is established as upper Valanginian in age; neither of these units occurs in central Peru. The middle heterogeneous unit of Steinmann's Barremian is determined by Benavides to range in age from uppermost Valanginian through the Aptian and is correlated with the Goyllarisquisga formation of central Peru. The upper limestone unit of Steinmann's Barremian is placed in the lower Albian. Benavides confirms Steinmann's correlation of the Aptian and Albian limestones with the two members of the Machay of McLaughlin, but both are dated as middle Albian as the result of this recent work. The Jumasha limestone, traced into Ancash by Benavides, is considered as ranging in age from upper Albian through the Turonian, or older than the previous age determination by McLaughlin.

THE LOWER NEOCOMIAN SEQUENCE OF STEINMANN

Steinmann (1930, p. 98, 112–114) shows sections of the lower Neocomian sandstones, shales, and coal beds in the valley of the Río Santa near Marcará and in the Departamento de Huánuco near Huallanca. Yáñez León (in Steinmann, p. 98) reported the sequence to be as much as 760 meters thick in the valley of the Río Santa. Steinmann described two profile sections of the Cretaceous rocks in the valley of the Río Torres west of Huallanca in which strata of the lower Neocomian sequence are shown as carbonaceous sandstone containing intercalations of shale.

We found that the sandstone in the valley of the Río Torres crops out throughout the Huallanca district, and a similar sandstone is exposed in the Pachapaqui and Pacllón-Llamac districts. At most places it appears to be several hundred meters thick and is medium to thick bedded and light gray. Certain zones contain bituminous shale and in most of the mining districts the sequence contains one or more beds of coal. The sandstone consists of firmly cemented, uniform-size, irregular to angular quartz grains, many of which have been secondarily enlarged. In places it contains small amounts of sericite, pyrite, and augite.

In the Quebrada Honda-Vesuvio district, a sequence probably corresponding to the lower Neocomian crops out east of the Jurassic(?) strata. In the Quebrada Illauro (Quebrada Juitush on older maps) the bulk of the rock is sandstone, but shales and included coal beds crop out several kilometers farther east (Dueñas, 1904, p. 77–96). It is possible that some rocks in this area represent the middle unit of the Barremian sequence, but the intervening lower limestone unit of the Barremian was not seen.

A light-gray thick-bedded sandstone cropping out west of the main fault at the mouth of Quebrada Antamina (fig. 3) is correlated with the lower Neocomian on the basis of lithologic similarity.

In summary, the lower Neocomian of Steinmann has widespread distribution in Ancash and northwestern Huánuco. The only district in which we did not see it is the Tuco-Chira. It is best exposed in the Huallanca and Pacllón-Llamac districts.

THE BARREMIAN SEQUENCE OF STEINMANN

The sequence of calcareous rocks with associated shales, sandstones, and tuffs immediately overlying the lower Neocomian was said by Steinmann (1930, p. 111–116, 121) to be of Barremian age. On the basis of Steinmann's section Weaver (1940, p. 171) referred to it as the Huarás formation. As noted above, important changes have been suggested by Benavides, one in the age of the sequence and another in his correlation of the middle unit with the Goyllarisquisga formation.

Steinmann reported that the Barremian sequence crops out in the valley of the Río Santa from Monterrey northward, in the vicinity of Paso Yanashallash east of Recuay, and in the valley of the Río Torres in the Cordillera Huayhuash. The general descriptions by Steinmann of sections in four localities in the valley of the Río Santa between Quebrada de Baños and Carhuás indicate that the sequence consists of three units. The basal unit is a limestone, described only as being relatively thin and barren of fossils. Above lies a unit as much as 300 meters thick consisting of a heterogeneous group including marls, dark limestones, impure limestones, tuffaceous marls, tuffs, light sandstones, and dark shales; the calcareous strata contain fossils, some of which are of marine and some of which are of brackish- and of fresh-water origin. The uppermost unit is dominantly calcareous and as much as 100 meters thick; near Marcará its lowest part is well-bedded blue-gray limestone, the middle is poorly bedded limestone, and the upper part is marl. Near Paso Yanashallash, according to Steinmann, the middle unit consists of marl and volcanic tuff overlain by sandstone, and the upper unit is limestone. In the valley of Río Torres (fig. 4) the lowest unit is blue-gray fossiliferous limestone about 100 meters thick, the middle unit consists principally of marls and sandstone, and the upper unit is fossil-bearing massive limestone at least 80 meters thick.

Although all units of Steinmann's Barremian are not seen in every district, the sequence is sufficiently widespread to indicate its extent throughout central and southeastern Ancash. The entire section is best exposed in the Pacllón-Llamac mining district and, despite complex structure, most of it also may be discerned in the Pachapaqui and Huallanca districts. Good exposures of the sandstones and shales of the middle unit are seen east of the crest of the Cordillera Blanca along the Recuay-Huari road.

The lower unit is thin- to medium-bedded, dark-gray, fine-grained to lithographic limestone containing shale layers and partings. We definitely established its presence only in the Huallanca and Pacllón-Llamac mining districts, where it is 100 to 200 meters thick. The middle unit, seen in all four southern districts, consists of interbedded shales, shaly sandstones, and impure limestones. It varies widely in lithology from place to place and is several hundred meters thick. The upper limestone unit is directly overlain by younger limestones of similar lithology and in the absence of fossils is difficult to recognize as a distinct stratigraphic unit, especially in reconnaissance examination.

Along the Recuay-Huari road, the sandstones and shales of the middle unit are closely folded and underlie a belt from 15 to 20 kilometers wide. The sandstones include thin- to massive-bedded rocks of gray, yellowish, and brown colors. The shales are brown, reddish, and dark gray. Several thin coal beds also are found in these rocks. Neither the underlying nor the overlying limestone units were seen in this area. The thickness of these clastics seems to be considerably greater than the 300 meters measured for the middle unit of the Barremian by Steinmann in the Santa Valley.

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MACHAY AND JUMASHA LIMESTONE

Near Marcará, Steinmann (1930, p. 112–113, 120–121) found units equivalent to the lower and upper members of the Machay limestone. The lower unit consists of marly limestone and yellowish marls, and the upper unit of bituminous black shales with interbedded light and dark limestone. He stated that similar limestones rest on the upper limestone unit of the Barremian sequence in the valley of the Río Torres west of Huallanca. Benavides traced the overlying Jumasha limestone from central Peru into central Ancash, where it had not been previously identified by Steinmann.

The Machay and probably the Jumasha limestones crop out in the four southern mining districts and are best exposed in the Huallanca district. The Jumasha limestone underlies a broad area in the Antamina-Contonga district.

West of Huallanca, we found that the limestone above the upper unit of the Barremian was several hundred meters thick and consisted of an impure fossiliferous limestone and interbedded soft bituminous shale. Fossils collected above that part of the section described by Steinmann were studied by R. W. Imlay of the Geological Survey, who identified the ammonite *Mortoniceras* (*Pervinquieria*) sp. and the pelecypod *Inoceramus* sp. Imlay stated that the ammonite is of upper Albian age and is common in the Washita group of Texas. The upper limestones of the Huallanca area thus are roughly equivalent to the Machay and the lower part of the Jumasha.

In the Pachapaqui district thick-bedded fine-grained dark-gray limestone predominates. Comparable limestones in the Pacllón-Llamac district contain minor amounts of shale. Limestones overlying the middle unit of Steinmann's Barremian in the Tuco-Chira district are several hundred meters thick. They may be equivalent to the upper unit of Steinmann's Barremian sequence, the Machay, and part of the Jumasha.

About 5 kilometers east of San Marcos a folded limestone sequence at least 700 meters thick is in fault contact with the lower Neocomian sequence of Steinmann. In the Antamina-Contonga district the formation is principally limestone, but includes several dolomite beds. The strata are thin to massive bedded, and various shades of gray, and range from extremely fine grained to moderately coarse grained in texture (fig. 9). Above Lake Antamina on the east side of the cirque several massive beds contain concentric structures that may be of algal origin. Fossils are scarce and poorly preserved. Collections made from talus below a steep bluff near the Pallares prospect include specimens of *Lopha*, *Pecten*, and *Arctica*, which according to R. W. Imlay indicate only that the strata are of Cretaceous age.

The lithology of the limestone of the area corresponds to that of the Jumasha. On aerial photographs the limestone can be traced south-

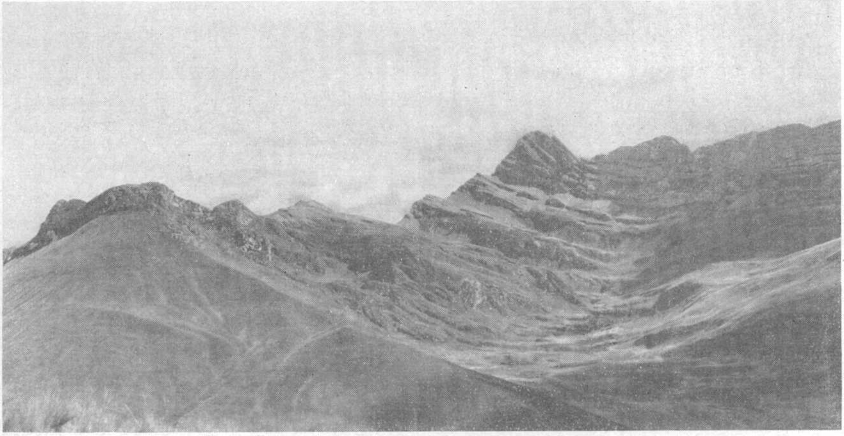

FIGURE 9.—Jumasha limestone in the Antamina area. View to the southwest from near the Cantonga area; Quebrada Antamina is beyond the crest line extending from the high peak to the shoulder on the left.

ward to a point west of Huallanca. V. E. Benavides (personal communication) found both the Machay and the Jumasha in the Quebrada Puchca, 15 kilometers north of San Marcos.

TERTIARY SYSTEM

Folded volcanic flows and agglomerates, cropping out in the Santa Valley between Huarás and Recuay, are said by Steinmann to have been deposited during the orogeny occurring from the end of the Cretaceous to early in the Tertiary. They possibly are equivalent to similar folded volcanic rocks found in the valley of the Río Rimac east of Lima (Steinmann, 1930, p. 191, and McLaughlin, 1924, p. 622).

Volcanic rocks of Tertiary age, deposited after the last period of major folding before and during epeirogenic uplift of the Andean block, lie along the crest of the Cordillera Negra and along the upper parts of the valleys of the Río Fortaleza and the Río Santa. For the most part the rocks are found only in areas west of the Río Santa, but at the south end of the Santa Valley outcrops extend eastward nearly to Chiquián. The volcanic rocks here appear to be andesite flows and rhyolite tuffs which in most outcrops are deeply weathered or have been altered by hydrothermal solutions. The outcrops near Chiquián seem to be the most easterly extent of the volcanic rocks in Ancash, as they appear to be absent throughout the rest of the region described in this report.

PLEISTOCENE AND RECENT SERIES

As a result of glaciation during the Pleistocene and Recent epochs, areas formerly covered by ice are now partly mantled with till, and pro-glacial areas are blanketed with outwash deposits. In higher regions active glaciers are still depositing morainal material, and run-off water charged with rock debris is filling in newly formed glacial lakes. These unconsolidated glacial deposits are described more fully in the section on glaciation (p. 41–46).

During Recent time hot springs have been depositing travertine and calcareous sinter. In the Santa Valley a spring at Chancos is depositing a travertine of comparatively pure calcium carbonate, and another spring at Monterrey is depositing both ocherous and calcareous material (Dueñas, 1904, p. 30). In the southern part of the region one thermal spring in Quebrada Azulmina (fig. 4) near the Pachapaqui-Huallanca trail is depositing small amounts of travertine, and another spring, no longer flowing, has built up a small travertine deposit on the north side of Quebrada Tuco (fig. 7). None of the four deposits is large.

INTRUSIVE ROCKS

Intrusive rocks in the region include the batholith in the Cordillera Blanca, several stocks, and many dikes and sills. The batholith and several stocks are composed of granodiorite; other stocks are of rhyolites or diorite. Sills and dikes consist of rhyolite, granodiorite, granite, aplite, granite pegmatite, andesite, and diabase. The batholith in the Cordillera Blanca is at least 120 kilometers long by 10 kilometers wide. Stocks are from less than 1 to about 5 kilometers in diameter; dikes and sills range from less than a meter to 20 meters in thickness and are traceable over distances ranging from 50 meters to several kilometers.

The intrusive mass in the Cordillera Blanca is one of the largest in Peru. Although on the Geologic Map of South America (Stose and others, 1950) this intrusive mass is shown as being more than 250 kilometers long, its southern limit is incorrectly indicated; the southern margin is between the pass on the Recuay-Huari road and Huarapasca Pass 20 kilometers to the south. The western limit of the batholith in the vicinity of Huarás, as shown on the geologic map, also seems to be too far west, because sedimentary and volcanic rocks crop out along the Río Santa both north and south of the city (p. 24–27).

Above Marcará the western margin of the batholith is comparatively regular and forms the steep front of the Cordillera Blanca facing the Santa Valley; here the contact with sedimentary rocks is faulted, but the magnitude of the movement is not known (p. 38). In the Quebrada Honda-Vesuvio district the eastern margin of the mass is less regular; to the east of the border are stocks that evidently are cupolas of the main body. The stock in the upper part of the Quebrada Honda is 5 kilometers in diameter, and the one just southeast of Pompei is smaller. Outcrops are massive and owing to recent glaciation are comparatively fresh and light in color. Granodiorite forms most of the higher peaks in the range.

Most of the rock has granitic texture, although in places it is somewhat porphyritic. At a few places, especially near contacts, the rock is foliated. Such structure can be seen near the power plant in the Cañón del Pato and has been described by Boit (1926, p. 52) as occurring in Quebrada Llanganuco north of Nevado Huascarán.

As far as can be determined from the microscopic study of a few specimens, the batholith consists mainly of metaluminous granodiorite, but in a few places is an albite granite or a soda tonalite. The more calcic variety contains more andesine and dark minerals and less quartz than the average type. In granodiorite medium-sized plagioclase feldspar grains form from 40 to 50 percent of the rock. The composition of the plagioclase ranges from An_{16} to An_{50}, but most is between An_{20} and An_{30}. Zoning is common and is both oscillatory and normal; where zoning is normal, cores may be andesine and mantles, oligoclase. Orthoclase or microcline, occurring as finer grains interstitial to plagioclase, forms from 10 to 15 percent of the rock. Fine-grained quartz, also interstitial to plagioclase, forms from 15 to 25 percent of the rock. One highly altered specimen from the Huamaná area contains 40 percent of quartz, but some may be secondary. Biotite and hornblende form medium-sized grains and make up from 5 to 30 percent of the rock. Apparently biotite is present in all specimens, but hornblende is not. Hornblende may be poikilitic, enclosing flakes of biotite. Accessory minerals are apatite, zircon, and epidote. Very small amounts of muscovite and microperthite were seen in several specimens.

Biotite and hornblende, together with the accessory minerals, crystallized first. Following, plagioclase feldspars formed and then orthoclase and quartz. Microcline may have crystallized either before or after the quartz. Orthoclase corrodes plagioclase and biotite, and quartz seems to have replaced some plagioclase.

Feldspars are sericitized and dark minerals chloritized to some degree in all rocks, and in the most intensely altered rock, part of the orthoclase is epidotized. Slight alteration is attributed to the action of deuteric solutions, but more intense alteration, generally found in the vicinity of sulfide veins, evidently has been caused by hydrothermal solutions.

The stock in the upper part of the Quebrada Honda, particularly in the vicinity of the Arequipa and Chaco mines (fig. 2), contains bleblike inclusions of darker material several centimeters in diameter. Microscopic examination shows that the inclusions have gradational contacts with the host rock and that they contain the same minerals. However, biotite, hornblende, and muscovite are present in larger and orthoclase in smaller percentages than in the normal granodiorite, and the texture is finer grained. A dark-colored dioritic rock along the north edge of the stock, exposed most extensively in the vicinity of the Rataquenua deposit, shows a more marked divergence from the predominant rock type. This dioritic rock occurs in a belt at least 100 meters wide and has highly irregular contacts with the granodiorite. Minerals comprising the diorite include plagioclase, orthoclase, and hornblende as well as accessory apatite and sphene. About 50 percent of the rock is zoned plagioclase averaging An_{40} in composition. Locally this plagioclase is partly replaced by orthoclase. Hornblende, which originally formed about 30 percent of the rock, is largely altered to chlorite; some grains have pyroxene outlines, indicating transformation during crystallization.

The batholith is cut by aplite and pegmatite dikes, and the stock in the upper Quebrada Honda contains diabase dikes. The aplites have sugary texture and are made up of equal-sized grains of quartz and orthoclase and a slightly smaller amount of plagioclase. The dikes are light tan or light gray, and most are unaltered. Diabase dikes in the vicinity of the Arequipa and Chaco mines in the upper Quebrada Honda are gray green, have equigranular texture, and consist of plagioclase (An_{48}), pyroxene (pigeonite), and biotite. The pigeonite is partly changed to amphibole and the biotite partly altered to chlorite.

Stocks are found in 4 of the other 5 mineral districts. Those consisting of granodiorite are in the Tuco-Chira, Pachapaqui, and Huallanca districts. Stocks with granitic composition occur in the Tuco-Chira and Pachapaqui districts, and the stock in the northern part of the Antamina-Contonga district is rhyolite. A poorly exposed intrusive of dioritic composition in the Huallanca district may be a stock. Most of these bodies have associated sills and dikes with lithology comparable to the parent mass. Neither these nor other small igneous bodies have prominent lineation of minerals.

The largest of these stocks, in the Tuco-Chira district, crops out in the vicinity of the Mercedes, Siberia, Rusia, and Chira deposits (fig. 7). It consists of granodiorite similar to that of the batholith. The texture is granitic with mineral grains from 2 to 3 millimeters in diameter. The rock consists principally of oligoclase, quartz, orthoclase, and biotite as well as the accessory minerals apatite, sphene, zircon, and magnetite. In specimens studied oligoclase about An_{20} in composition makes up 50 percent or more of the rock; grains of this mineral are zoned. Orthoclase constitutes from 5 to 10 percent of the rock, quartz from 10 to 20 percent, and biotite about 10 percent.

Smaller stocks of granodiorite porphyry crop out in the Pachapaqui district and at the Sirena Encantadora deposit in the Huallanca district (fig. 4). This granodiorite contains phenocrysts of quartz and oligoclase in a fine-grained matrix predominantly of quartz and feldspar with minor amounts of biotite, augite, hornblende, apatite, and sphene. Most of these rocks are altered and contain sericite, chlorite, epidote, and calcite.

In the Tuco-Chira and Pachapaqui districts small irregular bodies which may be either stocks or sills are composed of porphyritic granite. The rock consists predominantly of orthoclase and quartz; northeast of the Cascajal deposit in the Tuco-Chira district it contains Carlsbad twins of orthoclase as much as 5 centimeters long. At the Perla deposit in the Huallanca district several outcrops of diorite in an area of poor exposures may be part of a stock. The rock has granular texture and consists largely of andesine, oligoclase, and orthoclase, with small amounts of ferromagnesian minerals, partly altered to chlorite, and minor amounts of apatite. The stock in the Contonga area of the Antamina-Contonga district is rhyolite containing phenocrysts of quartz, feldspar, and dark minerals. The marginal part of this body is noticeably finer grained than its interior.

Dikes and sills not related to larger igneous masses are composed of rhyolite, granodiorite, granite, and andesite. Those consisting of grandiorite and granite are comparable petrographically to the porphyritic stocks of similar composition described above.

The most common rock type in dikes and sills is a rhyolite consisting of phenocrysts of andesine, oligoclase, orthoclase, and quartz, set in a microcrystalline or cryptocrystalline groundmass of quartz and feldspar with minor amounts of biotite, hornblende, apatite, zircon, and magnetite. On the basis of phenocrysts some material may be classed as rhyodacite or quartz latite, but owing to the difficulty of identifying the feldspars and quartz in the groundmass by means of microscopic examination, the classifications used here can be only general.

The rhyolite intrusives are altered, some only slightly but others to such an extent that of the original rock only a few grains of quartz remain. Biotite is altered to chlorite or is bleached and grains of hematite and pyrite formed along cleavage planes. Feldspars are altered to sericite and calcite. In a few intensely altered rhyolites outlines of feldspar phenocrysts are preserved, but the interiors consist of felted masses of sericite crystals set in groundmasses of fine-grained sericite and quartz. Phenocrysts of quartz commonly are corroded and rounded, and borders have a thin layer of radiating quartz prisms. In some specimens feldspar phenocrysts have been dissolved, and their former presence is indicated only by wispy fragments at the edges of cavities.

In the Antamina area sills and dikes contain phenocrysts either of oligoclase or of andesine (An_{33}), rounded quartz grains, biotite, and in places the pyroxene pigeonite set in a groundmass of quartz, orthoclase, biotite, and chlorite. Feldspars are sericitized and dark minerals chloritized; epidote occurs in specimens containing oligoclase but not in those containing andesine. Quartz phenocrysts are more numerous in rock from the western part of the area, and chlorite representing altered dark minerals is more abundant in rock from the eastern part of the area; thus it would appear that the rock is rhyolite in the west and rhyodacite in the east.

Andesite dikes consist of plagioclase feldspar ranging in composition from oligoclase to labradorite; hornblende or biotite; and minor amounts of orthoclase. Textures range from granular to porphyritic. In the south, andesite dikes were seen only at the Misericordia deposit in the Pacllón-Llamac district (fig. 6) and the Venus and Cosmos deposits in the Tuco-Chira district. In the north an andesite dike occurs at the Apash deposit at the north end of the Quebrada Honda-Vesuvio district (fig. 2); in addition to the usual minerals the rock here contains pyroxene and some quartz.

The batholith is similar in lithology to the coastal batholith, and they may be genetically related and contemporaneous. Both McLaughlin (1924) and Harrison (1943, p. 33) considered the coastal batholith in central Peru to have been intruded at or near the end of the second major orogeny (the Incaic orogeny of Steinmann). The two orogenies as yet have not been differentiated in Ancash, so in the absence of further evidence nothing can be added to these prior opinions of McLaughlin and Harrison.

The smaller granodiorite stocks and sills possibly may be contemporaneous with the batholith in the Cordillera Blanca, but the age of stocks of different composition cannot be fixed other than that they are younger than the period during which folding took place. Some sills, such as those of andesitic composition in the Tuco-Chira district, may have been intruded before folding, but most tabular bodies definitely were emplaced subsequently. Because these bodies are fractured, brecciated, and faulted in places, they probably antedate at least part of the series of uplifts which raised the Andean block to its present elevation.

STRUCTURE

The Andean Cordillera was formed during orogenesis which began in either Late Cretaceous or early Tertiary time and has continued to the present. Deformation and uplift occurred in three principal stages. The first two, the more important, were periods of compression, or orogenic movement; the third was predominantly a period of uplift, or epeirogenic movement. During the orogenic stages, folds; small, reverse faults along bedding planes; and larger, reverse or thrust faults were formed. Folds are the most prominent structural features in southern Ancash. They are accompanied by many bedding faults, but large-scale reverse faults were seen in only one district. During the epeirogenic stage, open flexures and many normal faults were produced.

Sedimentary rocks of central Ancash have been compressed into long, relatively narrow, alined folds striking about N. 30° W., parallel to the regional trend of the Andean Cordillera and to the coastline. Major folds in most places are upright or only slightly overturned; many are closed or isoclinal, having sharp crests and steeply dipping limbs (figs. 10, 11).

In certain areas folds are noticeably overturned and in the Quebrada Tuco are nearly recumbent; in the latter area the axial plane of one major fold is nearly horizontal (fig. 12). Competent beds, such as those of limestone or sandstone, forming the broad outline of folds are bent into simple curves, but at places these beds may be complexly folded (fig. 13). Associated incompetent beds, principally of shaly sediments, are, in general, much more complexly folded. Shaly sediments are predominant in areas which show isoclinal folding.

Other than crumpling and minor flowage of incompetent strata in the folds, most movement during folding apparently has taken place along bedding faults. At most places the competent strata are only slightly thinned on limbs and thickened on crests, so the folding seems to be predominantly of the parallel type (fig. 14). However, in a few of the more complexly folded areas even competent strata show considerable flowage, and folds tend to be of the similar type. The quartzites and phyllites of Jurassic(?) age on the east side of the batholith in the Quedrada Honda-Vesuvio district and some of the Cretaceous limestones in the Tuco-Chira district seem to have developed flowage to some extent. Throughout the region, however, few folds can be classed as either ideally parallel or purely similar. Bedding faults contemporaneous with folding are characterized by reverse movement and consist of gouge and breccia zones with slickensided walls. These faults are limited to bedding planes or are closely parallel to them and obviously are restricted to one limb of any fold. Although movement along most is comparatively small, a few appear to have cut several tens of meters of beds.

Large-scale reverse faulting was recognized only east of San Marcos. Several hundred meters east of the contact between the lower Neocomian sandstone and the Jumasha limestone a reverse fault completely within limestone dips 60° SW. The bedding in the western block parallels the fault plane, but the bedding in the eastern block is truncated by the fault (pl. 1, sec. *A–A′*). At the contact between the lower Neocomian sandstone and the Jumasha limestone, stratigraphic and structural evidence indicates that the lower Neocomian is upthrown more than 1,000 meters along another fault.

Normal faults, considered to have formed during the stage of epeirogenic movement, have displacements ranging from a few meters

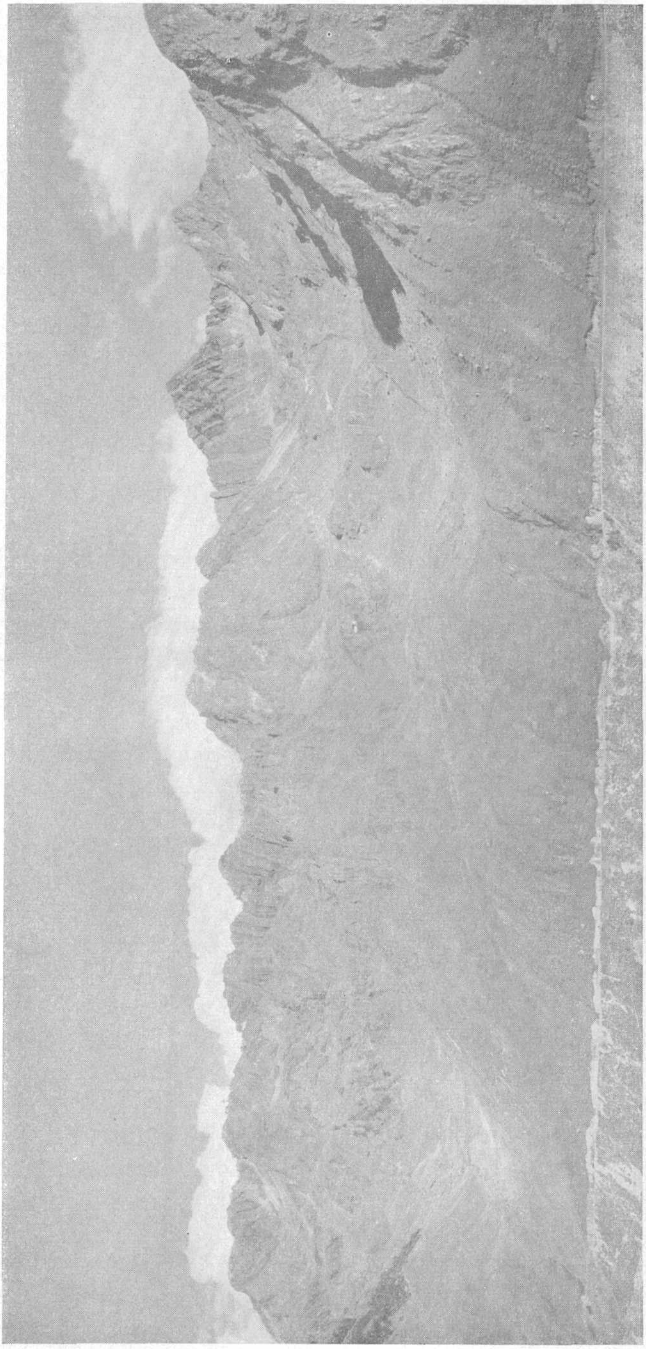

FIGURE 10.—Isoclinally folded sedimentary rocks of the middle unit of the Barremian sequence, looking south just east of pass, Recuay-Huari road. Apophysis of batholith extends from right to right center of photograph. Axial planes of folds are nearly vertical.

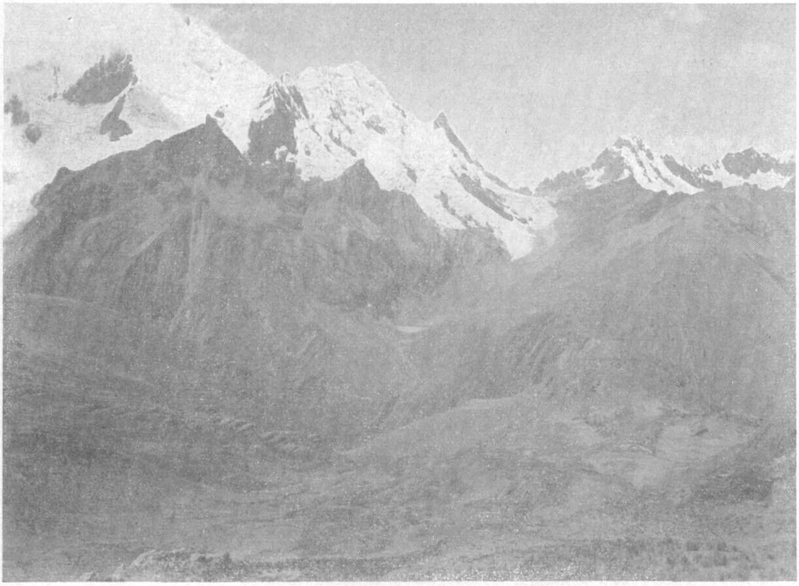

FIGURE 11.—Isoclinal folding of Cretaceous sedimentary rocks on northwest side of Nevado Yerupajá (peak obscured by clouds). Axial planes of folds are nearly vertical. Isoclinal anticline is visible to right and syncline to left of glacial valley. Lake in valley is dammed behind recessional moraine.

FIGURE 12.—West side of Quebrada Tuco, showing nose of overturned syncline. White streaks extending downward from axis of structure near nose are dumps of the Cascajal mine.

FIGURE 13.—East side of Quebrada Tuco showing complex overturned folding of Cretaceous sedimentary rocks. Contorted layer near left side of photograph is limestone.

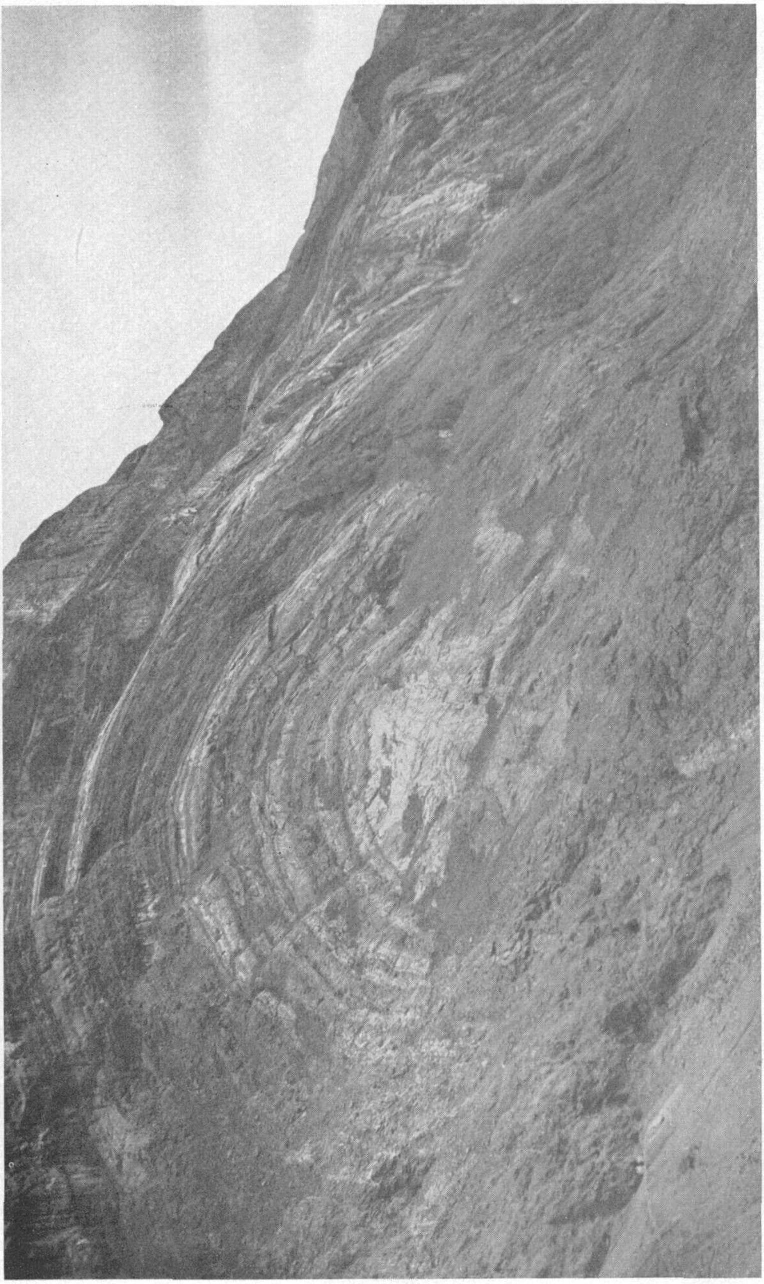

FIGURE 14.—Crest of parallel fold in south wall of Quebrada Antamina. The anticline is flanked by two sharply folded synclines; strata along ridge crest above are unfolded and dip eastward at low angles. In lower part of photograph, material devoid of bedding is silicated limestone containing disseminated copper sulfides.

to several hundred meters. In the southern districts many valleys have been eroded along large fault zones, as is indicated by different structures and rock types on opposite valley walls. Some folds in the medial parts of the southern ranges appear to be broken by normal faults having displacements of several hundred meters. Smaller faults, common throughout the region, are traceable for only a few hundred meters; their short horizontal extent indicates that their vertical displacements are correspondingly small.

Normal faulting is taking place at the present time; in 1946 an earthquake in northeastern Ancash resulted from movement on a fault which produced a scarp as much as 2 meters high (Heim, 1949). Fault scarps, between 5 and 10 meters high, cut glaciofluvial fans and extend for kilometers along the western front of the Cordillera Blanca east of Recuay, east of Huarás, and in the vicinity of the Quebrada Honda east of Marcará. These scarps provide clear evidence that the range has been raised relative to the Santa Valley block comparatively recently.

The sedimentary rocks of the region are intensely fractured and jointed. At most places the fractures and joints form very complex patterns, but in the southern districts limestone at several localities is broken by joints into large, nearly equal-sized rhombic blocks. At several other localities intersecting joints and bedding planes separate the rock into rectangular blocks.

Joints, fractures, and faults with small displacements also cut all igneous rocks. Joints in massive rocks do not form well-oriented systems in most places, but some prominent sets are seen here and there. At the mouth of Quebrada Honda strong sheeting near the west contact of the batholith dips about 45° SW. The joints steepen to the east and then fade in prominence several hundred meters from the contact. Faults in massive rocks also seem to be alined in a few areas. The stock in the upper Quebrada Honda is cut by small faults generally trending north to northwest. At the Huamaná mine in the Vesuvio area intersecting faults strike north to northwest; one set dips about 15° and a second set about 70° westward.

Faults of small displacement are common along contacts between sedimentary and igneous rock. Along the large intrusive bodies these faults may branch into either rock type; examples are the Cruzada vein in the Atlante mine and the veins around the stock in the Contonga area (pl. 2). Contact faults may swing completely across tabular igneous bodies and follow opposite contacts, as shown by a number of structures followed by veins in the Antamina area. Other faults with small displacements transect contacts at large angles.

Few generalizations can be made regarding differences of magnitude of faulting in one rock type as compared with another. Mine maps of the Quebrada Honda-Vesuvio district show that some faults are strong in igneous rock and fade in sedimentary rock a short distance from the contact, whereas the opposite is true along other faults.

Small faults with either normal or reverse movement are economically important because many are loci of mineral deposits. Most are narrow shear zones ranging from about one-half to several meters in width. Details of their configurations, internal structure, and associated fractures are given later in the descriptions of mineral districts and deposits.

METAMORPHISM

Sedimentary rocks have been regionally metamorphosed throughout extensive areas and locally metamorphosed along contacts of the more acidic intrusive rocks. Shales, shaly limestones, and shaly sandstones seem to have been the rocks most susceptible to regional metamorphism. Shales and shaly limestones are changed to low-grade phyllites and, in a few isolated places, to slate and schist. The purer sandstones are quartzitic in some areas, but, in general, are not regionally metamorphosed. Shaly sandstones are changed to argillaceous quartzite. Most limestones are not metamorphosed but in places contain scattered crystals of wollastonite; elsewhere beds have been silicified or serpentinized. Such alteration of limestone over wide areas may have resulted in part from regional metamorphism of impure limestones and in part from introduction of new minerals by hydrothermal solutions.

In contact zones, especially near granodiorite and rhyolite intrusives, limestone and shaly limestone are silicated, and shaly sandstone is metamorphosed to tough gray or green hornfels. Hornfels, silicic or argillaceous rock recrystallized by heat of intrusion, occurs with Jurassic(?) quartzites and phyllites in the Quebrada Honda-Vesuvio district. One specimen collected at several hundred meters distance from the contact with the batholith consists of 40–45 percent quartz, occurring as angular grains, and 50–55 percent zoisite, as well as accessory zircon; this rock originally may have been an arkose. Thirty meters from the batholith at the Huamaná mine the rock consists of 15 percent quartz, 50 percent andalusite, 30 percent biotite, and 5 percent muscovite; its unmetamorphosed equivalent could have been an argillaceous sandstone.

Silicated limestone was formed either by reaction with or replacement of limestone by silica and other lesser constituents introduced in magmatic solutions or by recrystallization of impure limestone by heat of intrusion. The first process seems to have been predominant because in most silicated zones highly altered limestones contain patches of limestone which have been only bleached and recrystallized to either fine- or coarse-grained marble, an indication that the original rock was comparatively pure. Minerals in silicated limestones include garnet, idocrase, epidote, diopside, wollastonite, serpentine, and quartz.

Most silicated limestones in the southern districts consist of quartz and grossularite garnet or epidote. In addition to these constituents, felted or radiating masses of acicular to bladed crystals of white wollastonite may be present. The rocks range in color from gray to pale green and bright green. Vugs and fractures commonly are lined with well-formed crystals of green garnet, which range from less than a millimeter to about 2 centimeters in diameter. A few contact zones contain minor quantities of brown garnet. Additional petrographic details on silicated limestone are given below (p. 56–57).

A substantial mass of silicated limestone occurs along a large rhyolite sill(?) in the middle of the Antamina area. The highest degree of alteration produced an assemblage identified by R. V. Lewis of the Geological Survey as diopside, grossularite garnet, wollastonite, and idocrase. Less profound alteration produced garnet-serpentine and garnet-diopside rocks.

GLACIATION

Glaciation during Pleistocene and Recent time has produced Alpine sculpture in most of the higher ranges of the Andean Cordillera and has resulted in deposition of great amounts of till and drift (Steinmann, 1930, p. 267–76). Although ice still covers some ranges, glaciers have been receding at a rapid rate throughout the country during the past 25 to 50 years (Broggi, 1943).

In the Cordillera Blanca and in the northern Cordillera Huayhuash the present snowline lies at an altitude of 5,100 meters or above. The lower limit of most glaciers is several hundred meters below this altitude, and some valley glaciers extend as low as 4,300 meters. On the north side of Nevado Huandoy, one glacier reaches the exceptionally low altitude of 4,100 meters. During a period of greater glacial activity in the past ice extended even lower; Steinmann (1930, p. 270) reported a terminal moraine above Huarás at an altitude of 3,300 meters. The lowest glacial deposit seen during our investigations is the lateral moraine just below the mouth of Quebrada Honda. This moraine lies at an altitude of 3,400 meters, 950 meters below the lowest ice now present in the upper part of the quebrada. Evidence of rapid recession of ice is provided by the uncovering of one mineral deposit in the Huallanca district within the past 15 years. At the Atlante mine in the Vesuvio area a fairly large lake has formed behind a small recessional moraine that marked the ice front in 1932, and the ice has retreated from the portal of level 3 since this working was first cut. One valley glacier has stagnated to such an extent that its lower extremity is completely separated from the main body of ice (fig. 15), and ice caps on shoulders of peaks are wasting irregularly (fig. 16).

Most of the erosional features commonly resulting from mountain glaciation, including horns, arêtes, cirques, faceted spurs, U-shaped valleys, hanging tributary valleys, stoss and lee topography in valley floors, and striated outcrops (figs. 11, 17, 18, and 19), may be seen in these ranges. Floors of many valleys are divided into steplike treads a few hundred meters to several kilometers long, covered with marshes and drier pasture land. Interspersed are steeper sections in which outcrops are polished and striated or quarried on the downslope side. The relief between main valley floors and ridge crests is commonly more than 1,000 meters.

Glacial deposits include many forms of till and stratified (or washed) drift. From the mouths of U-shaped valleys upward, most deposits are till which forms lateral, terminal, and ground moraines (figs. 15, 16, and 20). Stratified drift occurs only locally, in basins behind rock dams or where lakes were temporarily impounded behind terminal moraines and at the bases of oversteepened and hanging valleys where fans were deposited over either moraine or lake-filling material.

Below the mouths of U-shaped valleys glaciofluvial deposits predominate. In the valley of the Río Santa tremendous deposits are found in the area between Lake Conococha on the south and the Cañón del Pato on the north. In most places they form large fans which may coalesce to form aprons extending for many kilometers along the base of the steep front of the Cordillera Blanca. Most of the glaciofluvial material is only rudely sorted and stratified, probably because streams fed by glaciers were heavily loaded and had steep gradients. Steinmann (p. 276) stated that north of Carás much outwash material was deposited as the filling of a now-extinct lake. Present glacial lakes, especially those newly formed below receding glaciers, are being filled slowly with glacial debris, and broad, flat valley floors, such as those on the step-like treads in the upper reaches of Quebradas Honda and Llamac, are suggestive of filled-in lakes.[4] Banded clays exposed at Chancos are definitely of lacustrine origin and are considered by Heim (1947, p. 114) to be varved.

At the south end of the Santa Valley the glaciofluvial deposits have been dissected only slightly during the present cycle of erosion, but from Huarás northward they have been strongly dissected. Between Carás and the Cañón del Pato at least four terrace levels are visible above the present river channel. The Río Santa still is cutting down-

[4] Flat marsh- or grass-covered areas at the bottoms of glaciated valleys are locally called *pampas* and are referred to as such throughout this report.

FIGURE 15.—Wastage of ice and lateral moraine, Quebrada Cancahua. View to the west, showing tongue of ice in bottom of valley completely separated by wastage from main valley glacier above. Well-developed lateral moraine is shown at base of hill at right. Spur on left and hill on right are metasedimentary rocks of Jurassic(?) age; granodiorite underlies peaks in background. Esparta mine is at foot of shoulder above lower glacial remnant.

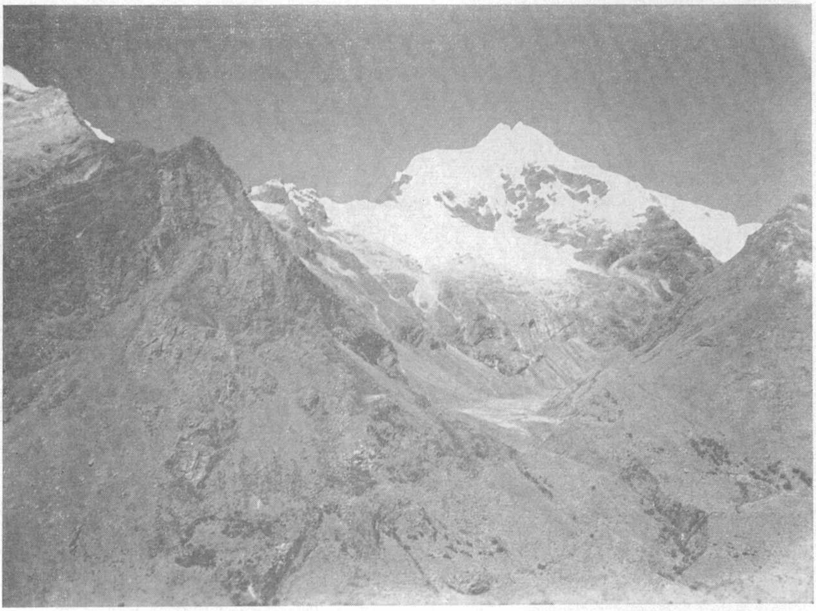

FIGURE 16.—Wastage of ice and recessional moraine, Quebrada Cancahua. View to the south from upper Quebrada Honda, showing irregular wastage of ice caps on peaks. The quebrada is a hanging valley; recessional moraine occurs at its foot, and lacustrine sediments cover its floor. Right shoulder of main peak is underlain by metasedimentary rocks of Jurassic(?) age; other rock in photograph is granodiorite. Arequipa and Chaco mines are just below the ice line, right center of photograph.

FIGURE 17.—Alpine sculpture of peaks and oversteepening of valley walls by glaciation, upper Quebrada Honda; view to the south, showing Alpine sculpture of peaks resulting from mountain glaciation. Spur on right has been trimmed and oversteepened through erosion by valley glacier. Spur and lower slopes around valley consist of granodiorite; upper slopes and peaks are folded metasediments of Jurassic(?) age.

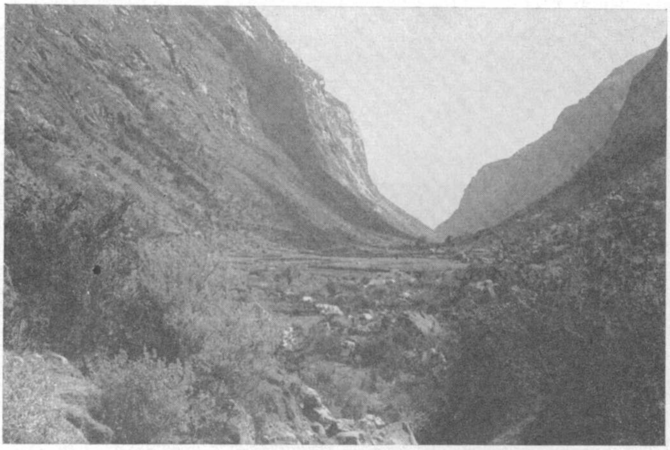

FIGURE 18.—U-shaped glaciated valley, the lower Quebrada Honda, view to the west; flat floor in the middle foreground is result of lake filling.

FIGURE 19.—U-shaped glaciated valley, the Quebrada Llamac, view to the west; pampa in foreground is at Hacienda Palca.

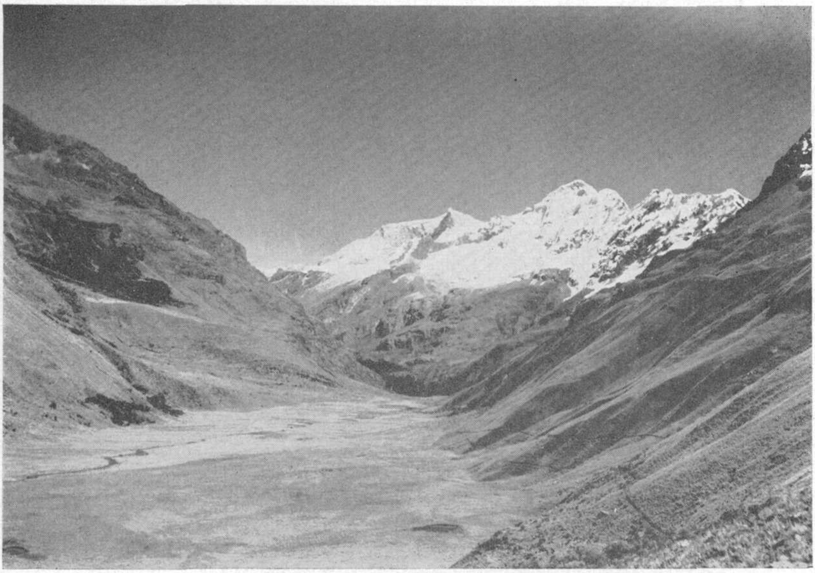

FIGURE 20.—Lateral moraine and post-glacial sediments, upper Quebrada Honda. View to the west, showing lateral moraine, which on the right wall of the valley extends to above the height of the observer. The flat valley floor, the Viñoyapampa, contains lacustrine sediments deposited in a lake dammed by rock barrier. Ice-covered peaks on right are underlain by metasedimentary rocks of Jurassic(?) age and in center and right center by grandodiorite.

ward, but in a few places between Huarás and Carás it is cutting laterally and is forming small and separated flood plains.

As is common elsewhere in glaciated regions, erosion and deposition resulting from ice action have blocked and disrupted normal drainage. During the present cycle of glacial recession many lakes have formed in front of receding glaciers in basins which before had been occupied by ice. The waters are dammed either by the downslope rims of rock basins or by recessional moraines. Steinmann (p. 275) reported that Lake Llanganuco in the quebrada north of Nevado Huascarán is dammed solely by a landslide. Lake Parrón, the largest lake in the Cordillera Blanca, in the quebrada on the north side of Nevado Huandoy, is dammed partly by a glacier from a tributary valley and partly by a terminal moraine. Lake Conococha, at the head of the Río Santa, apparently formed by the disruption of drainage by large coalescing fans emanating from quebradas at the southern end of the Cordillera Blanca.

Morainal dams of glacial lakes are subject to failure, and resultant "aluviones," or mud flows, have transported and deposited large quantities of material. Since 1941 three morainal dams in the Cordillera Blanca have broken, and aluviones have devastated the valleys below.

The most destructive aluvión from the standpoint of loss of life and property occurred in December 1941 when a lake at the head of Quebrada Cohúp broke through its morainal dam. Water, mud, rocks, and huge boulders swept for a distance of 23 kilometers down the quebrada and through the center of Huarás, burying one-fourth of the city to a depth of about 20 meters and causing a great loss in lives, estimated as between four and six thousand (fig. 21). The power of this aluvión is shown by the fact that it carried into Huarás a block of granodiorite, the visible part of which was estimated to weigh at

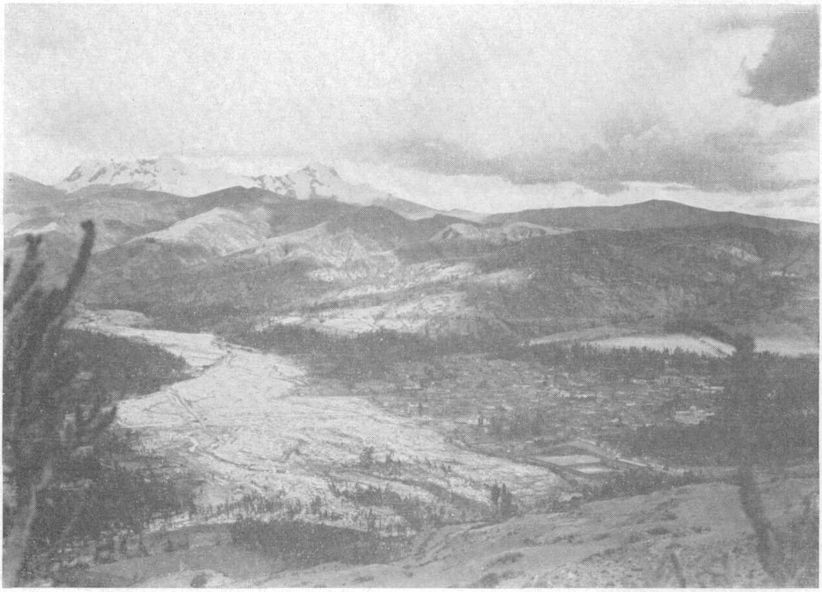

FIGURE 21.—View of the aluvión that devastated Huarás in December 1941, looking east from the Cordillera Negra.

least 700 tons. Along the Río Santa farms downstream were washed out or buried, and those a short distance upstream were flooded when the river backed up against the mudflow barrier. Two days later the river breached the mudflow, and the resulting flood caused further damage downstream.

In January 1945 a similar aluvión swept down the Quebrada Huachesca, the mouth of which is at the town of Chavín, 7 kilometers south of San Marcos. The lesser amount of material carried by this aluvión combined with sparse population of the area, resulted in comparatively small loss of life (Indacochea and Iberico, 1947; Spann, 1947). In 1950, during the course of draining a lake above the Cañón del Pato in an attempt to forestall similar destruction in the lower Santa Valley, the moraine broke prematurely. Hydroelectric installations downstream were damaged, and the access bridge to the power plant as well as railroad bridges below Huallanca were washed out.

There is no reason to suppose that aluviones occur more frequently now than in the earlier stages of ice recession, and it is probable that in the aggregate they have been important geologic agencies. Inasmuch as Flint (1947) does not mention this type of pro-glacial feature, it is either not too common or has not been recognized to any extent in North America or Europe.

GEOLOGIC HISTORY

The rocks of the Andean Cordillera include both marine and continental sedimentary rocks, and volcanic and intrusive rocks, of pre-Cambrian through Tertiary age, as well as local poorly indurated glacial, fluvial, and lacustrine deposits of the Pleistocene and of Recent age. In the Paleozoic and Mesozoic eras the site of the Peruvian Andes was occupied by a major geosyncline in which as much as an estimated 15,000 meters of sedimentary and volcanic rocks were deposited. During the first of two major orogenies, in Late Cretaceous and Early Tertiary time, the rocks were folded and to a lesser extent faulted, and marine deposition in the Andean area came to a close. Deposition of continental clastics and volcanics in intermontaine basins followed, and then in a second major orogeny, definitely during the Tertiary, the rocks were again uplifted and folded. Large batholiths were intruded, probably at or near the end of the second orogeny. Thereafter, many stocks and related bodies were emplaced, and abundant volcanic material was extruded. Volcanism continued into Recent time in parts of Peru. Epeirogenic movement later in the Tertiary again raised the Andean region several thousand meters and also caused block faulting and flexing of the rocks. The present physiography results from fluvial and glacial erosion of the uplifted Andean block during the Pleistocene and Recent epochs (Steinmann, 1930, p. 294–302; Harrison, 1943, p. 30–33; Yates and others, 1951, p. 5; and Jenks, 1951, p. 216–218).

Our studies can contribute little to the geologic history of Peru as given above. In the region under discussion in this report sedimentation took place from the Late Jurassic to the Albian stage in Middle Cretaceous time. During this interval seas occupied the region in the Portlandian stage of the Jurassic and during Early and Middle Cretaceous. Volcanism occurred during the late Neocomian, and some tabular bodies may have been intruded into rocks of comparable age before their folding. The absence of younger strata prevents close dating of the subsequent stages of diastrophism and large-scale igneous intrusion. Most Tertiary volcanic rocks probably were emplaced after major folding and subsequent planation and either before or during epeirogenic uplift. The region attained nearly its maximum elevation by Pleistocene time, but small vertical movements are continuing even to the present. Glaciation which began during the Pleistocene is continuing, although glaciers now are receding at a comparatively rapid rate.

Deposits of metallic sulfide minerals were formed at some time in the Tertiary after the igneous masses solidified and fractured. In the batholith underlying the Cordillera Blanca these deposits are younger than diabase dikes which intruded the hardened and fractured mass.

MINERAL DEPOSITS

LITHOLOGIC AND STRUCTURAL ENVIRONMENT

Metallic sulfide and associated gangue minerals were deposited in all types of rock. The size or number of deposits does not seem to be related to lithology of the wall rock, although deposits are not as common in argillaceous or partly argillaceous rock as in other rock types. Lithology therefore does not exert clear-cut control on mineral deposition. The absence of lithologic control perhaps is best illustrated in the Quebrada Honda-Vesuvio district where good ore bodies occur in igneous rocks and in metasedimentary quartzites and phyllites. Even where veins cross contacts, as at the Atlante mine, large ore bodies are apt to be found in rocks of both types. The comparatively small incidence of deposits in rocks either partly or entirely argillaceous in composition is attributed to their relatively low competence and, hence, low permeability.

Most deposits occupy fissures or faults which clearly were channelways for mineralizing solutions. These fractures were formed during different stages of the structural development of the region. The oldest planes of weakness originated along or nearly parallel to bedding planes during folding. Later some planes of weakness apparently formed at contacts during intrusion of igneous masses. During epeirogenic uplift of the Andean mass other faults and fissures were produced, not necessarily alined with older structures. It is reasonable to suppose that earlier bedding-plane and contact faults were reopened and made more permeable during this uplift. Movements along all these structures continued during the period of mineralization, as shown by brecciation of mineral masses, slickensiding of mineralized walls, and successive reopenings of fissures during deposition. All such movement, as well as nearly all occurring after mineralization, was along the plane of the veins. Only a few ore-bearing structures are cross faulted, and these are displaced only a few meters.

Ores were deposited by fissure-filling and by replacement. The two types are gradational to different degrees, but in most deposits one process has dominated over the other, and the deposits may be classified on the basis of mode of emplacement. The few contact deposits that are not associated with obvious fissure channelways logically form a subdivision of the replacement class.

The large replacement deposits of disseminated copper sulfide minerals in silicated limestone in the Quebrada Antamina are not included in this section of general description. These were studied only briefly, and therefore only a brief summary of their characteristics is given in the section on the Antamina area (p. 99–100).

FISSURE-FILLING DEPOSITS

Fissure-filling deposits consist for the most part of minerals deposited in open spaces in fault and shear zones.[5] With few exceptions the structures have limited horizontal and vertical extent and small displacement. Ores consist principally of sphalerite and argentiferous galena, with smaller amounts of copper sulfides. Ore minerals occur with gangue throughout the veins, but minable material in most deposits is confined to high-grade shoots of comparatively limited extent.

Fissure-filling deposits show crustified banding or layering of the minerals. In some deposits crustification is very faint, whereas in others it is so prominent that the material appears to be made up of distinct layers of individual minerals. Nearly all veins contain lenticular- to irregular-shaped cavities and pores, most of which are lined or filled with crystals. Some cavities are lined with the same minerals as in the adjacent vein, suggesting merely incomplete filling, whereas others are lined with different minerals, suggesting a second stage of mineralization. Most of the minerals are in medium to large, well-formed crystals.

Minerals that replace country rock along fissure veins are principally pyrite, quartz, and silicates. These occur as disseminated grains, irregular pods, or massive bodies and generally are confined to zones less than 1 meter to either side of the vein; along some veins replacement zones extend outward for several meters. Ore minerals deposited as replacement of wall rock may either be massive or be disseminated and tend to be restricted to narrow zones generally only a few centimeters thick around the ore bodies. Breccia and shear fragments in many ore bodies are partly replaced by vein minerals.

At most deposits only one fault or shear zone forms the locus of deposition, but branches or splits from the vein may also be mineralized. In the larger deposits, where several fault or shear zones carry ore, most veins are parallel or nearly parallel, but in some deposits veins intersect at fairly high angles. Most mineralized fault or shear zones are comparatively straight or slightly undulating, but a few are quite irregular. Dips of most are steep, but may change with depth. One vein at the Atlante mine dips as much as 65° in the upper part and

[5] Fault zones, as used in this report, clearly show displacement of the country rock or contain well-developed breccia, whereas shear zones show no obvious displacement and contain sheared wall rock with little or no breccia.

flattens to as little as 20° in the lowest part of the mine workings. Ore occurs predominantly in breccia, at intersections of branching fault or shear zones or shear planes within an individual vein, or at places where the vein changes in strike and dip.

The larger parts of most veins are from 0.5 to 1.0 meter wide, although in even comparatively small veins the maximum width may be greater over short segments of the mineralized structure. In horizontal and vertical dimensions one of the largest single veins in the region is the Animus in the Huamaná mine, exposed in mine workings 400 meters horizontally and 160 meters vertically (see pl. 8). Fault or shear zones are traceable for greater distances in both dimensions, but it is rare to find mineralization along the entire length of these larger structures.

Most silver is intimately mixed with galena, but some occurs as veinlets of proustite, and some is with copper minerals, principally tetrahedrite. The silver content of galena ore may be less than 100 grams and as much as 4 kilograms per ton. In every mine and prospect in this region the silver content of ore is of utmost importance to profitable operation, as lead, zinc, and copper veins low in silver commonly cannot be exploited. Sphalerite with uniformly low silver content is either left unmined or is discarded before shipment. Very few deposits contain enough copper to warrant mining for that metal alone.

Ore bodies have wide ranges both in tenor and in dimensions. Some of the highest grade ore bodies, containing 75 percent or more combined galena and sphalerite, were seen in the Huamaná mine and in several mines of the Antamina area. One sphalerite lens in the Huamaná mine was 20 meters long and as much as 40 centimeters thick, and galena lenses in the Antamina area were as much as 10 meters long and had a maximum width of 30 centimeters. Lower grade ore shoots are larger, not uncommonly 90 meters long and as much as a meter wide in the Huamaná and Atlante mines. The over-all grade of ore from all operating deposits is generally low and requires some form of concentration to obtain shipping-grade material.

REPLACEMENT DEPOSITS

Replacement deposits, in contrast to fissure-filling deposits, result from replacement of pre-existing rocks. However, most replacement deposits also contain vein minerals deposited in fractures, fissures, and cavities which served as channelways for mineralizing solutions. In the region herein discussed these deposits typically consist of disseminated grains or a granular mixture of sulfide minerals cut by veinlets, pods, and lenticular masses of more solid and crystalline vein material which was deposited in cavities. The deposits are restricted largely to limestone, but occur also in calcareous shales, either along fault or shear zones or along contacts with intrusive bodies. In a few contact deposits minerals replaced intrusive rock as well as sedimentary rock, but always to a lesser extent.

Replacement of limestone by sulfide minerals along steeply dipping fault or shear zones is common. Some of the zones are parallel to bedding planes, and others cut across bedding at an angle. The richest ore shoots occur where the country rock is most strongly brecciated and sheared. Apparently these areas were more permeable to mineralizing solutions. The association of breccia and ore is well shown at the Patria mine in the Pachapaqui district, where the highest grade ore and most complete replacement occur where the rock is most strongly brecciated. At the San Antonio prospect minerals replaced limestone along en echelon gash fractures of an extensive shear zone. Vein minerals also replace limestone along bedding planes at Patria and several other mines.

In contact zones, especially along granitic or rhyolitic intrusives, minerals replaced the country rock along fractures and bedding planes in the sedimentary rock, fractures in the intrusive rock, or along the contact. Whereas much of the contact zone may contain disseminated grains of minerals, most of the ore is concentrated in isolated lenticular or podlike bodies. Contacts between these bodies and the surrounding rock may be gradational, indicating incipient replacement, or may be comparatively sharp. Many of these ore bodies occur along some contacts, but all are small.

The principal ore minerals in order of their abundance are sphalerite or marmatite, galena, and chalcopyrite, and the principal gangue minerals are pyrite, quartz, calcite, rhodochrosite, and rhodonite. Some of the deposits also contain minor amounts of arsenopyrite, barite, fluorite, stibnite, and tetrahedrite. Two or three small bodies at the Susana mine contain magnetite and pyrrhotite. The silver content of most replacement deposits is lower than that of most fissure-filling deposits. However, small ore bodies of nearly solid galena at the Sirena Encantadora mine in the Huallanca district contain as much as 4 kilograms of silver per ton, the highest of any operating mine in the region.

As most of the ore minerals are intimately mixed with the wall rock, structures such as crustification or banding are faint or absent. Minerals tend to be fine grained and poorly crystallized, and vugs or cavities are rare. In a few deposits faint banding is discernible where replacement has taken place parallel to bedding or closely-spaced parallel shear planes. In each deposit the richer ore shoots tend to have a preponderance of one ore mineral which may be coarse grained but seldom has well-formed crystals.

Country rock in and near replacement deposits tends to be more intensely altered than along fissure-filling deposits. Sedimentary rocks generally are altered by introduction of quartz, garnet, epidote, and serpentine; intrusive rocks are altered by introduction of quartz and by conversion of feldspars to sericite clay, and by ferromagnesian minerals to chlorite. In many deposits it is evident that the alteration took place before deposition of the sulfide minerals. Alteration of wall rock will be discussed in more detail below.

Replacement deposits show great variation in size, ranging from small irregular bodies less than a meter long to large tabular bodies several kilometers long. The largest deposits in the region, at Patria, Esperanza, and Otito, are replacements of brecciated and sheared limestone on two limbs of a complex anticline. These are at least 4 kilometers long and range from 10 to 50 meters in width. Contact deposits may be several meters wide and several hundred meters long, but most of the sulfide minerals are in small bodies a few meters long and less than a meter wide.

MINERALOGY

Information on mineralogy is based on macroscopic field and laboratory study of hand specimens, supplemented by blowpipe determinations and microscopic study of thin and polished sections. The only minerals listed in this section are the sulfides and their alteration products, and gangue minerals.

Data on chemical composition and physical properties of the sulfide and oxide minerals were taken from Dana (1932 and 1944) and data on the other minerals from Winchell (1933).

PRIMARY MINERALS

Argentite, Ag_2S. Veinlets and disseminated grains of argentite were seen at two or three mines, and minute quantities of argentite may be associated with most of the argentiferous galena of the region. The argentite is fine grained, lead gray, and very sectile.

Arsenopyrite, FeAsS. Massive and crystalline arsenopyrite occurs in only a few of the deposits.

Barite, $BaSO_4$. White, crystalline barite occurs in small cavities or as veinlets in a few veins, associated with galena and sphalerite or as a webbing in limonite.

Bornite, Cu_5FeS_4. Small grains of bornite are associated with chalcopyrite in the large replacement body at Antamina. Dueñas (1904, p. 53) reported that he found this mineral at the Atlante mine.

Bournonite, $2PbS.Cu_2S.Sb_2S_3$. Dueñas (1904, p. 53) reported that bournonite occurred in the Atlante mine. Although we did not identify it in this mine or in other mines of southern Ancash, possibly it occurs in small amounts, associated with a few lead ores.

Calcite, $CaCO_3$, is one of the common gangue minerals. In a few veins it forms pyramidal (dog-tooth) white to transparent crystals, but in most veins it forms compact masses of white to gray rhombs showing only cleavage faces. Rhombs range in size from less than a millimeter to several centimeters in diameter. The most coarsely crystalline calcite is associated with low-grade fissure-filling deposits in limestone.

Chalcopyrite, $CuFeS_2$. Chalcopyrite is massive and occurs as small blebs disseminated in other vein minerals. Replacement deposits in the Antamina area contain disseminated grains of chalcopyrite in silicated limestone.

Dolomite, $CaCO_3.MgCo_3$. White crystalline dolomite occurs in small quantities in most of the veins in the Quebrada Honda-Vesuvio district, but is comparatively rare in the other districts.

Fluorite, CaF_2. Small amounts of white or purple fluorite are found in a few veins in the southern districts and in most veins in the Antamina area. It appears to fill cavities between earlier minerals.

Galena, PbS. Three distinct varieties of galena can be recognized: cubic, plumose or bladed, and very fine-grained or massive. Cubic galena, occurring in nearly all the veins, forms compact masses which show cleavage faces and crystal faces in pores or cavities. Mine owners report that this type of galena contains only a few grams of silver per ton. Plumose or bladed galena is less common. The blades are flattened and elongated cubes which retain cubic cleavage and are commonly oriented so that the long axis is parallel to the vein walls. This type of galena is reported to have a high silver content. Fine-grained galena, also high in silver, occurs in minor quantities in many of the veins.

Magnetite, $FeFe_2O_4$. A small body of fine-grained magnetite was found in one of the Susana veins of the Pacllón-Llamac district. It was not observed elsewhere.

Polybasite, $9Ag_2S.Sb_2S_3$ and Stephanite, $5Ag_2S.Sb_2S_3$, were reported by Dueñas (1904, p. 47) as occurring in the enrichment zones of veins at the Atlante mine in the Quebrada Honda-Vesuvio district. We did not see these minerals, but it is possible that they occur in ores of some veins.

Proustite, Ag_3AsS_3. Veinlets of the light-ruby silver mineral proustite were recognized in a few specimens on the dumps of one silver mine in the Huallanca district. The proustite is finely crystalline, soft, and vermilion in color.

Pyrargyrite, $3Ag_2S.Sb_2S_3$. The dark-ruby silver mineral pyrargyrite was seen at one mine in the Antamina district.

Pyrite, FeS_2. Pyrite is by far the most common sulfide mineral and ranks with quartz as a major gangue mineral. Pyrite ranges in texture from massive or finely crystalline to coarsely crystalline; in the crystalline variety cubes and pyritohedrons are as much as three centimeters in diameter. Striated cubes appear to be much more common than pyritohedrons. Practically all the veins and nearby wall rock contain disseminated pyrite. Most pyrite is hard and solid, but in a few replacement veins pyrite and wall rock form a granular mixture that is soft in the vein and disintegrates rapidly on the dump. This unstable variety probably is marcasite.

Pyrrhotite, $Fe_{1-x}S$ (where x varies from 0 to 0.2). Small quantities of pyrrhotite occur in a few veins of the Pacllón-Llamac district and at one mine in the Quebrada Honda area. It is fine grained, bronze yellow to brown gray, and moderately magnetic.

Realgar, AsS. Veinlets of realgar were observed only at the Danubio mine in the Pachapaqui district. The material is soft, bright red, and fills narrow fractures which cut through the other sulfide minerals.

Quartz, SiO_2. Quartz, the most common gangue mineral of the region, ranges in texture from massive to crystalline and is white to clear. White massive quartz is the predominant type. Crystals seldom exceed a centimeter in length.

Rhodochrosite, $MnCO_3$, and rhodonite, $(MN,CaFe)SiO_3$, are major gangue minerals in many replacement deposits and are so intimately mixed that they can be differentiated only by close examination; they also are found in some fissure veins. Rhodochrosite occurs in irregular grains 1 to 2 millimeters in diameter, whereas rhodonite is massive. Fresh surfaces of these minerals are rose red to yellowish gray but weather readily to black.

Siderite, $FeCO_3$, and ankerite, $2CaCO_3.MgCO_3.FeCO_3$. Gray to tan manganiferous carbonates occurring in a few veins were tentatively identified as siderite or ankerite.

Sphalerite, ZnS. Most sphalerite contains iron, and a more accurate chemical formula is (Zn,Fe)S. Ordinary sphalerite contains less than 10 percent iron and is white to light brown; marmatite, a variety, contains more than 10 percent iron; and christophite, another variety, contains the theoretical maximum of 26 percent iron (Dana, 1944, p. 212). In most veins of this region sphalerite is the most abundant ore mineral. Massive sphalerite veins are made up of irregular grains which show only cleavage faces, whereas in cavities and porous parts of fissure veins sphalerite grains exhibit well-developed crystal faces. Specimens of sphalerite from a few veins are triboluminescent, i. e., give off sparks when scratched with a harder material.

Much of the sphalerite is dark brown to black and probably is the variety marmatite. Chemical analysis of marmatite from the Susana mine of the Pacllón-Llamac mining district showed 13.65 percent iron.

Stibnite Sb_2S_3. Stibnite was found in one or two lead-zinc veins and in several quartz-calcite veins. It forms slender, striated, prismatic crystals either in radiating masses or in open meshworks.

Tetrahedrite, $(Cu,Fe)_{12}Sb_4S_{13}$, and tennantite, $(Cu,Fe)_{12}As_4S_{13}$. Small blebs and crystals of argentiferous tetrahedrite or tennantite occur in many veins of the region. The material is steel gray to black, very brittle, and hard. Massive tetrahedrite-tennantite ore is mined only from a fissure vein at the Carmen del Macizo mine in the Huallanca district.

SECONDARY MINERALS

Azurite, $Cu(OH)_2.2CuCO_3$, and malachite, $Cu(OH)_2.CuCO_3$. Crystals and crusts of malachite with minor amounts of azurite occur in cavities in the oxidized zones of copper-bearing veins. Crystals are few in number and are seldom more than 1 to 2 millimeters long. Malachite stain and thin crusts are common in many old drifts and pits. Water from a few adits has deposited malachite on outcrops and boulders of limestone.

Cerussite, $PbCO_3$. A few white prismatic crystals of cerussite 1 to 2 millimeters long were found in cavities in oxidized zones at the Huanzalá mine in the Huallanca district. Small cavities in many oxidized veins in the same area are coated with a white powdery material which may be in part cerussite. It is also probable that oxidized portions of many other deposits throughout the region contain minor quantities of lead carbonate.

Chalcanthite, $CuSO_4.5H_2O$. Protected walls of old surface pits and drifts in some places exhibit coatings several centimeters thick of bright-blue crystalline chalcanthite.

Chalcedony (chalcedonite) and opal, SiO_2 or $SiO_2.nH_2O$. A few veins contain small masses or coatings of white to tan, cryptocrystalline or non-crystalline SiO_2, which appear to have been deposited by surface water. This material is either chalcedony or opal.

Gypsum, $CaSO_4.2H_2O$. Crusts of prismatic to acicular white crystals of gypsum form on walls or floors of some old workings. Some gouge contains fine-grained gypsum, and a few iron oxide zones and gossans contain veinlets of the mineral. A soft, plastic white material which oozes from fractures in workings at the Cosmos mine in the Tuco-Chira district consists largely of fine-grained gypsum.

Epsomite, $MgSO_4.7H_2O$, and goslarite, $ZnSO_4.7H_2O$. Walls of many old mine workings have thin crusts or are coated with hairlike crystals of water-soluble, white epsomite and goslarite. Old workings of the Ispac mine in the Huallanca district contain stalactitic masses of these minerals.

Limonite—cryptocrystalline goethite—$Fe_2O_3.H_2O$, with adsorbed or capillary water; and hematite, Fe_2O_3. The iron oxides are the most abundant secondary minerals and can be seen in all the veins. They form gossans over many veins, especially those some distance from recently glaciated areas. In the field no attempt was made to distinguish between the iron oxide minerals. Although iron oxide in the gossans ranges in color from ocher yellow through red brown to black, the color of most is dark red brown. Limonite can be found as pseudomorphs after blebs or crystals of pyrite, sphalerite, or chalcopyrite; as crusts on walls of old workings; as thick and extensive gossans; as cementing material in fault breccia zones; and as cementing material in alluvium. Gossans are porous to massive, and in most only a part of the sulfide minerals has been altered to iron oxide. Well-developed boxwork structure is rare.

Smithsonite, $ZnCO_3$. Crusts as much as 2 millimeters thick of moderately fine-grained (1 to 3 millimeters) light-tan or cream-colored smithsonite coat crystal faces of sphalerite in vugs at the Humaná mine. Surfaces of sphalerite crystals under smithsonite crusts are corroded or etched. It is probable that smithsonite also occurs in small quantities in the oxidized parts of many veins, but it was not recognized in the field.

WALL ROCK ALTERATION

Alteration of wall rock along the veins is accomplished by heat and by the action of hydrothermal solutions and gases. Several processes may be involved in the ultimate alteration, but the most important probably are reaction between existing minerals to form new minerals and reaction between existing minerals and elements introduced by solutions or gases. Walls of most veins in limestone and calcareous shale have been silicified and those of some veins garnetized, serpentinized, or epidotized. Calcareous and shaly sandstones near a few veins have been similarly altered. In most places such alterations preceded sulfide mineralization, but during mineralization wall rock was further altered by the development of sericite and clay minerals.

During silicification of limestone, quartz replaced calcite along fractures and bedding planes and in scattered grains in the groundmass, forming a tough gray to light-gray rock. Microscopically, such rock consists of irregular to wispy veinlets or wormlike growths of quartz in a granular groundmass of quartz and calcite. Locally the calcite has been completely replaced. In some veins the wall rock was silicified during sulfide mineralization.

Garnetized limestone, most common in contact metamorphic zones, occurs along a few veins away from intrusive bodies. In thin section the garnet is colorless, pale yellow, pale yellow brown, or pale green; garnet crystals show four- to six-sided outlines and have anomalous extinction to first order white. Many crystals consist of irregular isotropic centers surrounded by twinned layers parallel to the crystal faces. Some crystals with six-sided outlines consist of wedge-shaped twins; each wedge has a crystal face as a base and apexes at the center of the crystal. Under crossed nicols, opposite wedges become extinct simultaneously. Some garnet crystals contain pyrite grains near their centers, or sericite and calcite grains between twin wedges or bands. Most of the garnet is probably the variety grossularite.

Silicified wall rock at many veins has a pale-green color, which may result from small amounts of associated epidote or serpentine. Limestone in the walls of a few veins was altered by the introduction of both epidote and garnet and at places contains irregular bodies or stringers of bright-green material, largely epidote. In thin section the epidotized limestone consists of irregular grains or bladelike crystals of epidote in a matrix of granular quartz and calcite. The most intense epidotization occurred in contact metamorphic zones.

Walls of nearly all veins contain veinlets and disseminated grains of pyrite, which fill fractures and cavities as well as replace the host rock. Pyrite ranges in texture from massive to crystalline; in crystalline form cubes are more common than pyritohedrons. Microscopically, pyrite appears to have replaced the wall rock along fractures and in isolated grains and patches away from fractures. In a few specimens pyrite appears to have replaced large calcite crystals along cleavage planes.

Sericitization, already mentioned in the discussion of igneous rocks, also has affected shaly limestones, shaly sandstones, and sandstones to a slight degree. In these rocks minerals along fractures and in the more dense groundmass have been altered to fine-grained sericite. Sericitization of intrusive bodies is most intense near sulfide deposits, and it is possible that this type of alteration was contemporaneous with sulfide mineralization.

Limestone of some contact deposits has been partly altered to wollastonite or has been bleached and recrystallized. Bladed white wollastonite, associated with other silicate minerals in a few deposits, occurs as scattered crystals or, more commonly, as radiating crystals in pods as much as 50 centimeters in diameter. The largest pods of pure wollastonite were seen at the Sirena Encantadora mine in the Huallanca district. Lenticular, tabular, or irregular bodies of recrystallized white limestone occurring near ore bodies of many contact deposits range in size from a few meters to nearly a kilometer in length and from a few centimeters to more than 10 meters in width. One of the largest bodies seen at the Susana mine in the Pacllón-Llamac district is nearly a kilometer long and ranges from 2 to 10 meters in width. This body is in a band of silicated limestone parallel to a rhyolite sill.

Some of the white and tan clays associated with many veins probably resulted from hydrothermal alteration of wall rock. J. M. Axel-

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rod of the Geological Survey carried out X-ray examination of clay-like material from 6 of the mines and determined that only 2 specimens contained the clay minerals kaolinite, halloysite, and—possibly—endellite. The other specimens consisted of one or more of the following minerals: mica (one unidentified form and another form similar to phlogopite), hydromica, quartz, and gypsum.

CLASSIFICATION AND GENESIS OF DEPOSITS

Most veins are porous, vuggy, and banded, and the minerals are well crystallized, indicating that deposition was fairly near the surface in an environment of medium to low pressures. The minerals in the deposits of this region are known to have a range of deposition which includes formation at medium and low temperatures, and some minerals in these deposits, such as the silver sulfides, are restricted entirely to formation at low temperatures. In view of these conditions the deposits are classified as ranging from mesothermal to epithermal, according to the classification of Lindgren (1933, p. 211). A few deposits contain pyrrhotite, a mineral commonly found in ore deposits believed to have formed at high temperatures. Inasmuch as these pyrrhotite-bearing veins also contain minerals deposited at lower temperatures and possess textures characteristic of deposition at low pressures, they probably are telescoped deposits, deposits in which geochemical environment during the period of mineralization changed rapidly owing to near-surface penetration of igneous source-rock.

Replacement deposits of the contact type contain silicate gangue minerals formed at high temperatures as well as sulfide minerals probably deposited at lower temperatures. On the basis of the sulfide minerals and structures of ore minerals (p. 51) these deposits are classed as mesothermal.

As the result of extensive studies, the geological staff of the Cerro de Pasco Corporation (1950) has concluded that all major lead-zinc-copper-silver deposits in central Peru were derived from hydrothermal solutions emanating from Tertiary intrusive stocks of intermediate composition. Although many deposits in central and southern Ancash are related spatially to intrusive bodies, at most places their genetic relationship is not obvious. Contact replacement deposits are probably closely related to the intrusions, but there is no positive evidence that other replacement deposits and fissure-filling deposits far from visible intrusive bodies were derived from igneous rocks.

ECONOMIC FACTORS AFFECTING MINERAL PRODUCTION

METHODS OF MINING AND CONCENTRATING ORE

All active operations visited in 1948 and 1949 were worked by hand. Ore was drilled by hand, blasted with small charges, and either backpacked or hand-trammed to the portal. Atlante was the only mine to have any power; a small dynamo run by mine water and glacial melt water generated enough current to operate a small inclined hoist and pumps.

All veins are worked either by open or by partly filled stopes; stoping is overhand from most drifts but also underhand from pits and some drifts. The larger mines, under supervision of engineers, are worked by moderately systematic mining methods and are adequately timbered and pillared. Smaller mines, worked by prospectors and miners, are less systematically developed. In such mines winzes may be cut across floors of drifts, stopes left in precarious condition, and waste dumped wherever convenient. A number of irregular veins and replacement deposits are opened through surface pits which are deepened and become complex as ore bodies are mined. The resulting underground workings are almost impossible to describe in conventional mining terms. These workings, as well as any below the lowest level opening directly to the surface, flood soon after operations cease, leaving no access to areas beyond flooded sections.

The only concentrating plants operated during 1948 and 1949 were at the Atlante mine, at Pompei just below the Huamaná mine, and at Pachapaqui; of these, Pompei closed in 1948. At the Pachapaqui plant ores are ground in a ball mill, and a bulk concentrate of lead, copper, and silver is produced in flotation cells; comparatively low-grade ores from two or three small mines furnished the mill feed in 1949. Both the Atlante and Pompei concentrators are small flotation plants concentrating lead, copper, and silver only. The Empresa Minera Vesuvio, operators of Atlante, were planning a larger concentrator to handle lower grade ore and fill from old stopes. The Empresa Minera Pompei handled ores from its own mine, Huamaná, and also custom-treated ores from other mines to the north.

At all other operating mines ore is broken on flat rocks with sledge hammers and fragments of sulfides are sorted out by hand. In 1948 and 1949 sphalerite was discarded with gangue. At most mines ore is further crushed and hand sorted to produce the final concentrate, but at a few after the second crushing it is hand-jigged to produce shipping-grade material. The concentrate, consisting of fragments 1 centimeter or less in diameter, is packed in burlap bags for shipment. Lead-silver concentrate is the main product, but copper-silver concentrate was being produced from one deposit in 1949, and several mines were producing lead-copper-silver concentrate. Antimony (stibnite) concentrate was produced at one mine and lead-antimony concentrate at another.

The only smelter in operation in the region is at the main camp of the Empresa Minera Vesuvio. It is a comparatively simple unit designed to produce lead-silver bullion. Coal and limestone are obtained from the surrounding area, and these, as well as lead concentrate, are stockpiled throughout the year for an annual charge. The only ore handled at the smelter is that from the Atlante mine.

At larger mines supervised by engineers most laborers work for wages which in 1949 were S/o. 5.00 ($0.28) or less per day.[6] Operations at most smaller mines and prospects are carried out by contract miners who do all work, development included, at a per-ton of production rate. Hand crushing and sorting generally is done by the families of these miners. In 1949 contracts were S/o. 150.00 ($8.32) and higher per ton of lead concentrate. It was not possible to gather precise data on costs, but it is estimated that mining and concentrating ore at the various deposits ranged from S/o. 100.00 ($5.55) to S/o. 400.00 ($22.22) per ton of concentrate in 1949.

TRANSPORTATION FACILITIES AND COSTS

All the mines use pack animals for transport of ore from mine to roadhead; ore is backpacked short distances to trails at a few deposits where terrain is exceptionally rugged. In the Tuco-Chira district concentrates are packed by burros and mules only 1 to 2 kilometers from the deposits to the road leading to Conococha; from all other districts concentrates are packed 15 to 60 kilometers. Roadheads are at Chancos for the Quebrada Honda-Vesuvio district, at San Marcos for the Antamina-Contonga district, and either at Conococha or Chiquián for the southern districts other than Tuco-Chira. From these points ore is trucked to ports (p. 13–14).

The cost of animal transport depends on the trail distance and the availability of animals. A fairly representative cost is that of the Sirena Encantadora mine in the Huallanca district. Sr. Arnulfo Carbajal, owner of the mine, stated that he contracted to have concentrates packed directly to Conococha, a trail distance of about 60 kilometers for S/o. 120.00 ($6.67) per ton. From Conococha to Lima the concentrates were trucked for the same price, so the total cost of shipping from the mine to Lima was S/o. 240.00 ($13.35) per ton. With transportation costs from the southern districts to Lima ranging from S/o. 200.00 to 300.00 per ton, and mining costs from S/o. 100.00 to 400.00 per ton, total cost of ore laid down in Lima may be between S/o. 300.00 and 700.00 per ton or between $17.00 to $39.00 per ton.

In 1948 transportation from the Quebrada Honda to Chancos cost S/o. 100.00 per ton and from Pompei or Vesuvio to the same roadhead from two to three times this amount. From Chancos most ore was shipped to Huarás by truck for about S/o. 15.00 per ton and sold there to ore buyers who assumed the cost of shipment to ports.

[6] Cost data in dollars are computed at the exchange rate of S/o.18.00 : $1.00.

PRODUCTION AND RESERVES

In 1948 at least 14 lead-zinc mines and prospects were being operated or explored in the two northern districts, and in 1949 11 deposits were producing lead and copper concentrates in the southern districts; in addition one mine in the Pacllón-Llamac district produced stibnite concentrates. The production figures listed below are based on information furnished by mine owners and operators or estimated by the writers. Miners and prospectors generally overestimated production and potential production.

The principal product of the region is silver-bearing lead concentrate, but some material contains a little copper as well. All producers try to ship concentrate containing 60 percent of lead, but this grade is not always attained. The concentrate varies considerably in silver content and may contain from less than 100 grams per ton to as much as 4 kilograms per ton. As a result profits may be as high as several hundred soles per ton, but on the other hand some material shipped may not pay mining and shipping costs. In 1948 and 1949 sphalerite with low silver content was discarded because prices offered did not pay shipping costs.

The one active mine in the Pacllón-Llamac district produced about 5 tons of stibnite concentrate in 1949, and one mine in the Huallanca district produced a few tons of stibnite as well as galena. The total stibnite production was probably less than 10 tons for the year. Several mines near San Marcos on the east side of the Cordillera Blanca also produced stibnite concentrates, but these mines were not seen during our investigation.

Production of lead-silver and lead-copper-silver concentrates, central and southern Cordillera Blanca, and northern Cordillera Huayhuash, Departamento de Ancash and Departamento de Huánuco

District	Number of active mines [1]	Estimated production of concentrates (in tons)
Quebrada Honda-Vesuvio	6	400
Antamina-Contonga	7	400
Huallanca [2]	4	90
Pachapaqui	5	100
Tuco-Chira	2	35
		1, 025

[1] Quebrada Honda-Vesuvio and Antamina-Contonga, 1948; Huallanca, Pachapaqui, and Tuco-Chira, 1949.
[2] Includes one mine producing both galena and stibnite concentrates and another producing copper-silver concentrates.

The available data on reserves and grade of ore are so scanty that we cannot estimate closely the ore reserves of the region. Most of the veins are small, and possible reserves range from a few tons to a few hundred tons. A few veins of intermediate size have possible reserves of a few thousand to a few tens of thousands of tons. The largest mineralized zones of the region, in the Pachapaqui district, have possible reserves of several million tons. Many of the small veins and a few of the intermediate ones can be worked profitably by small scale hand mining, but most are too small to support mechanized operations. The largest deposits of the region are low in grade and under present conditions of poor transportation cannot be worked at a profit.

FUTURE POSSIBILITIES AND RECOMMENDATIONS

The present rate of mineral production probably can be maintained for several years. The 1950 price of base metals and concentration facilities at Pachapaqui should bring about a material increase of production in that district.

No great increase in mineral production is possible until adequate roads are available. The road from Chiquián to Huallanca could be constructed at a comparatively low cost. The cheapest and most logical route for this road would be along the Río Chiquián, through Pachapaqui, up Quebrada Tunacancha, across the north end of the Cordillera Huayhuash, and then down the Río Torres to Huallanca. This route offers the least amount of rock work and an easier grade than other routes under consideration, including those through Paso Burro between Huallanca and Pachapaqui or through Paso Cuaush between Huallanca and Quebrada Llamac. Road transportation in the Pachapaqui and Huallanca mining districts should stimulate mineral production, and the added tax revenue from this source would probably pay for the road in comparatively few years.

Additional roads are not necessary in the Tuco-Chira district. The reserves of this district are small, and although small scale mining may continue for several years, any great increase in production is doubtful. The main veins of the Pacllón-Llamac district have fairly large tonnages of marmatite but are low in sulfides of lead, copper, and silver. A careful study of the milling qualities of the marmatite should be made before constructing roads and opening mines, principally because the comparatively long access road will require a major investment.

At both northern districts spur roads built part way to the mining districts would greatly reduce the cost of transporting ore. A comparatively inexpensive road from the hotel at Chancos up the Quebrada Honda to the fork in the trail just below the Viñoyapampa, a distance of about 20 kilometers, would reduce the haul by 2 days per round trip and save about 50 soles per ton of ore. Extensions of the road to the upper Quebrada Honda and across the pass to the Vesuvio area would be expensive and unwarranted in view of reserves in sight at the time of our examination. A similar spur road from San Marcos leading eastward up the Quebrada Yaquish, a distance of about 6 or 7 kilometers, would save 1 day per round trip for pack animals carrying ore from Quebrada Antamina.

Production of lead ore from the Antamina area would be greatly stimulated by the construction of a small mill.

DESCRIPTION OF DISTRICTS AND DEPOSITS

The names of mining districts used in this report are those in local usage, and names of individual mines were furnished by mine owners and guides. These do not necessarily correspond to the listing in the Padrón General de Minas (issued biannually), the official roster of the Dirección de Minas of mining concessions on which taxes have been paid. The district names used in this report and the official designations (Padrón General de Minas, 1949) are:

Quebrada Honda-Vesuvio	Huari
Antamina-Contonga	Huari
Huallanca	Huallanca
Pachapaqui	Bolognesi
Pacllón-Llamac	Bolognesi
Tuco-Chira	(Not listed)

Less than 50 percent of the mines and prospects herein discussed are listed in the Padrón General de Minas (second half, 1949), and no deposits of the Tuco-Chira district are included. The discrepancies are due to lapsing of ownership of old concessions, lag in entering new registrations, and differences between local and registered names. Owing to the last, some concessions listed in the Padrón may correspond to concessions on deposits visited in our investigations, but locations as given in the Padrón are so brief that it was not possible to correlate these with deposits we saw in the field.

In terms of mining activity in the present century, the two most important districts are Quebrada Honda-Vesuvio (Vesuvio area) and Huallanca. Several good-sized fissure-filling deposits have been the mainstays of production in each, but these mines now have comparatively small reserves. Nevertheless, the presence of steadily producing mines has been a great stimulant to prospecting and exploration in these districts, and sufficient ore is in sight to indicate that production will continue on the present scale for several years to come. Of the remaining districts, the Pacllón-Llamac contains large reserves of low-grade zinc ores; two low-grade veins in the Pachapaqui district are the largest in central and southern Ancash, and the Antamina-Contonga district includes a number of good fissure-filling deposits which have been comparatively little mined as well as large reserves of copper ores. With improved transportation these three districts would be the main source of future larger scale production.

QUEBRADA HONDA-VESUVIO MINING DISTRICT

The Quebrada Honda-Vesuvio mining district is near the crest of the Cordillera Blanca and from 16 to 25 kilometers east and northeast of Chancos, in a belt about 25 kilometers long and roughly parallel to the trend of the Cordillera. The southern deposits are in the upper end of the Quebrada Honda, a valley extending eastward from the valley of the Río Santa, and in tributary valleys of the quebrada. The upper Quebrada Honda locally is known as the Quebrada Pomabamba, and its flat floor is named the Viñoyapampa. Those tributary valleys containing mineral deposits are Quebrada Cancahua and Quebrada Pacllash, both south of the main valley. The northern deposits are at the heads of valleys draining eastward into the Río Marañon. The southern deposits of the northern group are at the head on the west side of Quebrada Checchipampa. This valley joins Quebrada Huichjanca at Vesuvio and drains northeastward through Pompei. Several veins in Quebrada Huichjanca have been worked in past years. The northern deposits of the group are north of Pompei in the Quebrada Apash (figs. 2 and 8).

The only means of access to the district is a trail extending from Chancos to Huari. From Chancos the trail ascends the Quebrada Honda for a distance of about 20 kilometers, crosses the north wall of the valley (about 10 kilometers), and descends Quebrada Illauro northward to Chacas, an additional 15 kilometers. From Chacas it continues via a number of valleys to Huari, 29 kilometers airline distance to the southeast. Spurs leading to deposits branch from the main trail. One spur branches from the main trail about 20 kilometers beyond Chancos and continues up the Quebrada Honda about 8 kilometers. Another branches about 5 kilometers southwest of Chacas and extends about 5 kilometers westward to Pompei.

Trails connect Pompei with Vesuvio and nearby mines. All mineral products from the district move to Chancos and Marcará; none are shipped via Huari. The high point of the trail system is the pass between the Quebrada Honda and Quebrada Illauro, at an altitude of 4,822 meters.

The physiography of the district displays the results of strong glaciation; most valleys are U-shaped, with flat floors and steep walls, and most ridges and peaks are cut into arêtes and horns (p. 40–41 and figs. 15–21). The floors of quebradas are easily passable except where glaciers quarried bedrock or deposited heavy end moraines. Where trails ascend valley walls, however, gradients are steep and travel is difficult. Ice caps mantle all peaks above 5,000 meters, and valley glaciers occupy the upper parts of most quebradas. Ice lies above most mines in the Quebrada Honda and above the Atlante mine.

Floors of quebradas have a moderately good cover of pasture grasses, and in places quinual trees form comparatively thick growths on floors and walls of valleys. The quinuales in the northern area are sufficiently abundant to provide adequate mine timber. Vegetation is sparse along most valley walls and virtually absent just below ice sheets.

The major rock units in the district are the granodiorite batholith and stocks and the Jurassic(?) metasedimentary rocks. Associated with the granodiorite are local masses of diorite and dikes of pegmatite, aplite, and diabase (p. 28–30). The sequence of metasedimentary rocks consists mainly of dark-colored quartzites, shales, and phyllites, but also includes zoisite- and andalusite-bearing hornfels (p. 18–20, 39). Lower Neocomian sandstone was seen in Quebrada Illauro but is not exposed in the mine areas.

The outcrop of the batholith is from 10 to 14 kilometers wide; its west contact follows the steep west front of the Cordillera Blanca. From south to north, the east contact runs from just west of the Esparta mine in Quebrada Cancahua to the Atlante mine and then swings west past the Huamaná mine. At most places the contacts are vertical or dip steeply. The stock in the upper Quebrada Honda, as much as 5 kilometers in diameter, lies 1.5 kilometers east of the batholith in Quebrada Cancahua. Its contacts dip 45° N. in the vicinity of the Soledad mine and 65° E. at the Santa Bárbara prospect. A smaller stock southeast of Pompei occupies part of the north end of the ridge between Quebrada Illauro and Huachacpampa (fig. 8).

The metasedimentary rocks are closely folded; axial planes of major folds strike northwest, and beds dip vertically or steeply to the east or west. Along the north and northeast wall of the upper Quebrada Honda, an anticline broken along its axis is seen in the vicinity of the Rataquenua prospect. Immediately to the northeast is a strong syncline. At the Condor mine near the head of the quebrada, beds are uniformly steeply dipping and may be isoclinally folded. At the Huamaná mine beds strike east and dip north from low to high angles, a marked divergence from the regional structure elsewhere in the district.

The deposits of the district are near the contacts of the batholith or stocks and the surrounding metasediments and occur in both rock types. Minerals were deposited as fissure-fillings and to a minor extent as replacements along small faults or shear zones. In the upper Quebrada Honda area, deposits in metasedimentary rock are in fault or shear zones which parallel or almost parallel bedding planes; deposits to the north tend to cut across bedding planes. The attitudes of fault or shear zones in igneous rocks are not conspicuously related to regional structure.

Most minerals in the veins are primary, but several secondary and oxidized minerals are common. Primary metallic minerals found in this district are galena, sphalerite, chalcopyrite, tetrahedrite-tennantite, stibnite, bornite, bournonite, silver sulfides, polybasite, stephanite, gold, pyrite, pyrrhotite, and arsenopyrite. Of these, galena, sphalerite, and pyrite are present in largest quantities and arsenopyrite occurs in many veins. Minor quantities of copper minerals occur in most deposits. Silver is in galena and in copper minerals and also was found as polybasite and stephanite in the upper parts of the veins of the Atlante mine (Dueñas, 1904, p. 47). Pyrrhotite was seen only at the Tomelamano mine and stibnite only at Huamaná. Gold occurs in minor amounts (a few grams per ton) in a number of deposits but never is megascopically visible. Dueñas (1904, p. 53) stated that bornite and bournonite also were found at Atlante.

Nonmetallic primary minerals include quartz, dolomite, rhodochrosite, siderite or ankerite, and—rarely—calcite. Alteration of silicates of wall rock produces sericite, chlorite, and minerals of the clay group. Secondary and oxidized minerals are silver sulfides, limonite, malachite, manganese oxides, smithsonite, anglesite, and cerussite. Limonite is the most common, found along outcrops and in the upper parts of all veins, and malachite and manganese oxide stains do extend deeper in most mines. Smithsonite coats sphalerite only at Huamaná, and anglesite and cerussite are reported to have been common in the upper parts of the veins at the Atlante mine (Dueñas, 1904, p. 47).

Ore shoots in this district, consisting of galena and silver sulfides, may be as short as a few meters and as long as 90 meters. Where silver content is high, as little as 10 centimeters width of galena is stoped. Such minable shoots, lenticular, tabular, or irregular in shape, are found sporadically along veins that for the most part contain insufficient amounts of recoverable sulfides or are barren. In well-exposed veins it can be seen that location of shoots is related to configurations of vein structure.

Some deposits in the Vesuvio area were prospected or mined on a small scale by the Spanish during the Colonial period and in the early 19th century, according to Dueñas (1904, p. 13, 46, 65, 71), but between 1860 and 1885 only mines farther north, in the vicinity of Cajavilca and San Luiz, were operated. The Sextri deposit was discovered in 1885, and the company now known as Empresa Minera Vesuvio built concentrating units and the smelter at Vesuvio for treating ore from the mine. Operations were financially unstable until the Atlante vein was discovered in 1895; this area had no signs of previous prospecting. Laurión, mined before on a small scale, was rediscovered by the company before 1900. The lead-silver ore at Sextri was mined out by 1904, but the Atlante and Laurión mines have been producing with moderate regularity since their development. Only small amounts of high-grade lead-silver ore remain in the deposits of the two mines, but they still contain moderate amounts of low- and medium-grade ore. To recover material with lower tenor, concentrating units are necessary at both deposits.

Huamaná, worked in some earlier period and then forgotten, was rediscovered between 1895 and 1900, and as a result the Empresa Minera Pompei was formed. Shortly after, this company built a lixivation plant which more recently has been converted to a flotation plant. Huamaná produced with moderate regularity until 1948 but ceased operations in that year owing to depletion of high-grade lead-silver ore. This area, Sextri, Atlante, and Laurión have moderate to substantial reserves of sphalerite, and mining for zinc ore could be started should transportation costs be reduced or the price of zinc increased.

Discovery of the deposits in the upper Quebrada Honda area came much later, and the only date we have is that of the opening of the Tomelamano deposit in 1928. Tomelamano, Condor, Chaco, and Esparta are the only mines shown on the Kinzl map of the Cordillera Blanca, published in 1939 (Kinzl, 1939a). Apparently most other known deposits were found after that date. From what we could see in 1948, lead-silver ore in developed parts of Condor, Esparta, Anna, and Chaco mines had been worked out. The Santa Bárbara, Rataquenua, and Damelamano, as well as the prospects in Quebrada Pacllash, are small and seem to offer little promise for development. The Tomelamano and possibly the Arequipa mines are the only ones having lead-silver ore reserves; and Soledad, just being opened at the time of our examination, may develop some workable shoots. As in the northern part of the district, moderate amounts of sphalerite occur in workings and on dumps in both active and inactive mines.

In summary, the mines in the Quebrada Honda-Vesuvio district having promise of continued production of lead-silver ore are:

Tomelamano—Small high-grade reserve
Atlante—Substantial medium- to low-grade reserve
Huamaná—Small medium- to low-grade reserve
Laurión—Moderate medium- to low-grade reserve

Locations of deposits in the upper Quebrada Honda are referred to the falls at the foot of the Viñoyapampa, and locations of deposits in Quebrada Cancahua are referred to the stream flowing along the Viñoyapampa. Trails leading to the deposits are clearly visible from the Viñoyapampa; travel time from the falls to any of the mines and prospects is from 1 to 2½ hours. Altitudes of the Rataquenua, Tomelamano, Damelamano, Chaco, Arequipa, and Soledad deposits were established by plane table triangulation and are correct to within 20 meters relative to each other; the datum is interpolated from the map of the Cordillera Blanca by Kinzl (1939a). Altitudes of the remaining deposits visited in the upper Quebrada Honda area were obtained by aneroid and can be considered correct only to the nearest

150 meters. Altitudes at the Atlante mine are based on an assumed elevation of 4,600 meters at the portal of level 3, interpolated from the map of the Cordillera Blanca by Kinzl (1939a). The altitudes at the Huamaná mine are from a company map, but these seem to be about 200 meters too high when compared to altitudes of the area shown on the map of Kinzl. Altitudes at the Sextri mine are aneroid readings, using the elevations of the company survey at Huamaná as a datum. Altitudes at Laurión were taken from company maps and seem to be about 100 meters too low as compared with the map of the Cordillera Blanca by Borchers (1935a).

RATAQUENUA PROSPECT

The Rataquenua prospect is on the north side of the upper Quebrada Honda 2.25 kilometers northeast of the falls at the foot of Viñoyapampa, in outcrops between scree and lateral moraine below and ice above. The camp near the prospect is at an altitude of 4,490 meters.

The country rock is granodiorite and diorite in contact with Jurassic(?) quartzite. Contacts of diorite both with granodiorite and quartzite are exceedingly irregular. The quartzite forms the west limb of a closely folded anticline broken by faults along its axial plane.

Fissures and narrow shear zones contain small amounts of galena and sphalerite together with pyrite, arsenopyrite, quartz, and kaolin, as well as limonite and hematite. Small pits and short tunnels expose the veins over an area about 200 meters long which has a vertical extent of about 100 meters; the uppermost prospect is just below glacial ice.

The lowest vein, in granodiorite, strikes N. 2° W. and dips 45° W. It is traceable 20 meters and is from 15- to 20-centimeters wide. Sphalerite stringers as much as 5 centimeters in width contain veinlets of galena several millimeters wide. The middle vein, a vertical distance of 25 meters above the lower vein, is also in granodiorite and is traceable for 40 meters. It strikes N. 45° W. and dips from 35° SW. to horizontal. This vein consists of iron-stained gouge and contains a few veinlets of galena and sphalerite. The upper prospect, in quartzite north of the stock, exposes a 20-centimeter wide shear zone striking N. 45° W. and dipping 25° SW. Gouge and clay, stained by iron oxide, contain veinlets and short lenses of galena, sphalerite, and arsenopyrite as much as 5 centimeters wide.

Other than material removed during prospecting, no ore has been mined and reserves are small, so it is doubtful that the prospect can be developed from the present showings.

TOMELAMANO MINE

The Tomelamano mine, on the north side of the upper Quebrada Honda, is in a small valley cut in quartzite and underlying granodiorite. The outcrops form a comparatively narrow band along the valley wall between scree and morainal material below and ice above. The main adit is at an altitude of 4,480 meters, about 300 meters above the floor of the valley and 4 kilometers east of the falls at the lower end of the Viñoyapampa.

The country rock is dark-gray massive-bedded quartzite on the west limb of a closely folded syncline. The contact between quartzite and the granodiorite stock is from 30 to 40 meters vertically below the main adit. West of the main adit the quartzite strikes N. 5° W. and dips 55° E., but within the mine workings the strike is more westerly. The rock has been bleached along parts of the veins.

The main vein, followed by a drift on the main level for about 175 meters, lies in a bedding-plane fault zone striking N. 25° W. at the south and N. 45° W. at the north end of the workings; the vein dips from 50° NE. to vertical (fig. 22). Vein walls are slickensided.

The vein contains argentiferous galena, sphalerite, pyrrhotite, pyrite, arsenopyrite, and quartz which were deposited for the most part as fissure-fillings. In places the vein is banded and contains numerous vugs. Part of the pyrrhotite is replaced with galena and sphalerite. Graphite, apparently derived from carbonaceous material in quartzite, occurs at places, and miners stated that chalcopyrite occurs in small quantities.

Most galena consists of grains from 1 to 2 millimeters in diameter; along openings grains may be as much as 5 millimeters in diameter. The richest ore evidently contains less than 20 percent of galena. Miners stated that silver in the concentrates was as much as 180 ounces per ton. Ore shoots and minable pockets are comparatively small, ranging from 5 to 15 meters in length, as judged by sizes of stopes, and from several centimeters to 2 meters in width. Most ore bodies occur at intersections of shear planes or at places where the vein changes in dip or strike.

The main ore body, located where the adit intersects the vein, has been stoped to the surface some 20 meters above as well as below the floor of the drift. In 1948 the northwest heading on the main level was being advanced, but no ore had been encountered, and a crosscut 35 meters below had not yet reached the vein.

Four shear zones are cut by the crosscut on the main level but contain only quartz and minor amounts of sulfides. About 200 meters northwest of the main adit another shear zone exposed in a trench and a crosscut contains only small amounts of sulfides.

Reserves in sight will enable the mine to operate several years at the present rate of production, but it is doubted that further exploration will reveal larger ore bodies.

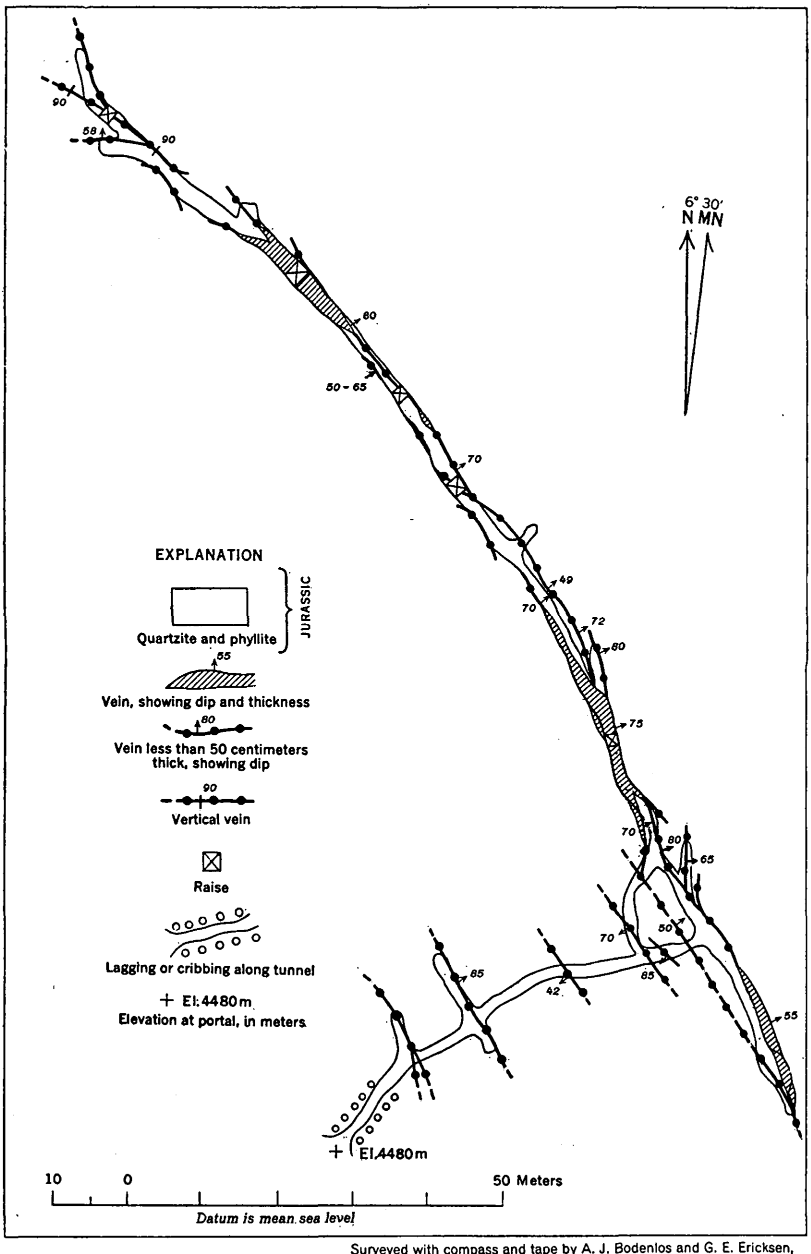


FIGURE 22.—Geologic map of the main adit of Tomelamano mine, Quebrada Honda-Vesuvio mining district.

SANTA BÁRBARA PROSPECT

The Santa Bárbara prospect is at the base of steep cliffs on a spur in the northeast wall and near the head of Quebrada Honda, just south of the tributary valley Quebrada Yanatsilca. It is about 6 kilometers airline distance from the falls and about 2.5 kilometers southeast of the Tomelamano mine. The altitude of the lowest workings is 4,500 meters (barometric).

The country rock is quartzite and phyllite, striking N. 20°–30° W. and dipping steeply northeast, on the west limb of the same syncline exposed at the Tomelamano mine. The quartzite is dark gray to white, and interbedded phyllite is gray. The contact with granodiorite is about 50 meters west of the mine.

The prospect is on a vein traceable for 110 meters and from 0.4 to 1.0 meters wide. Shear-plane walls are continuous, and movement along them is indicated by gouge and breccia in the vein. The vein strikes a few degrees west of north and dips 70°–80° W. in most underground workings but dips 85° E. near the portal of the north drift.

Minerals, in order of deposition, are quartz, pyrite, carbonate (ankerite?), and galena. Galena, occurring only in breccia cavities, is in crystals as much as 2 centimeters in diameter.

The north drift is 30 meters long with a winze at its heading. The south drift, although partly inaccessible, is at least 20 meters long. From what could be seen in accessible workings, a few small ore bodies were mined before the prospect was abandoned. There is little hope of finding additional ore.

CONDOR MINE

The Condor mine, also known as the Cahuide mine, is in the steep north face of a shoulder east of the glacial lake at the head of Quebrada Honda and above a tributary glacier flowing southwest from Nevado Copap. The country rock is quartzite and phyllite striking N. 5° W. and dipping from 80° NE. to vertically. Several veins appear to occupy bedding plane faults. The trail to the mine is washed out, and the workings are inaccessible, so we were unable to examine the veins.

PROSPECTS IN QUEBRADA PACLLASH

Three prospects occur in Quebrada Pacllash, a tributary valley which trends southeast from near the head of Quebrada Honda. The prospects are Cusca, Ollanta, and Estrella de Oriente. Local miners reported that the Ollanta vein was explored by a 10-meter drift, the Estrella de Oriente vein was trenched, and the Cusca vein was covered by an ice fall. Another small prospect, Recompensa, is on the shoulder overlooking the upper Quebrada Honda between Quebradas Pacllash and Cancahua. These prospects had been abandoned prior to 1948 and were not visited in the course of our examination.

DAMELAMANO PROSPECT

The Damelamano prospect is on the south side of the Viñoyapampa, 3 kilometers southeast of the falls and at the foot of a steep cliff between Quebradas Pacllash and Cancahua. The lower tunnel, 4.5 meters long, is about 10 meters above the pampa at an altitude of 4,150 meters; the upper tunnel, about 10 meters long, is 45 meters S. 20° E. of the lower. The vertical difference between the two is 7 meters.

The two workings follow a low-dipping shear zone in granodiorite. In the lower tunnel the zone strikes N. 20° E. and dips 15° NW. In the upper tunnel it strikes N. 5° E. and dips 25° W. It ranges from 30 to 40 centimeters in thickness and consists largely of iron-stained gouge and altered granodiorite. In the upper tunnel the zone contains veinlets and disseminated grains of galena, sphalerite, pyrite, arsenopyrite, and quartz.

The vein is essentially barren, and it is doubtful that further prospecting is merited.

CHACO MINE

The Chaco mine, on the east wall of Quebrada Cancahua, is 1.5 kilometers south of the stream flowing along the Viñoyapampa. Workings on the principal vein are between the altitudes of 4,755 and 4,775 meters. A trail from the floor of the quebrada extends to both this and the neighboring Arequipa mine.

Granodiorite, the country rock, is cut by steeply dipping diabase dikes striking N. 25°–65° E. The principal vein, striking N. 25° E. and dipping steeply, is at least 50 meters long. It has been explored and mined in two short adits. All ore has been removed from the lowest level to the surface, a maximum vertical extent of about 20 meters. Two smaller veins carrying mostly quartz and pyrite are in parallel diabase dikes east of the principal vein. These were explored by three short adits.

As far as could be ascertained from pillars and from rock on dumps, the minerals in the Chaco vein are galena, sphalerite, dolomite, pyrite, and quartz; local miners reported that the veins also contained copper sulfides. Little could be determined of the nature of ore shoots or their dimensions, but one pillar shows a width of 30 centimeters of galena and sphalerite. The mine was closed at the time of our examination in 1948, but it is possible that ore shoots could be found at depth.

A number of other veins, essentially barren of sulfide minerals, have been prospected in the area between Chaco and the Arequipa mine.

Most of these have the same general orientation, striking a few degrees either east or west of north and dipping steeply.

AREQUIPA MINE

The Arequipa mine is in the southeast wall of Quebrada Cancahua 2 kilometers south of the main stream at the Viñoyapampa and 800 meters southwest of the Chaco mine. The lower level of the workings is at an altitude of 4,720 meters. The vein crops out between morainal material below and a glacier above. The country rock is granodiorite cut by diabase dikes below the mine.

The principal vein can be traced for more than 190 meters horizontally and 115 meters vertically. It is slightly sinuous, with an over-all strike of N. 27° W. and with dips ranging from 85° SW. to vertical to 85° NE. Shear planes along which the minerals were deposited are comparatively straight, branch or feather in places, and are slickensided, with striations plunging from 55° to 75° NW. Movement along the shear planes evidently was small but caused some brecciation of the rock (pl. 3 and fig. 23). The granodiorite is altered along this vein as well as along shear zones to the west.

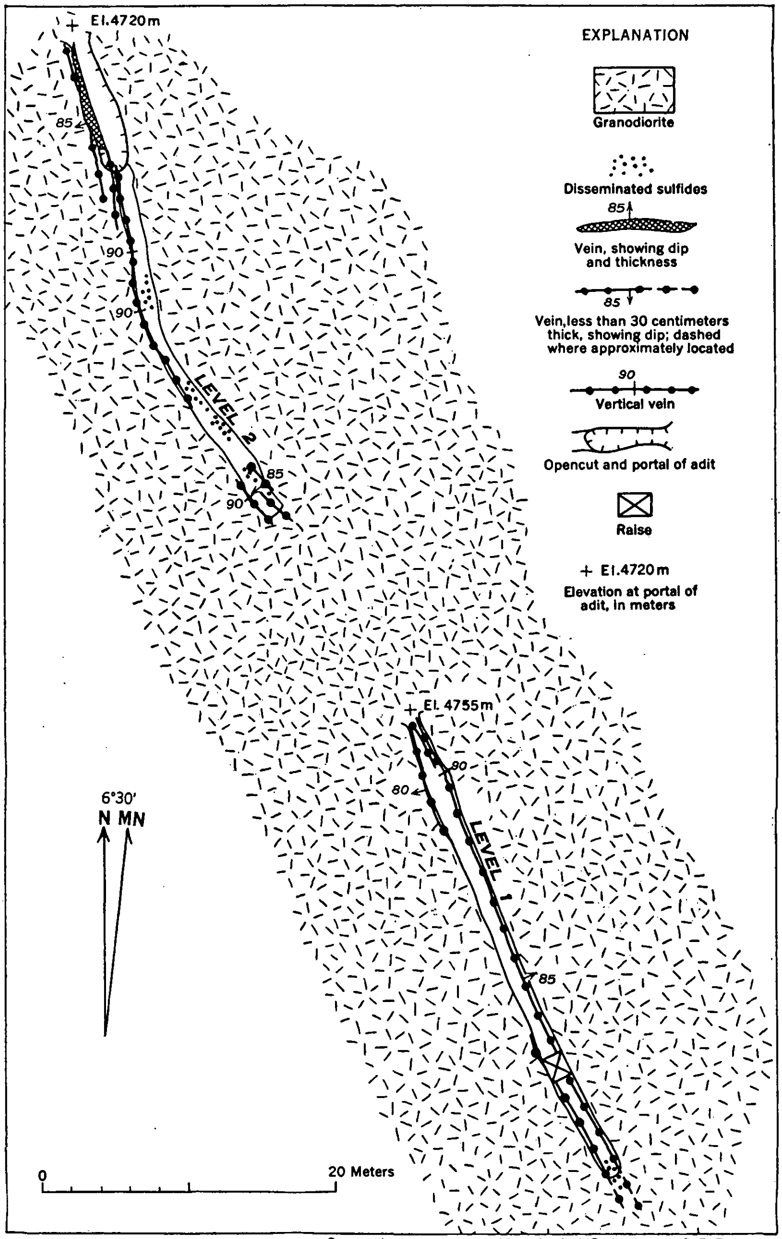
Minerals consist of quartz, pyrite, arsenopyrite, chalcopyrite, galena, sphalerite, and dolomite. Chalcopyrite and galena occur as coarse-grained crystals or blebs as much as 2 centimeters in diameter and as veinlets up to 1 centimeter wide and 10 centimeters long. Sphalerite at places forms stringers as much as 20 centimeters thick and several meters long.

Little ore was seen at the time of our examination, as the surface stopes had been mined out, and the upper and lower drifts apparently had not been advanced to the main ore body. In 1948 ore was mined from a vein 10 to 20 centimeters wide, of which at least 50 percent was gangue.

The main surface stope is about 70 meters long and was mined for a vertical extent of more than 20 meters. The upper drift (level 1) was being cut about 10 meters below the floor of the stope. In 1948 ore was not exposed in this drift, although the face was at least 20 meters beyond the front of the stope above.

A smaller surface stope, from which a lens possibly 15 meters long and 10 meters high had been mined, is below and north of the main ore body. Level 2, a drift below, exposed only minor amounts of ore. One short tunnel is said to have been driven on the camp level, about 10 meters below level 2, but dump material from the latter conceals its location.

Further exploration may expose additional ore at depth. Advancement of the upper level was the best possibility of finding ore in 1948:



Surveyed with compass and tape by A. J. Bodenlos and G. E. Ericksen, August 1948

FIGURE 23.—Composite geologic map of levels 1 and 2, Arequipa mine, Quebrada Honda-Vesuvio mining district.

if a moderate quantity was thus developed, driving on level 2 certainly is warranted.

SOLEDAD MINE AND CARMEN DEL PELARTE PROSPECT

The Soledad mine and Carmen del Pelarte prospect are on the east side of the glacier-capped mountain, Tocllaraju, which here forms the south wall of the upper Quebrada Cancahua. The deposits are from 2.5 to 2.75 kilometers south of the stream in Viñoyapampa and about 850 meters southwest of Arequipa mine. The lowest workings of the Soledad mine are at an altitude of 4,830 meters, and those at Carmen del Pelarte are at 4,785 meters. Carmen del Pelarte is about 300 meters N. 25° W. of the Soledad mine. The area is nearly surrounded by ice, and a major glacier terminates at ledges above the Soledad mine, making working conditions unsafe owing to constant ice falls. A stagnant glacier in Quebrada Cancahua is nearly directly below Carmen del Pelarte. The area is accessible by a poorly defined trail, passable only on foot.

Metasedimentary rocks form the host for the veins. At the Carmen del Pelarte prospect they strike N. 10° W., and dip 70° NE., and about 100 meters to the north they are in irregular contact with granodiorite.

A mineralized shear zone at the Soledad mine, striking N. 25° W. and dipping 80° NE., is from 15 to 70 centimeters wide and has an outcrop length of about 100 meters. Near its north end the zone splits, forming an eastern branch striking N. 25° W. and dipping 55° SW. and a western branch striking N. 35° W. and dipping 75° NE. The zone consists principally of bleached metasedimentary rock and quartz, with lesser amounts of argentiferous galena, sphalerite, chalcopyrite, pyrite, and arsenopyrite. At places it contains stringers as much as 15 centimeters wide of nearly solid galena with minor amounts of chalcopyrite and sphalerite. At the north end the eastern split is 50 centimeters wide and contains a stringer 12 centimeters wide of galena and sphalerite. The western branch is 70 centimeters wide and contains veinlets of galena.

The lower prospect pits at Carmen del Pelarte are in a 50-centimeter wide shear zone traceable only 10 meters. The zone strikes N. 25° W. and dips 75° SW. and contains short stringers of galena as much as 10 centimeters wide. The upper prospect, about 15 meters to the southeast and 20 meters higher, exposes a comparable zone which strikes N. 30° W. and dips vertically.

The owners stated that the concentrates from the mine were high in lead and carried up to 150 ounces of silver per ton. Because of the high silver content small ore bodies can be mined profitably, but unless larger shoots are found at depth, the mine can have only small production for one or two years. Surface showings at Carmen del Pelarte prospect are insignificant.

ESPARTA MINE

The Esparta mine is low on the north wall and near the head of Quebrada Cancahua. It is about 2.75 kilometers south of the stream in Viñoyapampa and nearly 1.5 kilometers west of the Arequipa mine. The veins are in a large precipitous shoulder surrounded by ice and glacial debris; the mine camp is on a well-developed lateral moraine (fig. 15). Ice from the main lobe of the glacier extends into the valley below the mine.

The country rock, quartzite and phyllite striking N. 25° W. and dipping steeply northeast, is cut by several veins. The principal vein, evidently the only one which carried ore, is traceable on the surface for nearly 100 meters horizontally and 70 meters vertically and is followed by the principal adit a total length of 105 meters (pl. 4). Twenty-five meters to the southwest of the vein a 4-meter wide breccia zone exposed by several short adits contains only quartz and pyrite. Other narrower zones opened only by prospect pits are similarly barren.

The principal vein contains galena, sphalerite, quartz, pyrite, arsenopyrite, and dolomite. Most galena and sphalerite occur in quartz-pyrite gangue but some is in sheared quartzite.

Two adits have been cut on the principal vein, one 4,730 meters in altitude and the other 35 meters higher. The lower adit, now flooded, exposes a zone of sheared quartzite 4 meters wide, which contains quartz and pyrite. The upper adit follows the principal vein 55 meters and a branching vein another 50 meters. At this level the principal vein strikes N. 27° W. and dips from 65° to 90° NE., and the branch strikes N. 18° W. and dips 70°–85° NE. The vein was stoped upward several meters, in part to the surface, and four winzes probably connect to the lower adit. In one pillar the sulfide-bearing part of the vein is 40 centimeters wide, and certain parts contain as much as 80 percent of galena.

One short segment of the branching vein contains galena. In this area a raise at least 20 meters long extends to workings above. The remainder of the branch contains only quartz, pyrite, and arsenopyrite. The principal vein, exposed in two short adits near the upper end of the outcrop at altitudes just under 4,800 meters, ranges from 0.7 to 1.5 meters in width and contains much pyrite and quartz with minor amounts of galena and sphalerite.

The mine was not operated in 1948, and it is evident that nearly all the ore was mined before the operation was abandoned. As the area is thoroughly prospected, it is doubtful that further exploration is warranted.

MERCED MINE

The Merced mine, also known as the Anna, is on the south wall of the Quebrada Honda 1.75 kilometers southeast of the falls. The upper drift is at an altitude of 4,560 meters.

A slightly curved vein, striking a few degrees west of north and dipping steeply southwest to vertically, is in granodiorite; slickensides along vein walls plunge 65° NW. Minerals in the vein are sphalerite, galena, quartz, pyrite, and arsenopyrite. In places arsenopyrite, pyrite, and quartz form distinct bands; elsewhere sphalerite-quartz bands are prominent. Local miners reported that the vein also contained chalcopyrite and that galena assayed as much as 70 ounces of silver per ton.

The upper level consists of a drift 37 meters long with stopes both above and below. All galena has been mined, but some sphalerite remains. To judge from the size of stopes, galena ore apparently occurred in shoots averaging 10 meters in both horizontal and vertical extents. About 40 meters lower a crosscut 30 meters long exposes only quartz and pyrite on the vein.

It is reported that the mine was worked as recently as 1947, but it was not working in 1948. No ore is exposed in the workings, and it is improbable that additional exploration would reveal ore.

ATLANTE MINE

The Atlante mine is at the head, or south end, of Quebrada Checchipampa 15 kilometers northeast of Chancos and east of the continental divide. From Chancos the trail distance to the mine is about 55 kilometers via Quebradas Honda, Illauro, and Checchipampa. The altitude at the portal of level 3 was interpolated from base maps as 4,600 meters. Veins in the area extend from the southwest wall of Quebrada Checchipampa across a spur to the tributary valley Quebrada Bayacocha, a distance of more than 1 kilometer. Glaciers from surrounding peaks extend into the mine area.

Atlante, discovered in 1895, produced 5,000 tons of concentrate by 1903 (Dueñas, 1904, pp. 46–65; Velarde, 1908, pp. 72–73) and since has had a comparable production up to 1948. According to data furnished by the Empresa Minera Vesuvio, in 1946 the mine produced 350 tons of galena concentrate which contained 28 percent lead, 20 percent zinc, and 1.9 kilograms of silver and a few grams of gold per ton. From the concentrates 100 tons of silver-bearing lead bullion were produced at the smelter. Production was somewhat less in 1947 and 1948.

At the Atlante mine the contact between granodiorite and metasedimentary rocks, principally quartzites, crosses the vein system, and although irregular, it generally trends northwest and dips steeply northward to vertically (pl. 5). The metasedimentary rocks for the most part strike northeast and dip southeast or northwest but in places strike northwest and dip southwest; evidently the rocks are folded, but data at hand are insufficient to ascertain the nature of these structures.

The three major veins, Atlante, Juno, and Cruzada, and several splits or smaller veins, have been explored and mined on six levels. Altitudes of the levels are as follows: level 1—4,735 meters, level 2—4,670 meters, level 3—4,600 meters, level 4—4,560 meters, level 5—4,540 meters, and level 6—4,532 meters.

Atlante, the most northerly vein, is arcuate, striking N. 10°–45° W. and dipping 35°–55° SW. at its southeast end and striking N. 60°–85° W. to west and dipping 55°–75° SW. at its northwest end. The vein is traceable for a total length of 400 meters and has been stoped from level 3 to the surface, a vertical distance of 150 meters. It extends from an intersection with the Cruzada vein on the east to irregular exploratory drifts and stopes in the Urano area on the west. In the central part of the workings a short parallel vein or split occurs a few meters north of the Atlante vein from above level 2 to the surface. This split extending along much of the western part of the vein is well shown on level 2 (pl. 5). All high-grade ore in the Atlante vein has been mined; the most productive part was near the southeast end of the vein.

About 150 meters southeast of the intersection of Atlante and Cruzada another vein, shown on the mine map as Atlante East, is followed 190 meters by a drift; only a short stope from level 2 to the surface was productive. Because this vein has about the same attitude as Atlante, mine operators are of the opinion that Atlante East is its extension. However, Atlante definitely is truncated by Cruzada, so the eastern segment is probably an independent fissure. The Atlante vein and its splits and most of Atlante East are in metasedimentary rock.

Southwest of the Atlante and Atlante East veins is the slightly sinuous Juno vein which strikes N. 35°–50° W. and dips 15°–65° SW.; the flatter dips are prevalent at depth. The Juno vein is traceable for a length of 400 meters but not for more than 240 meters on any one level and has been opened from level 2 to level 6, a vertical distance of 140 meters. On levels 3 and 4 it ends against the Cruzada vein, but it cuts across the Cruzada vein on level 5. Juno has been most productive from a short distance above level 3 to level 6, but near the southeast end of the mine workings a small ore body was encountered on level 2. High-grade ore remains only in the lowest levels. The Juno vein is in granodiorite except for the segment extending north of the Cruzada vein on level 5, which is in metasedimentary rock.

The Cruzada vein, extending between the Atlante and Juno veins, strikes eastward and dips vertically. The Cruzada is traceable for a total distance of 360 meters, with a maximum of 280 meters on a given level, and has been opened from levels 2 to 4, a vertical distance of about 110 meters. Apparently it fades at depth, and only a short east-trending segment is seen on level 5. The vein, now mined out, was productive only from half-way between levels 2 and 3 to half-way between levels 3 and 4. The Cruzada vein is more or less parallel to the contact between the metasedimentary rock and the granodiorite. As can be seen in pl. 5, this contact is very irregular and cuts across the vein several times.

Vein structures and mineralization seem to become weaker at depth, and ore bodies are progressively shallower northward. The vein structures are evidently faults of small displacement, all formed about the same time. Vein walls are slickensided, and the vein material contains much brecciated wall rock and gouge.

The principal vein minerals are galena, sphalerite, pyrite, quartz, and carbonate (probably dolomite). Chalcopyrite, tetrahedrite, and stibnite occur in minor amounts. In addition Dueñas reported that anglesite and cerussite were in the oxidized zone, polybasite and stephanite occurred in the upper parts of the mine, and arsenopyrite, bornite, and bournonite occurred at greater depths.

Sphalerite, at present the most abundant ore mineral in the veins, generally does not occur as discrete grains but forms veinlets, veins, or lenses. Galena occurs as crystals, veinlets, and massive lenses, either pure or associated with sphalerite. Gangue consists principally of carbonate and brecciated country rock, but at places quartz and pyrite are abundant. Minerals were deposited in fissures along the faults and in breccia cavities. Much of the ore is vuggy or drusy and at places is conspicuously banded.

Silver was concentrated in the upper parts of the veins by secondary enrichment. The first ore mined averaged over 3 kilograms of silver per ton of concentrate (Dueñas, 1904, p. 46) and was as high as 10 kilograms per ton (Velarde, 1908, p. 72). In contrast, some ore from the lowest levels of the Juno veins carries less than 100 grams of silver per ton.

Lead-silver ore shoots are as much as 90 meters long but more commonly are between 10 and 40 meters long, and their vertical dimensions are of comparable magnitudes. Ore bodies seem to be most frequent along those parts of veins having numerous flexures and comparatively infrequent along straight segments. Much less ore was encountered on the comparatively straight Cruzada vein than on either the Juno or Atlante veins.

Other than on the lower levels of the Juno vein most high-grade ore had been extracted from this deposit by 1948, so the possibilities of future mining of virgin ground are considerably limited. A company survey in 1939 showed substantial amounts of lower grade ore, either unmined or occurring as fill in old stopes. Construction of a larger flotation plant should permit extraction of much of the lower grade material, and this could result in continuing production at modest rates for several years to come.

The Italia mine, not visited during our investigation, was mined out by 1900 after producing several hundred tons of lead-silver concentrate. The adit of the main level is about 1 kilometer west of the adit of level 2 of the Atlante mine, and its altitude is above 4,750 meters. Between this mine and the Atlante two other small mines, the Urano and Judás, were opened before 1895. Subsequent exploration showed these to be on the western extension of one of the veins in the Atlante deposit. The vein at these two mines was worked out a number of years ago.

HUAMANÁ MINE

The Huamaná mine is high on the north wall of Quebrada Huichjanca, a west tributary valley of Quebrada Checchipampa, 17 kilometers northeast of Chancos and 3.5 kilometers southwest of the company camp and flotation plant at Pompei. The trail distance from Chancos is nearly 50 kilometers. The datum used in this report, taken from a company survey, is the adit of the Santa Rita tunnel just behind the mine camp; this seems to be several hundred meters high when compared to the topographic map of the Cordillera Blanca (Borchers, 1935). The Huamaná mine includes veins extending over an area about 350 meters east-west by 700 meters north-south, between the altitudes of 4,595 meters and 4,835 meters. Other veins just to the south, or downslope, are beyond the company concessions but form part of the Huamaná vein system.

Although several of the veins in this deposit had been worked during the Colonial period, the mine was forgotten and rediscovered only shortly before 1900. A lixivation plant, later changed to a flotation plant, was built by the Empresa Minera Pompei to concentrate ore from this area. By 1948 most of the silver-bearing galena ore was mined out, and the company stopped operations. Records show that concentrates produced before 1908 contained from 3.3 to 6.5 kilograms of silver per ton (Velarde, 1908, p. 75), and as late as 1946 hand-sorted ore ran to as much as 1.9 kilograms of silver per ton. In 1948 ore was selectively mined, hand-sorted, and sent by aerial tram to Pompei. The tram, 3 kilometers long, carries 60 buckets, each with a capacity of 150 kilograms. A new cable was installed and the tram renovated in 1947. The flotation plant has a capacity of 10 tons per day and produced only lead-silver concentrate.

At Huamaná the contact between the batholith and the metasedimentary rocks strikes nearly west and dips north at moderate angles (fig. 8). The dip of the quartzite, phyllite, and andalusite hornfels, generally parallels the contact. The veins, for the most part, are confined to granodiorite, but the northwest end of one, the Animus, continues into the metasedimentary rocks (pl. 6).

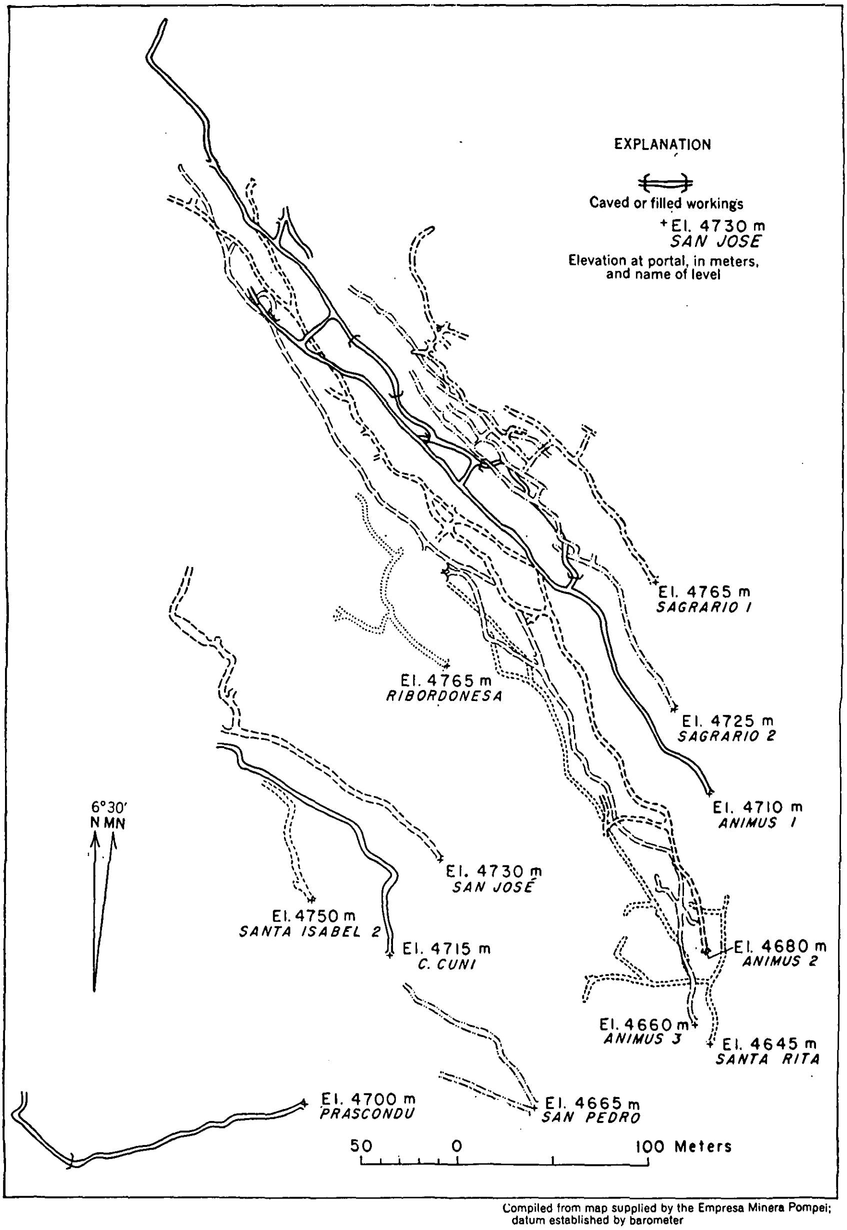
Minerals in the veins are galena, sphalerite, pyrite, stibnite, quartz, and rhodochrosite. Silver occurs with galena, and secondary smithsonite coats some sphalerite. Where the wall rock is granodiorite, it is altered; metasedimentary rocks appear to have been unaffected by mineralizing solutions. Galena and sphalerite occur as scattered grains, veinlets, and small pods or as stringers or lenses several meters long and as much as 70 centimeters thick. Most minerals were deposited as fissure fillings.

Galena is fine grained, occurring in massive or laminated aggregates, or is coarsely crystalline; grains are less than 1 millimeter in diameter, and crystals are as much as 5 centimeters in diameter. Sphalerite is crystalline and honey colored, and thin cleavage fragments are transparent. Grains forming massive aggregates are from 0.2 to 10.0 millimeters in diameter, crystals from 0.5 to 10.0 centimeters in diameter. Pyrite, quartz, and rhodochrosite are finely crystalline or massive, and stibnite occurs as interlacing or radiating groups of needles.

Ore shoots are lenticular, occurring most frequently along sinuous parts of the veins and where veins split or shear planes branch, and are very irregular, ranging in thickness from a few centimeters to as much as 1.5 meters. Sulfide minerals are banded in places but elsewhere form heterogeneous mixtures. Minerals were deposited in fissures as well as in breccia cavities.

The veins at Huamaná occupy three principal shear zone systems. The first strikes northwest and dips southwest at moderate to steep angles, the second has similar strike but dips southwest at only low angles, and the third strikes east and dips south at low to moderate angles. Of these, only the first carries major ore bodies. Movement along the shear zones evidently was small. The zones consist of comparatively short and branching shear planes along which are fissures, gouge, and breccia. Although several shear zones continue into the metasedimentary rocks north of the contact, mineralization outside the igneous mass is insignificant.

The principal veins are Animus, Ribordonesia, San José, Santa Isabel, Prascondu, and San Pedro. Several of these have smaller associated veins, and in addition a number of small unnamed veins occur south of Animus and San Pedro (pl. 6 and fig. 24). The Animus vein, on the east side of the area, is by far the largest and has furnished the bulk of the ore. It and Santa Isabel in the northwest part of the area were the only veins being worked in 1948.



Compiled from map supplied by the Empresa Minera Pompei; datum established by barometer

FIGURE 24.—Principal underground workings of the Huamaná mine, Quebrada Honda-Vesuvio mining district.

Ribordonesia, west of Animus and on the north side of the area, and Prascondu, in the southwest corner, are reported to have been mined out in the Colonial period, but some workings on them seem to be more recent. In our study all workings were visited, but only the geology of the surface and the two lower levels of the Animus vein were mapped.

The Animus vein is opened on six levels, the Sagrario 1 and 2, the Animus 1, 2, and 3, and the Santa Rita, exposing the vein for a length of 400 meters between the altitudes of 4,645 and 4,765 meters. Mining and exploration were extensive, and small amounts of high-grade galena remain only on the Santa Rita and Animus 3 levels. High-grade sphalerite ore remains in many parts of the vein.

On the Animus 3 level, about 110 meters from the portal, the vein is terminated at the southeast by a cross fissure. Below on the Santa Rita level the vein turns into the west wall of the drift about 125 meters from the portal. The intersecting vein is not exposed, but to the south the most prominent structures are south-dipping veins which undoubtedly cut off the Animus vein (pls. 7 and 8).

The overall strike of the vein is N. 30° W., and it dips 40°–80° SW. Two major branches are found on the lower levels (pls. 7 and 8); on the Animus 3 level the vein splits to the west about 200 meters from the portal and then to the east about 470 meters from the portal. The southeastern branch rejoins the main vein about 65 meters to the northwest; both junctions plunge steeply south. The junction of the northwestern branch plunges northwest at moderate angles and overlaps the southeastern on Animus 1 level. Additional splits or subparallel veins develop on the two upper levels, totalling four mineralized and two barren shear zones on Sagrario 1 level. Most mineralization occurred on levels Animus 1, 2, and 3; the vein definitely is thinner and ore shoots are smaller on the Santa Rita level.

The Santa Isabel vein, the most northwesterly of the area, is traceable on the surface for 150 meters and is opened on two drifts, one at 4,750 meters and the other at 4,770 meters altitude. It also is exposed in the Cerro Cuni adit at 4,715 meters altitude. In the upper drift the vein consists of straight segments striking N. 60° W., that are connected by more northerly striking simple or branching shear planes. In the lower drift the vein strikes about N. 40° W. and dips 40° SW. Ore shoots, all less than 1 meter thick, were mined out along the upper drifts, and probably another shoot was worked from the Cerro Cuni level. The upper drift on Santa Isabel was being advanced in August 1948, but the exposed vein contained only minor sulfides.

The Ribordonesia vein is at the north side of the mine area between the Animus and Santa Isabel veins. Several irregular drifts and undercuts follow it for a distance of 125 meters between the altitudes of 4,765 and 4,800 meters. The vein strikes N. 40°–60° W. and dips 15°–20° SW. It intersects more steeply dipping fissures in the two southwestern adits (pl. 6). Apparently all ore has been mined from the workings.

The San José vein, east of Santa Isabel and southwest of Ribordonesia, is exposed in two drifts, the longer at 4,730 meters and the shorter at 4,745 meters altitude, and also is exposed in the Cerro Cuni adit below. The main drift shows an arcuate vein striking N. 40° W. which swings to strike due west about 150 meters from the portal; the vein dips 20°–50° S. Well within the workings a 40-meter crosscut to the north exposes another vein striking N. 50° W. and dipping 50° SW. Galena has been mined out of several small stopes, but some sphalerite remains in the upper workings; only gouge was seen on the Cerro Cuni level.

The Prascondu vein in the southwest corner of the area is traceable 220 meters horizontally and 60 meters vertically in an arcuate outcrop trending N. 65°–70° E. at the northeast end and N. 80° W. near the southwest end of the outcrop. The dip is 10°–30° S. on most of the vein but locally is as much as 45°–55° S. Associated with the vein are splits, branches, and cross fissures as well as isolated vein segments to the north. Drifts are cut on Prascondu at the following altitudes: 4,700, 4,688, 4,675, 4,661, 4,651, and 4,638 meters, of which only the uppermost is shown on fig. 24. The vein as exposed in the drifts is very low grade, but the several stopes indicate that a few small ore bodies were found.

About 50 meters northwest of the 4,700 meter level adit, a vein striking N. 60°–70° W. and dipping 50° SW., traceable for 50 meters, has been stoped from 4,720 to 4,760 meters altitude. Branching north from this is a sinuous vein dipping 15°–35° W., which was explored by pits.

The San Pedro vein, between Animus and Prascondu, is exposed in an adit 120 meters long at 4,665 meters altitude and in a short adit to the southeast at an altitude of 4,621 meters. The vein strikes N. 20° W. and dips 65° SW. at the portal of the 4,665 meter level but strikes more westerly and dips at lower angles within the adit. Ore was mined from several small stopes, but the remaining material is barren. No ore was found on the lower level.

A number of small veins occur south of the Animus and San Pedro veins, several of which are shown on the map of the Santa Rita level (pl. 7). The largest veins have been stoped for short distances. Southeast of the lower San Pedro tunnel and at 4,595 meters altitude (pl. 6) are two shear zones followed by drifts, each about 50 meters long. Both zones strike northwest and dip southwest at moderate to low angles. The western is barren, but the eastern carries large lenses of pure sphalerite. About 50 meters to the north, at 4,615 meters altitude, are two tunnels. The western tunnel is short and follows a barren shear zone; the eastern tunnel, about 100 meters long, is on a branching shear zone with an overall strike of N. 15° E. and a dip of 45° NW. A few lenses of galena and sphalerite are on this zone, one of which has been stoped down 5 meters. At the base of the dump from the Santa Rita adit, at an altitude of 4,595 meters, a 20-centimeter thick vein striking N. 85° W. and dipping 30° S. is exposed in a 75-meter drift. The vein contains minor quantities of galena and sphalerite.

Below these and south of the company concessions two veins were explored by drifts at 4,570 and 4,550 meters altitude. The vein in the upper drift, which is 60 meters long, strikes N. 8°–30° W. and dips 45°–65° SW. It contains small lenses of galena and rhodochrosite. The lower adit, east of the main gully and below the vein at the base of the Santa Rita dump, exposes a shear zone striking north and dipping 25° W. This zone has a maximum width of 20 centimeters and contains only minor amounts of galena and sphalerite.

SEXTRI MINE

The Sextri mine, downslope from Huamaná and at the base of a steep wall in Quebrada Huichjanca, is about 2 kilometers northwest of Vesuvio. Velarde (1908, p. 75) reported that veins here contained high-grade galena and silver ore.

The country rock is granodiorite. Two drifts, one at 4,250 meters and the other at 4,270 meters altitude, follow a slightly sinuous vein for about 200 meters. On the lower level the vein strikes N. 30° W. and dips 30° SW. at the portal but trends N. 10° E. and dips 60° NW. near the north end of the workings. A barren cross fissure with the attitude N. 70° E., 45° SE. intersects the vein about half-way between the portal and the face. Stopes, most of which are open to the surface, have maximum widths of about 1 meter. To judge from examination of the vein and material on the dumps, mineralization is about the same as at Huamaná, except that pyrite here is more abundant and sphalerite is darker. According to Dueñas (1904, p. 71–72) the carbonate is siderite, and he further noted that the galena and sphalerite extracted prior to 1900 contained fine-grained argentiferous tetrahedrite.

Above the Sextri workings, at 4,315 meters altitude, a small tunnel follows a vein striking N. 5° W. and dipping 60° SW. The working is now flooded, but waste material contains rhodochrosite, quartz, pyrite, and minor amounts of galena.

Veins at Sextri appear to be barren or worked out, and further exploration is not warranted.

LAURIÓN MINE

The Laurión mine, about 24 kilometers northeast of Chancos and 7 kilometers northwest of Chacas, is in a ridge named Cerro Torojirca between Quebrada Apash on the east and Quebrada Carhuanca on the west. The camp and main workings are near the head of Quebrada Apash and are reached by a 10-kilometer trail from Pompei. Altitudes cited for this mine are from company maps and are low as compared with the map of the Cordillera Blanca.

Although the mine was worked either in the Colonial period or during the early days of the Republic, it was left dormant for many years before being reopened by the Empresa Minera Vesuvio just before 1900 (Dueñas, 1904, p. 65–66). The ore in the first decade of the present century commonly contained as much as 40 percent lead, 2 percent copper, and 3.3 kilograms silver per ton (Velarde, 1908, p. 74), but after 50 years of nearly continuous operations only moderate amounts of lower grade ore remain.

Argentiferous galena, sphalerite, pyrite, quartz, and carbonate are seen in present workings. Dueñas (p. 66) stated that chalcopyrite and silver-bearing tetrahedrite also were common in the deposits at the turn of the century. All minerals were deposited as fissure fillings; massive quartz, deposited first, was brecciated prior to deposition of the sulfide minerals.

The country rock, largely quartzite but including some phyllite, is cut nearly at right angles to the strike by several veins, of which only one, the Laurión vein, carries ore. In Quebrada Apash this vein is exposed on 5 levels at altitudes of 4,000, 4,060, 4,165, 4,220, and 4,290 meters. In Quebrada Carhuanca several other levels on the vein are known as the Lepanto workings. The Laurión vein is the largest in the district, traceable 750 meters horizontally and 400 meters vertically, but is not ore-bearing over the entire extent. Most of the vein has been mined above the 4,060 level. On the 4,060 level which is about 350 meters long, the vein consists of long, almost straight, and vertical or steeply dipping en echelon segments. The first segment is 225 meters long and strikes N. 30°–40° E.; the second, offset 15 meters to the southeast, strikes N. 60° E. and was followed for 35 meters; and the third, striking N. 50° E. was followed for 90 meters. All minerals occur as fissure fillings, and on this level, ore shoots range from 0.25 to 1.0 meter wide. Dueñas (1904, p. 66) stated that above level 4,165 the vein reached a maximum width of 2.5 meters.

In 1948 ore was dropped to level 4,060 through ore chutes and from there to the valley floor by aerial tram. It was concentrated in hand jigs before shipment to Pompei for flotation. A small flotation unit at Laurión would help to utilize the moderate reserve of low-grade ore still remaining above 4,060 meters. Little hope is held for finding ore at depth as the lowest level, at about 4,000 meters altitude, is essentially barren of sulfides.

APASH MINE

The Apash mine is northeast of the Laurión mine, on the north side of Quebrada Apash. Drifts on the vein are at the altitudes of 4,000, 4,040, 4,060, 4,080, and 4,130 meters. The country rock and minerals are similar to those at Laurión. The vein itself may be a continuation of the Laurión vein, but here it strikes N. 20°–40° E. and dips about 75° SE. Several adits are walled at the surface, and the others are blocked a few meters in from the portal, so little information was acquired on size of stopes or extent of reserves. It is inferred that a dike follows the vein in the mine because broken rock on the dump includes considerable andesite (p. 32).

Dueñas (1904, p. 66) concluded that old workings on the vein date from the Colonial period.

CHILE PROSPECT

Several hundred meters northwest of the Apash mine and high on the west slope of Quebrada Conchas a vein follows an andesite dike in the granodiorite batholith. The dike, as much as 2 meters wide, strikes N. 85° W. at the east end and N. 75° E. at the west end and dips 70° to 90° N. The vein, traceable about 125 meters horizontally, was explored in three prospects.

Only pyritized dike rock is seen in the eastern prospect pit. The second prospect 25 meters west and 10 meters higher is a tunnel and underhand stope in which quartz and some sulfides are exposed. The third prospect, 40 meters west and 10 meters higher, is a 40-meter drift. Here the vein follows both sides of the dike; the thin sulfide-bearing parts of the vein contain no more than 1 percent galena overall. The largest quantity of galena forms a lens only 1 meter long and 5 centimeters wide. Possibilities for mining this vein seem distinctly limited.

OTHER DEPOSITS

Dueñas (1904, pl. 1) shows several deposits in the upper tributary valleys of Quebrada Illauro and one on the west side and about halfway up the quebrada. He also stated (p. 75) that several small deposits are near the head of Quebrada Putaca, which is the valley extending west from Pompei. All apparently are small and are unknown to present inhabitants of the region.

ANTAMINA-CONTONGA MINING DISTRICT

The Antamina-Contonga district, consisting of two centers of mineralization about 5 kilometers apart, is east of San Marcos, a town 87 kilometers by road northeast of Recuay (fig. 1). The Antamina area centers at the head of Quebrada Antamina 10 kilometers S. 80° E. of San Marcos, and the Contonga area at the head of Quebrada Pajush is about 10 kilometers N. 70° E. of the town. Both areas are reached via a trail extending eastward from San Marcos up Quebrada Pajush. Four kilometers from town the trail forks, and one branch continues about 10 kilometers up Quebrada Pajush to the Contonga area. The other, also about 10 kilometers long, follows Quebrada Yaquirsh southeast, crosses a spur, and turns east-northeast into Quebrada Antamina (fig. 3).

The terrain is rugged in places and comparatively open elsewhere. Major valleys were glaciated and are U-shaped, but many ridges are rounded rather than serrate. The heads of Quebrada Antamina, the valley immediately to the north, and Quebrada Pajush are cirques. Outcrops are extensive only on steep slopes, most of which are walls of glaciated valleys and peaks. Moraine covers valley floors, and soil and scree mantle the flatter slopes and ridge crests.

Strata of the middle unit of the Barremian sequence and the Jumasha limestone (p. 24, 26–27) are the two major rock units of the region, and are separated by a thin band of Lower Neocomian sandstone about 5 kilometers east of San Marcos. Sedimentary rocks are folded and to a lesser extent faulted. Folds range from closed to open structures with vertical or steeply dipping axial planes trending in a northwesterly direction. Small gravity faults are common, but only two large reverse faults were seen (p. 33 and pl. 1).

The limestone is intruded by numerous sills and dikes in the Antamina area and by a small stock and sills and dikes in the Contonga area, all of rhyolitic or rhyodacitic composition (p. 31–32). The largest intrusive in the Antamina area is a dike 1,500 meters long and as much as 20 meters thick, cutting the south wall of the quebrada. A large mass in the cirque north of Quebrada Antamina may be either a small stock or, more probably, a thick sill. Other dikes and sills in this area are at most several hundred meters long and from 2 to 20 meters thick. The stock in the Contonga area has a maximum diameter of 350 meters; associated dikes and sills are from 20 to 300 meters long and from 0.5 to 15 meters thick (pls. 1 and 2).

Limestone immediately adjacent to all large and some small igneous masses is silicated, marbleized, or bleached (p. 39–40). The largest metamorphosed block is in the upper Quebrada Antamina, covering an area with maximum dimensions of 700 by 1,700 meters. Here limestone largely is converted to garnet-serpentine and garnet-diopside rock and, in places, to diopside-garnet-wollastonite-idocrase rock. Smaller patches of silicated rock are several hundred meters southwest of the main mass in the south wall of the quebrada. Elsewhere in the Antamina area and also at Contonga most alteration consists of recrystallization and bleaching of limestone, with or without accompanying silication.

Lead-zinc fissure-filling veins occur in both the Antamina and Contonga areas, and in addition large deposits of disseminated copper replacements, described separately below, are in the center of the Antamina area. Minerals in the lead-zinc veins include galena, sphalerite, pyrite, chalcopyrite, tetrahedrite, pyrargyrite, calcite, fluorite, quartz, and opal. Minerals of the oxidized parts of the veins are limonite and malachite.

In many veins the minerals are coarsely crystalline. For example, cleavage cubes of galena 1 to 2 centimeters across are common. Tetrahedrite and chalcopyrite occur as scattered grains or as crystals in cavities of many deposits. The material is vuggy. The deposits of this district contain less sphalerite and quartz and more calcite and fluorite than those in the Quebrada Honda-Vesuvio district.

DEPOSITS IN THE ANTAMINA AREA

The center of mineralization in the Antamina area is the large disseminated copper deposit in the floor of the quebrada, and this is flanked by two smaller copper deposits to the southwest and by lead-zinc veins peripherally located in the walls of the quebrada and across the ridge crest in adjacent valleys. All these occurrences are associated with intrusive dikes or sills. The lead-zinc veins are most common at contacts between igneous bodies and limestone or in either rock type near the contacts.

Vein structures consist of comparatively short fissures and shear planes, some linked and others isolated. The fissures and shear planes tend to parallel dikes but cut sills at high angles. Movement is indicated by the presence of breccia and gouge along the structures. Deposits are from 30 to 300 meters long and from 15 to 200 meters in vertical extent. Most ore shoots are small, comparatively pure lenses of galena from 2 to 15 meters long and from 10 to 50 centimeters thick, but larger shoots as much as 40 meters long and from 0.5 to 1.0 meter thick, with lower tenor (5 to 30 percent galena), are found in several of the larger veins. Galena concentrates are reported to contain from 50 to 70 percent galena, some of which contains 1 to 2 kilograms of silver per ton.

Raimondi (1873, p. 542–47) stated that during his visit to the area in 1860 the copper deposits were being explored, and ore from one lead-zinc vein was being smelted near San Marcos. He stated that replacement copper deposits were mined before the arrival of the Spaniards, but because of the low silver content of these deposits, the Spanish did little work on them and apparently did not notice the lead-zinc veins. Several mining companies explored the copper deposits in the past few years, but as yet none has started mining.

Most lead-zinc veins seem to have been developed since the close of World War II. All mining in 1948 was either from small pits and underhand stopes or from short drifts and small overhand stopes. All operations were manual. In 1948 and 1949 production was hampered by lack of pack animals to haul supplies and concentrates.

The map of the district (pl. 1) was compiled by plane table triangulation. Most topography was sketched in the field and refined somewhat after study of air photographs; those areas shown by dashed contour lines were sketched without ground control from air photographs. The datum is the peak on the north side of the quebrada, Cerro Yaquirsh, shown on the map of the Cordillera Blanca as 5,017 meters in altitude. All altitudes cited in the following deposit descriptions, other than those in areas shown by dashed contours, can be considered correct to within 20 meters of the datum.

Three deposits in the area probably contain moderate reserves: the Fortuna, the Rosita de Oro, and the Casualidad. Others, along small dikes or sills, have small reserves or are nearly barren.

FORTUNA MINE

The Fortuna mine is in a saddle on the divide between Quebrada Antamina and the cirque to the northwest, between the altitudes 4,680 and 4,745 meters. The dump of the southernmost working is 1 kilometer N. 23° W. of the outlet of the lake. The mine was the largest producer of the area in 1948 and contains moderate reserves.

Limestone striking northwest and dipping gently southwest is cut by two large and two small dikes (pl. 9). The major dike with a sinuous outcrop trending N. 15° W., dips 45° SW. and is traceable for 180 meters. East of this dike are two small dikes, each traceable for 10 to 20 meters, and northeast is the second large dike, with a sinuous northtrending outcrop and dipping from 25° to 40° W., traceable for nearly 90 meters.

The minerals, commonly occupying openings in fissures and shear zones, are galena, sphalerite, pyrite, pyrargyrite, and calcite. Both the limestone and dike rocks are pyritized, and the phenocrysts of the dike rock are altered.

Mineralized fissures and shear zones are comparatively short, at most traceable for 55 meters horizontally. The more important ones are parallel or semiparallel to the dikes. Ore shoots consist, for the most part, of small high-grade galena lenses but also include larger lower grade galena bodies. Most veins are in limestone, although all are within 50 meters of dike rock.

The largest vein is east of the major dike and is the southernmost of the group. It is sinuous, striking north-northwest and dipping 45°–55° W. It has been exposed and mined by pits, drifts, and small stopes for a length of 55 meters and a vertical extent of 17 meters. The vein ranges from 0.6 to 1.5 meters wide; galena lenses worked in 1948 averaged 20 centimeters wide and several meters long. Overlapping and possibly branching from this is an arcuate vein traceable for 40 meters, striking northward and dipping 45°–70° W. An adit on it exposed a stringer of galena 5 to 20 centimeters wide and 7 meters long; a lenticular body 3 to 4 meters long and 30 centimeters wide was mined from a pit to the north.

North of the overlapping vein are a number of short veins, several of which carry small lenses of galena. To the east short nearly barren veins parallel the two small dikes.

Northward along the major dike is another group of short veins, several of which follow the dike and then branch into limestone. Small lenses of galena are present in this vein group, but none seems to offer much promise of being minable at depth. Two veins in limestone between the two largest dikes are both essentially barren.

Another vein, traceable for 35 meters, occurs along the northeast dike, either at the east contact or just within the dike. The vein was opened by a surface stope 5 meters long and 7 meters deep. At the bottom of the stope the vein is 20 to 30 centimeters thick and contains a minimum of 50 percent sulfides. Twenty meters to the south is a pit which exposes a galena lens 2 meters long and 20 centimeters thick. The remainder of this vein and two other small veins in the dike contain only minor amounts of sulfides. About 50 meters east of the dike a trench exposes a 1-meter wide shear zone consisting of pyritized limestone with veinlets of calcite and galena.

The southernmost veins contains shoots of very high-grade galena, but unfortunately all veins are comparatively short. Additional exploration of the veins at depth probably would expose other small high-grade ore bodies.

BARRÓN PROSPECT

The Barrón prospect, in the northwest wall of the quebrada and several hundred meters east of the Fortuna mine, is at the base of a limestone cliff about 1 kilometer N. 10° W. of the lake outlet. The workings are both above and below 4,600 meters altitude.

Veinlets containing galena, sphalerite, pyrite, quartz, and tetrahedrite are exposed by prospect pits along the contact between a dike and limestone. The minerals occur in a zone about 30 centimeters wide, which can be traced along the contact for 30 meters. Both dike rock and limestone are pyritized, limestone at the contact contains talc, and veinlets contain minor amounts of malachite and limonite. The contact was explored by three pits and a 3-meter drift. The zone as exposed in these workings strikes N. 40°–45° W. and dips 55°–80° SW.

To judge from exposures, the zone contains little or no minable material.

SANTA ROSA PROSPECT

The Santa Rosa prospect, the lower tunnel of which is at an altitude of 4,410 meters, is near the north side of the lake 800 meters N. 17° E. of the lake outlet. Small veins occur along a short dike from 2 to 5 meters wide, which has a sinuous outcrop. Minerals in the deposit are galena, sphalerite, chalcopyrite, pyrite, quartz, and fluorite.

The principal vein, striking N. 10°–15° W. and dipping 60°–75° SW., follows the southwest contact of the dike through a vertical distance of 25 meters. The vein is from 0.5 to 1.0 meter wide and contains as much as 20 percent sulfides. Along this vein are several parallel veinlets; near its north end several branching veins strike N. 50° W. and dip 60°–85° NE.

The veins were explored through several adits, one as much as 10 meters long, and by pits. The veins are small and low grade, so it is doubtful that they can be worked at a profit.

SAN FRANCISCO MINE

The San Francisco mine, in the north wall of the cirque, is 1,300 meters N. 10° E. of the lake outlet; the veins extend from about 4,560 to 4,610 meters altitude. The deposit was opened in 1947 and was being mined and explored on a small scale in 1948. In contrast to operations at most other deposits in the Antamina area, where ore is removed by underhand stoping from surface cuts, mining at the San Francisco deposit is carried out by drifting and overhand stoping.

Limestone dipping southward at low angles is cut by a large sill or dike. The intrusive is at least 20 meters thick and is traceable 600 meters; its north end splits into three tongues. Overlying limestone has been stripped by erosion. In the mine area the basal contact is irregular but is nearly parallel to bedding.

Galena, calcite, and some pyrite were deposited in fissures, and the intrusive rock and limestone are pyritized in places. Galena bodies are exceptionally pure, being contaminated only by the two associated minerals or by wall rock where the veins contain breccia. Although shoots are small, ore is easily hand-sorted to a high-grade concentrate. Argentiferous galena is fine grained with laminated texture or is coarse grained.

The mine area centers near the east side toward the north end of the intrusive. Several short steeply dipping veins, mostly confined to the intrusive and striking northwest, crop out over an area 70 by 20 meters (fig. 25). The southernmost working is an adit 21 meters long. At the portal it cuts the contact between limestone and overlying intrusive rock, but owing to the low southeast dip of the contact, most of the adit is in limestone. The working follows a vein striking N. 20° W. and dipping vertically, which contains only minor galena and calcite. About 20 meters north of this adit is the south-

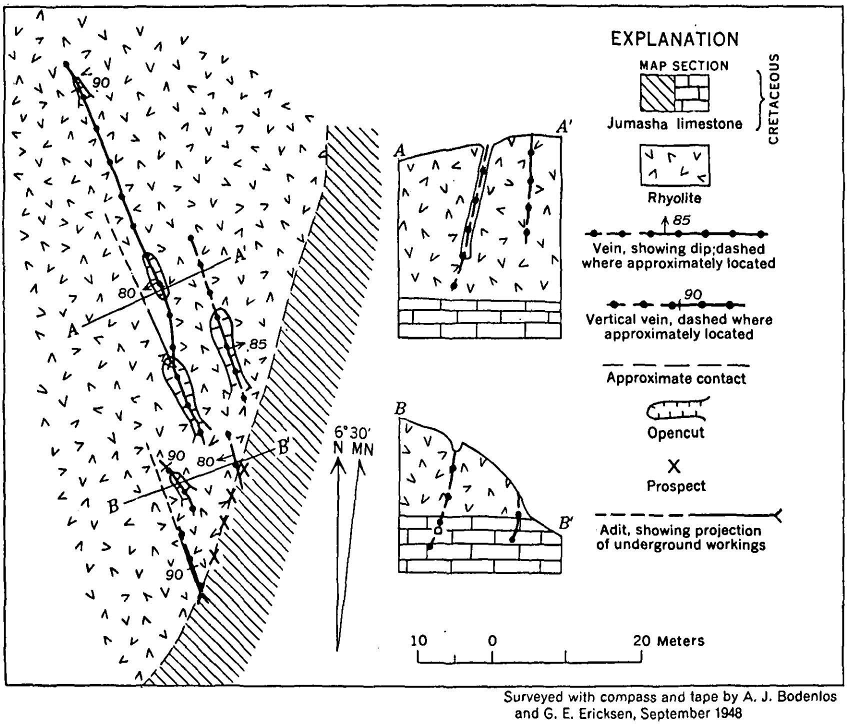


FIGURE 25.—Geologic sketch map and sections of the San Francisco mine, Antamina-Contonga mining district.

east end of the largest known vein of the deposit, traceable about 50 meters on the surface and in workings. This vein strikes N. 25° W. and dips from 80° to 90° SW. Ten meters above the limestone-intrusive contact are a surface cut and a drift which follow the vein for 30 meters. One short stope extends from the drift to the surface, and a prospect pit is cut on the northwest end of the vein outcrop. Parts of the vein contain short lenses of solid galena as much as 10 centimeters thick, but other parts contain much pyrite and calcite and lesser amounts of galena.

Between this vein and the south vein a pit exposes a 15-centimeter wide vertical vein striking N. 35° W., which contains about 50 percent galena mixed with brecciated intrusive rock. A few meters northeast of the main vein another pit exposes a small vein carrying some galena. Northward from the southern adit other pits along the contact expose a few veinlets of galena. Other small veins have been explored by pits to the north and west of the mapped area, but all are small and essentially barren of ore minerals.

Although reserves are small, the ore is sufficiently high in grade to permit mining of the comparatively small veins. Mining may continue to be profitable for a few years.

RECOMPENSA MINE

The Recompensa mine at the head of the valley north of Quebrada Antamina is just across the divide from the San Francisco mine and 1,600 meters N. 13° E. of the lake outlet. Workings extend along veins for a distance of 150 meters and are between the altitudes of 4,550 and 4,595 meters. The mine was being operated on a small scale in 1948. At that time pits and small surface stopes were the principal workings, although one adit, now caved, and one open adit 14 meters long also have been driven.

Limestone in this vicinity is cut by several dikes, the largest of which trends northwest and is traceable 450 meters from the ridge at the north end of Quebrada Antamina to the north of the deposit. It is paralleled by two shorter dikes. These three intrusive bodies dip 65°–85° SW. A fourth dike, near the divide, has a more westerly strike and dips 25°–35° SW.

The vein minerals, galena, sphalerite, pyrite, and calcite, were deposited along fissures in fractures or shear zones in and near the dike. Most intrusive rock is hydrothermally altered, and the limestone near the veins is pyritized.

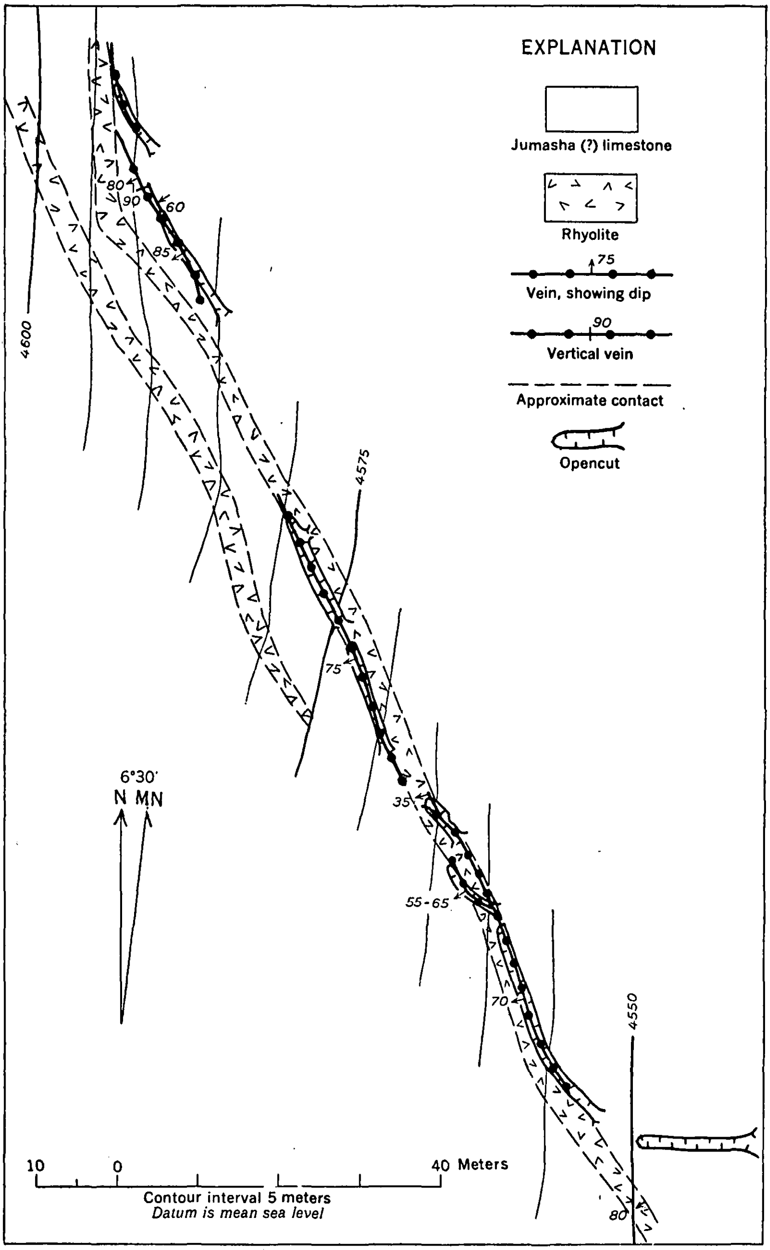
The deposit consists of four veins (fig. 26). The southeastern vein follows the northeast or footwall contact of the dike 40 meters, branching at the northwest end. Ore shoots are few but consist of high-grade lenses of galena as much as 4 meters long and 20 centimeters wide. The vein to the north is at the hanging wall of the dike. It is 35 meters long and as much as 40 centimeters wide and contains veinlets and lenses of galena from 1 to 10 centimeters thick. The northernmost veins, both east of the dike, are in limestone, the north end of each impinging against the footwall of the dike. These veins contain short stringers of solid galena, 1 to 10 centimeters thick. Just west of the divide, prospect pits and a 6-meter adit expose sulfide veinlets, none of which contains minable material.

Small stringers of galena in the veins might yield a few tons of high-grade concentrate, but elsewhere the veins are almost barren. It is improbable that further exploration will reveal sulfide bodies larger than those exposed in the workings.

PODEROSA PROSPECT

The Poderosa prospect, low in the northeast wall at the head of Quebrada Antamina, is 1,150 meters N. 37° E. of the lake outlet. A number of short drifts and pits were cut on the veins, but the deposit was not being worked in 1948.

In the vicinity of the deposit limestone, dipping at low angles, is partly serpentinized and is intruded by a rhyolite dike dipping steeply to the southwest. A second and smaller intrusive to the west may be a split of the larger mass. These bodies seem to be on the continuation



Mapped with compass and tape by A. J. Bodenlos and G. E. Ericksen; base elevation established with altimeter

FIGURE 26.—Geologic sketch map of the Recompensa mine, Antamina-Contonga mining district.

of the large dike at the Casualidad mine. The dike contains several veins, the largest of which has an outcrop length of about 60 meters. This vein strikes N. 25°–40° W. and dips 40°–70° SW. Smaller veins, most of which strike more northerly and dip more steeply, are along the contacts of the larger dike and also in the smaller dike.

The veins consist principally of quartz and pyrite with minor amounts of galena, sphalerite, chalcopyrite, opal, and fluorite. The largest vein averages between 0.25 and 0.5 meter in width but is 1.5 meters wide in one prospect; the smaller veins are from 5 to 50 centimeters wide.

The exposed veins are small and low grade. However, additional exploration of the largest vein might expose small ore bodies which could be mined at a profit.

CASUALIDAD MINE

The Casualidad mine in the northeast wall of Quebrada Antamina is southeast of the Poderosa prospect and extends from near the floor of the cirque to the ridge crest, between the altitudes of 4,480 and 4,680 meters. The veins, among the most extensive lead-zinc occurrences in the district, were being actively developed in 1948 by drifts and pits.

A dike at Casualidad, which can be traced 200 meters horizontally and about 175 meters vertically, strikes N. 40°–55° W. It dips about 40° SW. at the northwestern end and 80° SW. near its southeastern or upper end. Near the valley floor the dike is 20 meters thick, but it pinches to 5 meters at 4,570 meters, the altitude of the main drift, and to 1 or 2 meters above. The intrusive is cut by branching, crosscutting fractures and shear zones below the main drift and by comparatively regular parallel fractures above. The most persistent vein in the area is in the southeast part of the dike, and from the main drift it extends southeastward about 170 meters.

Mineralization is similar to that at the Poderosa prospect. Prospect pits in the lower part of the dike expose stringers of solid galena as much as 2 meters long and from 5 to 10 centimeters thick. Vein material near the stringers averages 30 centimeters in width and contains 10 to 30 percent of galena. The main drift exposes a shear zone about 2 meters wide, which contains stringers of sulfides, 10 to 30 centimeters wide. The vein in this drift was worked during 1948, and we estimated that the ore contained from 5 to 15 percent galena.

During 1948 short, narrow stringers of galena in the drift were mined, but as these are few in number, it is questionable that the production paid mining and shipping costs. However, as the main vein is more persistent than most other veins of the district, further exploration might prove moderate reserves of ore.

JULIA ELOISA PROSPECT

The Julia Eloisa prospect near the ridge crest on the east wall of the cirque is 1,100 meters N. 87° E. of the lake outlet. A 3-meter drift and several pits expose small northwest-striking veins through a length of 100 meters. Minerals in the veins are galena, sphalerite, chalcopyrite, pyrite, quartz, calcite, limonite, and malachite.

The veins seem to be in a northern extension of the mineralized area at Rosita de Oro (pl. 10). The southwestern vein is in the footwall of a south-dipping dike which crosses the ridge, and the other two veins, dipping to the southwest, crop out within 50 meters to the northwest. The sulfide-bearing segments of veins, at most 20 centimeters thick and 6 meters long, carry only minor amounts of galena and sphalerite. No ore is in sight, and it is doubted that further exploration would expose minable material.

ROSITA DE ORO MINE

The Rosita de Oro mine extends from near the ridge crest of the cirque down the slope of the valley just east of Quebrada Antamina. The deposit is from 1,100 to 1,200 meters east-southeast of the lake outlet, and mineralization occurs between 4,485 and 4,635 meters altitude. It is one of the largest deposits of the area and in 1948 was one of the largest producers.

Limestone in this vicinity strikes from west to northwest and dips south at low angles. It is cut by a ramified and branching dike system. The largest of the intrusives is the eastern continuation of the large dike in Quebrada Antamina, which crosses the ridge crest near the north end of the deposit. Several branching dikes can be seen near the ridge crest. To the east is another large dike which crosses the ridge crest in the Julia Eloisa area. These dikes generally trend north and dip west from 45° to 60°. In addition, a number of small dikes crop out both east and west of the main intrusive bodies.

The largest dike is traceable for a distance of nearly 600 meters southward from the ridge crest. At the ridge crest its outcrop width is more than 60 meters, but elsewhere it ranges from 10 to 20 meters in width. The eastern dike can be traced about 350 meters southward from the ridge crest and has an outcrop width of from 3 to 10 meters. Limestone along parts of the dikes is silicified.

Minerals were deposited in fissures and shear zones largely confined to dike rock or at contacts between dike rock and limestone; only in two places do veins extend short distances into limestone (pl. 10). Minerals include galena, sphalerite, tetrahedrite, pyrite, quartz, and fluorite. The feldspars in the dike are altered, and oxidation of pyrite and copper-bearing sulfides has produced limonite and malachite. Gouge is found along some shear planes.

The sulfides occur as isolated crystals, veinlets, and lenses in aggregates of quartz, fluorite, altered feldspar, and gouge. Ore shoots generally contain from 10 to 30 percent sulfides, although several carry as much as 50 percent sulfides. It is estimated that ore shoots contain from 5 to 20 percent galena.

The veins are along simple to branching and alined fissures and shear planes. In the principal dike these structures are short and simple at the north and long and branching at the south end of the main mineralized area. They range from 15 to 105 meters in length, have a vertical extent of as much as 25 meters, and generally are from 20 to 40 centimeters wide, although in places they are as much as 1 meter wide. They strike roughly parallel to the dike and dip westward from 20° to 60°. On the eastern dike veins range from 5 to 45 meters in length and average 25 centimeters in width, with a maximum of 60 centimeters. They dip from 15° to 70° westward.

Only the veins in the central part of the principal dike have been mined to any extent, although the veins in all parts of the area have been prospected by pits and trenches. Most ore has been mined from surface stopes as much as 15 meters long and 10 meters deep and from small pits. A 37-meter adit near the south end of the principal dike did not expose ore, but another 20 meters long near the north end of the main mineralized area exposed a small but rich ore body.

The main mineralized area on the principal dike should provide ore for small but steady production for a number of years. The showings in the rest of the deposit are small and probably cannot be mined at a profit.

PUTAPUQUIO PROSPECT

The Putapuquio prospect, in the valley east of the Quebrada Antamina, is about 450 meters southwest of the Rosita de Oro mine. The lowest working is at an altitude of 4,450 meters. A short adit and five pits expose mineralized shear and breccia zones along a sill for a horizontal distance of 40 meters and a vertical distance of less than 20 meters. The prospect was inactive in 1948.

The limestone in the vicinity strikes N. 10° W. and dips 25° NE. It is intruded by a fine-grained sill with an outcrop length of about 60 meters and a thickness of from 2 to 5 meters. Several outcrops of intrusive rock also occur about 100 meters southeast of the sill. The sill is pyritized in places and is cut by steeply dipping irregular, mineralized shear and breccia zones, en echelon gash veins, and isolated veinlets which contain minor amounts of galena, sphalerite, tetrahedrite, pyrite, quartz, fluorspar, limonite, and malachite. Limestone above and below the sill is barren. No ore is exposed at the prospect, and it is doubted that further exploration would reveal ore.

PALLARES PROSPECT

The Pallares prospect is in a precipitous spur on the south side of the lower part of Quebrada Antamina, 1,600 meters S. 35° W. of the lake outlet. A narrow mineralized area was explored by prospect pits through a length of about 120 meters between altitudes of 4,525 and 4,595 meters. The prospect was being explored in 1948, but as far as is known, no shipping-grade ore was produced.

Limestone in the vicinity of the deposit, striking N. 35°–70° W. and dipping 40°–70° SW., is in part dolomitized, serpentinized, and silicified. It is cut by several dikes, which in places contain feldspar phenocrysts as much as 4 centimeters long and quartz crystals 2 centimeters long. The largest dike, as much as 2 meters wide, has an outcrop length of about 125 meters. It strikes N. 40°–65° W. and dips 70°–85° SW. In places the dike is brecciated, and fragments as much as 10 centimeters long are common. Near the west end of this dike another dike, exposed in a small outcrop, strikes N. 45° W. and dips 40° SW.

Vein minerals were deposited along shear planes at rhyolite-limestone contacts, in rhyolite breccia cavities, and to a lesser extent in fissures in limestone. Galena and pyrite are most abundant; sphalerite, tetrahedrite, chalcopyrite, quartz, and calcite occur in minor quantities. Most veins are thin, short, and low grade. None of the veins seen in 1948 merited development.

PROSPECTS IN THE CIRQUE NORTHWEST OF QUEBRADA ANTAMINA

A number of small mineral deposits are in the cirque just northwest of Quebrada Antamina (pl. 1). All are along small dikes, except two which are in the large mass of igneous rock on the southeast side of the lake. In addition to those shown, several unmapped veins and dikes are in the low knoll on the northwest side of the lake. Two prospectors working in this area stated that they had recovered only 5 tons of galena concentrate during the previous year.

Northwest of the cirque in a steep valley wall above a large swamp a short tunnel exposes a brecciated and silicified zone in limestone. Breccia cavities contain small amounts of galena. In a narrow valley between the lake and the Fortuna mine, prospect pits along a dike expose a narrow shear zone which contains veinlets of sulfide minerals.

None of these prospects seemed worthy of development.

DISSEMINATED COPPER DEPOSITS

Limestone in Quebrada Antamina has been bleached, recrystallized, silicated, and mineralized over a large area nearly surrounding the lake at the head of the quebrada and extending about 900 meters southwest of the lake outlet. Two small areas of mineralized silicated limestone also occur in the southeast wall of the quebrada 1,300 and 1,600 meters southwest of the lake outlet (pl. 1). Minerals replacing limestone in the altered zone include diopside, garnet, wollastonite, idocrase, serpentine, dolomite, and chert (p. 40). The limestone is irregularly altered at most places, but on the northwest fringe of the main body it can be seen that silicates and quartz were introduced along fractures and joints. The largest altered mass is cut by the main dike of the area as well as by smaller dikes, and the two small southwestern masses likewise are cut by dikes.

Minerals introduced into the altered limestone are chalcopyrite, bornite, tetrahedrite, sphalerite, galena, pyrite, and calcite. Raimondi (1873, p. 543–46) stated that small amounts of native copper and molybdenite were found, and analyses published by him show a low percentage of silver in the copper. The sulfides, of which only pyrite and chalcopyrite occur in substantial amounts, were deposited principally as disseminated grains replacing altered limestone and to a lesser extent as filling of small fractures and cavities. Calcite is found only with fissure-filling material. The overall grade of copper is judged to be very low.

The sulfides have been oxidized at the surface, producing a gossan consisting of yellow, red, and black iron oxide with minor amounts of malachite and azurite.

Sulfide minerals can be found throughout most of the largest mass extending over an area 1,700 meters along the axis of the quebrada and from 400 to 1,000 meters across the valley, with a maximum vertical range of 350 meters. However, the highest degree of sulfide mineralization is near the center of the valley at the south side of the lake; areas on either side of the lake are only sparsely mineralized. The depth of the deposit is not known. The southeast contact of the deposit dips steeply to the northwest, and part of the northwest contact dips southeast at low angles (pl. 1, sections *B–B′*, *C–C′*). The southwestern deposits are at most 100 by 200 meters in horizontal dimensions.

The southwest part of the largest deposit and the smaller deposits to the southwest were prospected by pitting, tunneling, and the sinking of shafts, some of which are said to have been opened prior to the Spanish conquest. However, most of the work was done in the second half of the 19th century in an attempt to find high-grade copper-silver ore. The deposits have also been examined by several mining companies during recent years, but as yet have not been developed. The metal reserve in these replacement bodies is very large (these and large replacement bodies in the Pachapaqui district represent the two largest mineralized areas described in this report), and at some future time exploitation may be profitable.

DEPOSITS IN THE CONTONGA AREA

In the Contonga area the Jumasha limestone has been folded, forming a broad anticline to the east and a sharp syncline to the west. In the mine area bedding on the common limb of the two folds strikes northwest and dips 55°–80° SW. The limestone was intruded by stocks, dikes, and sills of porphyritic rhyolite. The largest intrusive is a stock measuring 300 by 350 meters, and around it are dikes and sills ranging from 20 to 300 meters in length and from 0.5 to 15 meters in thickness (pl. 2). At contacts rhyolite is noticeably finer grained, and limestone is partly bleached and recrystallized. Near veins the rhyolite is hydrothermally altered.

The principal lead-zinc veins are near the contact between the stock and the limestone, and the rest are along dikes and sills extending from the stock or along silicified zones in limestone. Another group of veins, northeast of the ridge crest, is in slightly silicified and pyritized fault or shear zones nearly parallel to the bedding of the country rock.

Except for the absence of tetrahedrite and pyrargyrite, the minerals found in the veins at Contonga are the same as those in the lead-zinc veins at Antamina. For the most part they were deposited as fissure fillings, but some pyrite and quartz were deposited as replacements of both rhyolite and limestone. In one vein, sulfides form concentric and banded spheres up to 15 centimeters in diameter; these are considered to be of replacement origin.

Structures forming the loci of mineralization are fault and shear zones which range from a few meters to 175 meters in length, and mostly from less than 1 meter to 3 meters in width. However, along the northwest contact of the stock one shear zone is as much as 15 meters wide. Quartz and pyrite are the most common vein minerals; galena, sphalerite, and chalcopyrite occur in irregular small veinlets, pods, and lenses which comprise only a fraction of the lengths and widths of the veins. Argentiferous galena, the only mineral being recovered in 1948, occurs in comparatively small shoots and is low grade.

Most of the workings are old, but in 1948 the area was being actively prospected and mined on a small scale from pits and two small adits, of which one is on a vein at the northwest side of the stock and the other on veins northeast of the divide. Production was less than 5 tons of lead concentrate per month.

In view of the low tenor and small size of ore shoots, the area is considered to have only limited reserves. Three veins on the north, west, and south sides of the stock may merit further exploration at depth.

The area was mapped by plane table traverses, using a barometric datum.

DEPOSITS IN THE VICINITY OF THE STOCK

In a knoll just south of the pond on the west edge of the map area (pl. 2) small rhyolite dikes are bordered by bleached and silicified limestone zones with maximum widths of about 20 centimeters. The silicified limestone contains a few small veinlets of pyrite, galena, and sphalerite. About 75 meters to the south a bedding-plane fault zone, exposed in trenches for a length of 50 meters, is from 0.5 to 1.0 meter wide and contains up to 5 percent combined galena and sphalerite. A split of the zone is 2 meters wide but contains only thin, short lenses of sulfide minerals. To the east, at the west contact of the stock, the limestone has been bleached, partly silicified, and mineralized for a distance of 75 meters and through a width of from 1 to 2 meters. This zone was explored by five prospect pits, and sulfide minerals make up 5 to 20 percent of the zone.

Along the south edge of the stock four pits extending over a distance of 75 meters expose a mineralized zone 0.7 to 2 meters wide, which crosses the contact between the intrusive and limestone at a narrow angle. In the intrusive the zone contains minor amounts of pyrite and galena with abundant calcite; at the contact it contains pyrite and some galena in quartz; and in the limestone it contains minor amounts of pyrite and galena associated with much gouge.

In a valley southeast of the stock and in bluffs northeast of the valley several short veins occur in limestone. These carry small scattered veinlets of pyrite, galena, and sphalerite, but in no place is mineralization sufficiently great to form an ore body.

Along the east side of the stock a mineralized zone about 120 meters long and as much as 3 meters wide has been explored in several prospect pits. The zone contains only limonite with scattered small veinlets and pods of pyrite, galena, and sphalerite, none of which forms a minable shoot. At the northeast side of the stock two sills are bordered by silicified limestone for distances of 120 and 150 meters. The silicified zone north of the south sill contains veinlets of pyrite and galena and in places sphalerite. Near the east end of the north sill the silicified zone contains pyrite, galena, and minor amounts of chalcopyrite. The zones contain a maximum of 5 percent galena and sphalerite.

Some 60 meters north of the west end of the sills are several northeast-striking veins in silicified limestone, the longest of which can be traced for 80 meters. The width of the silicified zones generally is about 1 meter but reaches 8 meters toward the northeast end of the longest vein. The sulfides occur as scattered veinlets, precluding the possibility of profitable extraction.

A number of discontinuous shear zones extend for a length of 180 meters along the north and northwest contacts of the stock. The easternmost, exposed in a shallow pit, consists of thin, irregular veinlets of sulfides in a zone 1.5 meters wide. About 50 meters to the west a prominent shear zone 65 meters long cuts across the contact. It is 15 meters wide at the west end but only 3 meters wide at the contact. At the west end the zone contains veinlets of calcite and sulfides, and at the contact it contains much quartz and pyrite and minor amounts of galena and sphalerite. Mineralization fades out on the zone in the stock.

On the northwest side of the stock are five northwest-striking and steeply dipping veins, all close to the contact. Each is short, between 1 and 2 meters wide, and contains veinlets and disseminated grains of galena and sphalerite together with larger amounts of pyrite.

A 20-meter adit and pits near the northwest contact of the stock expose a 1- to 3-meter wide breccia zone in bleached limestone. The zone as exposed in the adit and prospect pits consists of altered limestone with minor amounts of quartz, pyrite, galena, sphalerite, calcite, and fluorite. Minerals occur in veinlets and breccia cavities.

From 50 to 75 meters north of the northwest part of the stock a silicified zone as much as 5 meters wide parallels the bedding of limestone for a distance of 175 meters. Small veinlets and vugs, and in places breccia cavities, contain small percentages of pyrite and galena.

Within the stock two small veins carry quartz and disseminated grains of pyrite and galena. Elsewhere in the stock patches of igneous rock are heavily stained with limonite, but no primary sulfides were seen.

A few of the mineralized zones around the stock may be worthy of additional exploration, and it is possible that small ore bodies may thus be found. However, judging from the exposed veins, it is doubtful that exploration would reveal large ore bodies.

DEPOSITS NORTHEAST OF THE DIVIDE

Northeast of the divide scattered veins and veinlets in shear zones extend over an area 250 meters long by as much as 200 meters wide. Shear zones can be traced for a length of as much as 50 meters, and most are less than 1 meter wide, but one short zone is as much as 3 meters in width. The shear zones contain minor amounts of ore and gangue minerals. At no place do ore minerals occur in minable quantities.

OTHER DEPOSITS

A number of other small deposits are known in the San Marcos area but were not visited during our investigation. Among these is the Victoria, said to be a few kilometers from San Marcos and near Cerro Hueglla-Caga; it is a lead-zinc vein on which drifts have been cut over a vertical extent of 140 meters. Another is the Socorro, several kilometers southwest of Chavín. This is in Cerro Huecho and consists of a vein carrying galena and stibnite. In addition, several small stibnite veins west of San Marcos have been producing a few tons of antimony concentrate during recent years.

HUALLANCA MINING DISTRICT

The Huallanca mining district is west of the town of Huallanca and east of the crest of the Cordillera Huayhuash, in the province of Dos de Mayo, Departamento de Huánuco (fig. 4). Huallanca is nearly 80 kilometers airline distance due west of Huánuco, the capital of the departamento, and about 35 kilometers northeast of Chiquián. The district is accessible by a 60 to 70 kilometer trail from Chiquián, the nearest roadhead. It is also accessible by trails from Huánuco and from Conococha and Recuay in the Santa Valley.

Nearly all valleys of the region have been glaciated, and peaks along the crest of the Cordillera Huayhuash are still partly covered with glaciers. However, the area is near the north end of the range where peaks are not so high nor so heavily glaciated as they are farther to the south. The two major streams of the region, Río Torres and Río Viscarra, join at Huallanca to form the Río Huallanca which flows northeastward to the Río Marañon.

The regional structures here, as elsewhere in the Cordillera Huayhuash, consist of folds having a regional strike of N. 20°–30° W. in sedimentary rocks. These sedimentary rocks consist of lower Neocomian sandstones; Barremian shales, sandstones, and limestones; and Machay and Jumasha limestone and have an aggregate thickness of more than 1,000 meters. The lower Neocomian sandstone contains several seams of coal. The only igneous rocks are dikes, sills, and small irregularly shaped stocks.

Historically the district is well known for its silver production during the early part of the present century. Velarde (1908, p. 85) reported that the veins were discovered in 1721 and had been worked intermittently since that time. Prior to 1925, when most of the silver mines were shut down, at least three concentration plants and one smelting or roasting furnace were operated. The machinery of these old plants has been removed, and most of the buildings are now in ruins.

Since 1925 small mines have been worked for copper, lead, and antimony. A concentration plant and smelter was built in Huallanca and operated until 1940. The Compañía Minera Santa Bárbara, the only major company still operating in the district, owns most of the old silver mines, some of the copper and lead mines, and the mill. This company is working a silver-copper mine on a small scale, but its main operation is a stibnite placer to the east of Huallanca.

Several coal seams are mined for local use. Some coals, stockpiled in Huallanca, are blocky high-grade bituminous or anthracite. Other coals, such as those from seams near the west end of Quebrada Torres, are intermixed with shale and burn very poorly.

The ore minerals of the district are largely chalcopyrite, galena, marmatite, and tetrahedrite. Several veins can be worked profitably on a small scale, and one or two might be developed into moderate-sized mines if the district were accessible by road. A few mines are being worked by hand on a small scale.

The most promising mines of the district are:

Carmen del Macizo: high-grade copper-silver ore, several years' reserves for a small operation.

San José de Huanzalá: medium to low-grade lead-zinc-copper ore, potentially a moderately large mine.

Sirena Encantadora: high-grade lead ore, many short veins, exploration may prove substantial ore reserves.

Perla prospect: low-grade zinc-lead ore, warrants further prospecting.

Ispac: low-grade zinc-lead ore, many veins in rather large mineralized zone, possibly may be a moderately large mine.

Danubio-Diamante mine—moderate grade lead-zinc-copper-silver ore, reserves may support a small scale operation for several years.

HUALLANCA MILL AND SMELTER

The Huallanca mill and smelter is at the east edge of the town of Huallanca at the junction of the Viscarra and Torres rivers and at an altitude of about 3,420 meters.

The mill was in operation until 1940, when it was shut down because of difficulties in ore transportation and concentrate shipment. Eugenio Da Roet, General Manager of the Compañía Minera Santa Bárbara in Huallanca, stated that the plant produced about five tons of copper and silver concentrates per day. The furnace was experimental and produced only a minor amount of metal.

The following equipment or facilities are either ready for operation or could be put into operation within a few months: machine shop, woodworking shop, ball mill, flotation cells, ore roasters, leaching-tanks, brick kilns, electrical power plant, and hospital.

CARMEN DEL MACIZO MINE

The Carmen del Macizo mine is at the head of Quebrada Copacog 4.5 kilometers airline west of Huallanca. The portal of the main adit is at an altitude of 4,160 meters. A good trail 7 to 8 kilometers long connects the mine with Huallanca. The mine is owned and operated by Compañía Minera Santa Bárbara.

The country rock is coarse-grained light-gray sandstone in beds 10 centimeters to a meter thick, striking N. 35° W. and dipping 70° NE. The major vein consists of small isolated lenses and pods of tetrahedrite in solution cavities or fissures along a shear or fracture zone striking N. 35° E. and dipping 50°–70° SE. Most lenses are 2 to 4 meters long and have a maximum thickness of 50 centimeters; the pods, although irregular in shape, range from a few centimeters to as much as 50 centimeters in diameter. The ore bodies are several meters apart, and connecting fractures are tight and barren except in a few places where they contain crystals and veinlets of tetrahedrite. The lenses form an ore shoot which plunges 75°–85° NE. and has a horizontal range of about 25 meters and a vertical range of more than 100 meters. Slickensided walls, breccia, and gouge seem to be absent.

The individual ore bodies are either solid lenses and pods or cavities partly filled with tetrahedrite and quartz crystals. Many small splits from the main fissure carry veinlets of tetrahedrite which range from a few centimeters to as much as 3 meters in length. Most ore consists of massive and crystalline tetrahedrite with minor amounts of pyrite and quartz. Cavities in a few ore bodies are filled with a white plastic clay. Much of the ore appears to contain more than 75 percent tetrahedrite.

The vein has been explored by an adit 150 meters long, but ore was encountered only in the one shoot which has been stoped upwards for 50 to 75 meters. Two or three men produce less than one ton of hand-sorted concentrate per month.

Most of the ore has been mined above the level of the main adit, but the same ore shoot was cut in a second exploratory adit about 10 meters lower. The reserves are probably large enough to sustain small scale mining for several years.

A few other mineralized zones in Quebrada Copacog have been explored, but the workings were not accessible in 1949. We examined the surface areas and mine dumps of one or two of these zones but saw only iron oxide and pyrite.

MERCED, PURÍSIMA, SANTA ROSA, AND SAN FRANCISCO MINES

The Merced, Purísima, Santa Rosa, and San Francisco mines are at the west end of Quebrada Tucapac about 5 kilometers west of Huallanca and 1 kilometer north of the Carmen del Macizo mine. A mineralized zone containing many veins trends northwest about 500 meters and is 100 to 200 meters wide. It is perforated by many adits, prospect pits, and shafts. Most underground workings were inaccessible in 1949, and much of the surface area was covered with waste material, so we were not able to make complete examinations.

All four properties are owned by the Compañía Minera Santa Bárbara. The mines were worked until 1925 and then were shut down either because of lack of ore or because of transportation difficulties. According to reports from local people, these four mines, and the San José del Banco mine, produced most of the copper and silver of the Huallanca district.

The country rock is light-gray coarse-grained sandstone overlain by dark-gray metamorphosed shale, with a regional strike of N. 20°–35°

W. and a dip of 65° NE. to vertical. Movement along the contact between the shale and sandstone formed breccia and gouge, and at one place blocks of sandstone as much as a meter in diameter were broken out and mixed into a gouge zone in the overlying shale. A sill of altered rhyolite 2 to 3 meters thick crops out east of the mine area, striking about N. 35° W. and dipping 75° NE. to vertically.

The veins apparently occupy faults parallel or nearly parallel to bedding. They strike N. 20°–35° W., dip 45° NE. to vertically, and consist of shattered wall rock and gouge webbed with veinlets and irregular pods of finely crystalline pyrite. The few veins seen were barren. Careful examination of the many dumps revealed only a few specimens with crystals or veinlets of tetrahedrite and galena. It is possible that rich pockets of tetrahedrite similar to those at Carmen del Macizo were exploited and that the mines were abandoned after the pockets had been mined out.

The mines have been inactive since 1925; mill machinery has been removed, and most of the buildings are in ruins. Company maps on file in Huallanca show drifts and crosscuts totalling more than a kilometer in length.

Steinmann (1930, p. 342) stated that some of the veins contained 1.5 to 2.5 kilograms of silver per ton and 1.5 to 2 percent of copper but that others contained as much as 15 to 20 kilograms of silver per ton and 14 to 17 percent of copper.

As a thorough examination of the area was not made, it is impossible to evaluate the property. Inhabitants of Huallanca who are familiar with the mines mentioned that large rich ore bodies still remain in the now inaccessible workings, but the veins in the accessible workings are singularly barren.

SAN JOSÉ DEL BANCO MINE

The San José del Banco mine, owned by the Compañía Minera Santa Bárbara, is 1.5 to 2 kilometers northwest of the Santa Rosa mine in a small valley on the south side of Quebrada Torres near Lake Cotaicoccha. The explored area is nearly 500 meters long and lies between the altitudes of 3,700 and 3,900 meters.

The mineralized zone is near the same sandstone-shale contact exposed at the mines of Merced, Purísima, etc. However, most of the veins are in shattered and crumpled black carbonaceous shale which strikes N. 20°–40° W. and dips 60°–70° NE. The veins appear to be associated with breccia and gouge zones in the shale, and most are nearly parallel to the regional strike and dip of the strata. Several veins were worked from adits, shafts, pits, and surface stopes. A typical major vein of the area is 1 to 3 meters wide and more than 50 meters long, striking about N. 35° W. and dipping 80° NE. This vein consists of black, shattered shale webbed with veinlets of pyrite and quartz. The veinlets range from 0.5 to 5 centimeters wide and a few centimeters to a meter long.

The mine has not been worked since 1925. Mine buildings and the old mill have been completely destroyed, and most of the underground workings are inaccessible.

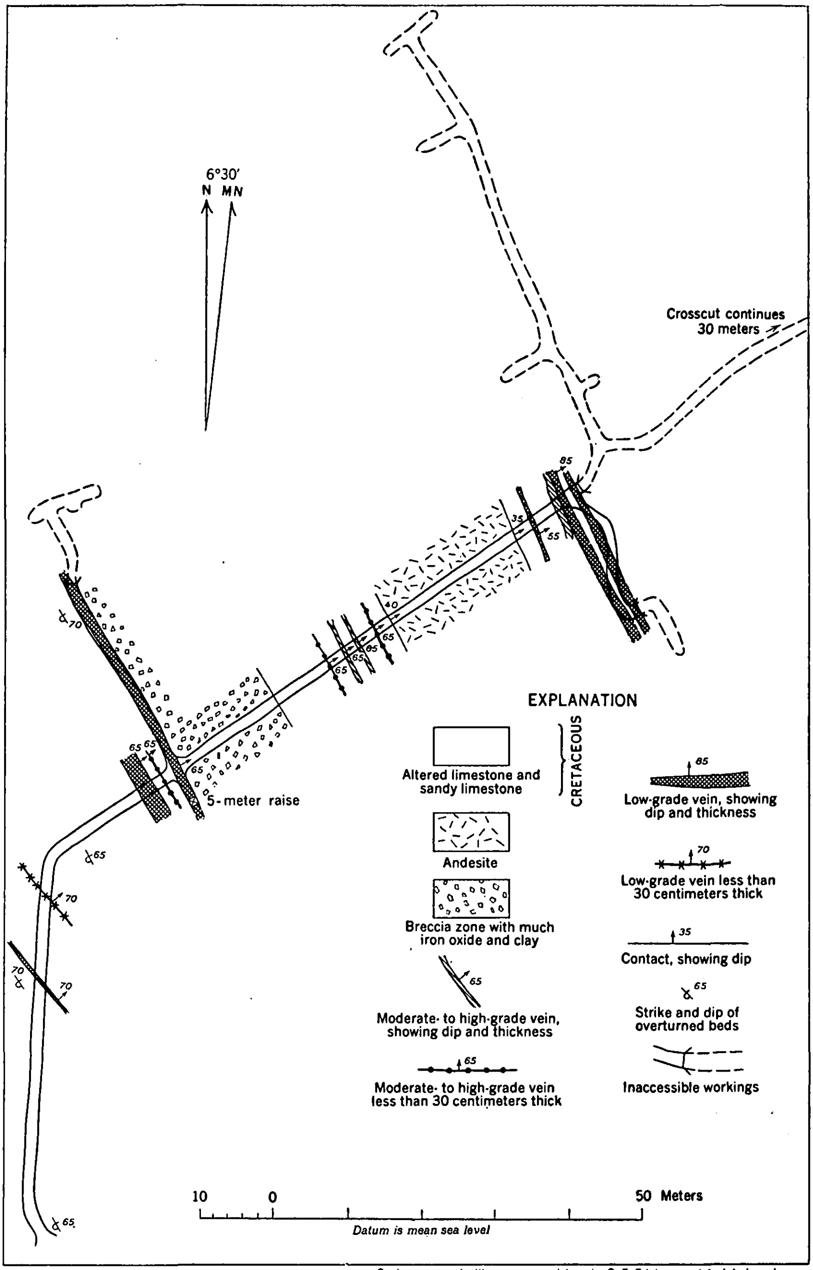
A careful examination of accessible workings and dumps revealed only a few crystals of sphalerite, galena, tetrahedrite, and chalcopyrite. Local inhabitants stated that the mine produced a large quantity of silver.

SAN JOSÉ DE HUANZALÁ MINE

The San José de Huanzalá mine is on the south side of Cerro Huanzalá north of Quebrada Torres and about 2 kilometers west of the San José del Banco mine. The altitude at the portal of the main adit is about 3,960 meters. Airline distance from Huallanca is 8 kilometers, and the trail distance along the Río Torres is about 12 kilometers. Like most of the other large mines in the district, the Huanzalá mine has not been worked since 1925.

Most of the veins are exposed over an area about 50 meters wide and 150 to 200 meters long and appear to be replacements of gouge and breccia zones in fine-grained pyritized and silicified, light-gray limestone and sandy limestone. The area is on the western, overturned limb of an anticline whose beds strike N. 20°–40° W. and dip 40°–70° NE.; the crest of the anticline is 200 to 300 meters to the east. An overturned sequence of coarse-grained light-gray sandstone, apparently the same as that exposed at San José del Banco and other mines to the east, crops out on the east side of the mine area. Most of the veins are in limestone near the contacts of two andesite sills which range in width from 5 to 10 meters and lie about 40 meters apart. The western sill is the more prominent and can be traced northwestward for more than three kilometers; isolated veins and irregular replacement zones of copper, lead, zinc, and iron sulfides are exposed along the entire outcrop. Three kilometers northwest of the Huanzalá mine is exposed a replacement body of nearly pure pyrite, about 10 meters long and 3 to 4 meters wide. Many of these mineralized zones have been explored by pits and short adits.

The main vein area is perforated by shafts and adits, most of which are now caved and inaccessible. The best view of vein structures and the nature of mineralization is afforded in the accessible portion of the principal adit. Within this adit, shown in fig. 27, are exposures of at least five veins which seem to contain a moderate percentage of lead and zinc as well as several low-grade veins which are largely pyrite and quartz. In addition, a zone of rubbly material about 12 meters thick, consisting of fragments of limestone mixed with iron oxide and clay, may be low-grade ore. The veins tend to be parallel to bedding planes of the limestone. Four of the richest veins occur within a 10-meter wide alteration zone at the west side of a sill (fig. 27), and it is possible that the altered limestone between these veins contains enough ore minerals to warrant mining the entire zone.



Geology mapped with compass and tape by G. E. Ericksen and A. J. Indacochea, August 1949 on plan supplied by Compañía Minera Santa Bárbara

FIGURE 27.—Geologic map of the principal adit, San José de Huanzalá mine, Huallanca mining district.

The higher grade veins consist of fine-grained galena, marmatite, pyrite, and minor chalcopyrite in a matrix of altered wall rock, clay, and quartz. Minerals are somewhat oxidized, and part of the ore contains crystalline cerussite. The major veins range from 30 centimeters to a meter in width and probably from 10 to 50 meters in length. The lower grade veins range from 20 centimeters to 2 meters in width and consist largely of pyrite, quartz, clay, and iron oxide with minor amounts of lead, zinc, and copper sulfides. Many cavities in these veins and walls of the adit along the veins are coated with copper sulfate and carbonate.

The number, size, and grade of the veins indicate that the San José de Huanzalá mine is one of the more valuable mines of the district. It seems probable that ore reserves are large enough to supply a small concentration plant for a number of years.

SIRENA ENCANTADORA MINE

The Sirena Encantadora mine is at Lake Tancancocha, a small lake at the head of Quebrada Chuspi near the crest of the Cordillera Huayhuash, 12.5 kilometers airline west of Huallanca. The trail distance to Huallanca via Quebrada Chuspi and Quebrada Torres is about 25 kilometers. The main mine area lies between the altitudes of 4,550 and 4,610 meters. (See fig. 28.)

Cerro Tancancocha to the south of the mine is covered by glacial ice, and one of the lobes extends down into the mine area. According to local reports, the area was covered with ice until about 1935.

Several veins crop out in a granodiorite porphyry stock and in altered limestone between the stock and a 7-meter wide dike to the west. The stock, although irregular in shape, seems to be 200 to 300 meters wide and extends southward from the mine area more than 500 meters along the axis of a sharp chevron anticline in unaltered fine-grained dark-gray limestone. The axial plane of the anticline strikes N. 20°–30° W. and dips vertically, and beds on the limbs dip steeply.

Limestone in the vein area has been recrystallized and bleached, partly silicified, and partly replaced by garnet, epidote, and white bladed wollastonite. At one place the dike was broken into sharp angular fragments a few centimeters to a meter across, and between these fragments spaces as much as 50 centimeters wide were filled with crystalline wollastonite.

Vein minerals filled fissures and replaced both the igneous rock and altered limestone along fracture zones ranging in length from 5 to about 30 meters. The veins strike N. 10°–65° W. and dip steeply from 60° NE. to 80° SW. In the altered limestone, high-grade lead-silver ore occurs in lenses and irregular pods a few centimeters to 1.5 meters wide and 1 to 5 meters long, whereas in the stock most sul-

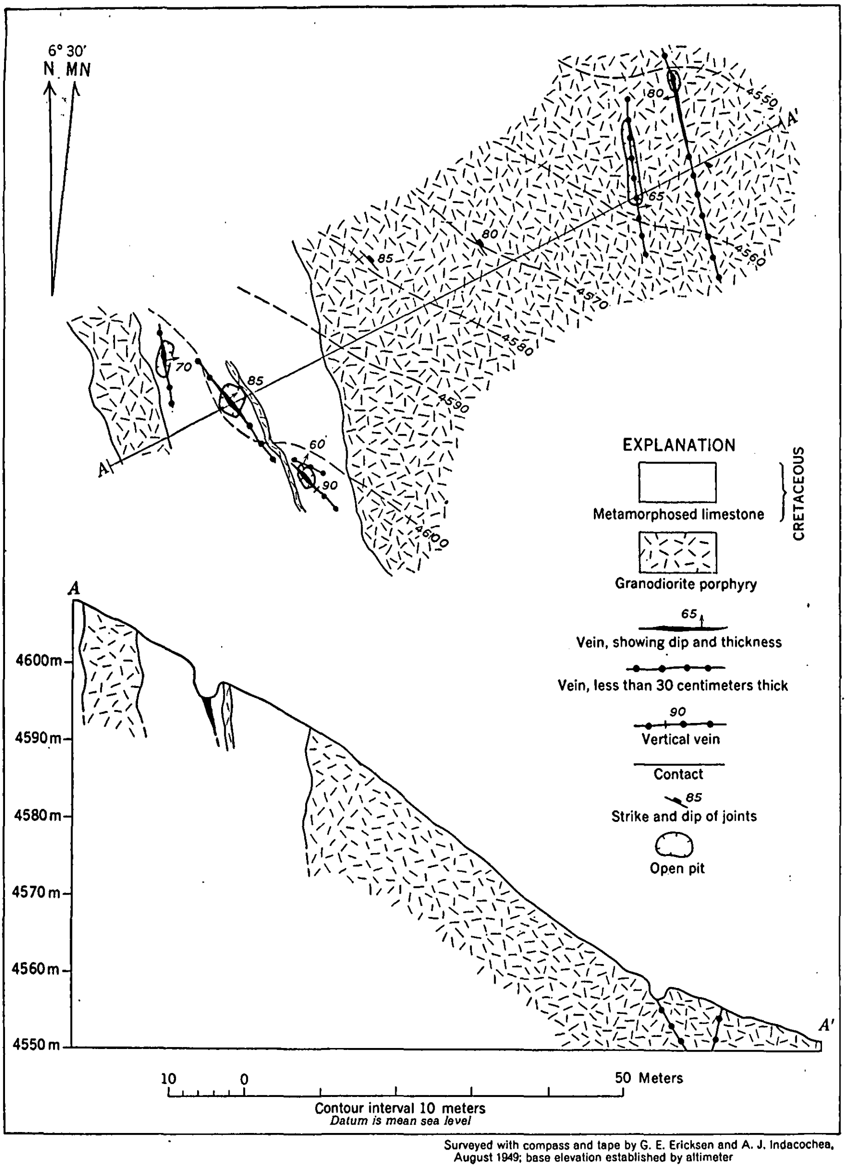


FIGURE 28.—Geologic sketch map and section of the Sirena Encantadora mine, Huallanca mining district.

fide minerals are localized as veinlets and small replacement pods of pyrite and galena along serpentinized fracture zones.

The richer ore consists of galena with disseminated grains of calcite, quartz, wollastonite, pyrite, and veinlets of very fine-grained argentite. Some of the galena is cubic, but most occurs as elongate grains 1 to 2 millimeters long oriented parallel to the vein walls. Argentite veinlets a few centimeters long and less than a millimeter thick tend to parallel the elongate galena crystals. Parts of the veins contain crystals and veinlets of sphalerite.

Southeast of the area shown on the map (fig. 28) several veins along the contact have been explored, but only a small amount of ore was encountered. One of these veins contains a small amount of bladed stibnite.

Mining began in 1948. Ore is mined from surface pits and sorted by hand to produce a concentrate containing more than 50 percent of galena. Twelve miners were employed at the time of our visit, and production was approximately five tons of concentrate per month. The owner of the mine, Sr. Arnulfo Carbajal, stated that the concentrate yielded 4 kilograms of silver and 8 grams of gold per ton. The concentrates were hauled by burros and mules to Conococha and by truck from Conococha to Lima.

Although the ore bodies are small, they are the richest seen in southeastern Ancash and are equaled in grade by only one or two of the better veins of the Antamina mining district to the north.

Exploration to greater depths in the present mine area and around the contacts of the stock should discover other ore bodies which may sustain a very profitable small scale operation for several years. At least 50 tons of high-grade ore were in sight at the time of our examination.

BELEC PROSPECT

The Belec prospect is on the north side of Quebrada Chuspi, near the crest of the ridge between the Cuarto de Dormir and Quebrada Tanash to the north (fig. 4). A 4-meter adit, the principal opening, is about 3 kilometers northeast of the Sirena Encantadora mine at an altitude of 4,400 meters. A trail crossing the ridge between Quebradas Chuspi and Tanash passes a few hundred meters east of the prospect.

Three small fissure veins cut gray dense sandstone which strikes N. 30° W. and dips 85° SW. to vertically. The contact with an overlying limestone is about 20 meters to the southwest. The north vein, explored by the adit, strikes about N. 65° E. and dips 85° S. to vertical. It contains a lens 10 to 25 centimeters wide and about 2.5 meters long of pyrite and quartz with pods and veinlets of galena and sphalerite. A second vein, exposed in a small prospect pit 50 meters to the southwest, strikes N. 45° E. and dips 65° NW. It is 20 to 30 centimeters wide and consists of sheared and fractured sandstone containing pods and veinlets of pyrite and lesser galena. A third vein, parallel to bedding in the limestone, is 75 meters farther to the southwest. It is 10 to 40 centimeters wide and 4 meters long and consists of iron oxide with a few small pods of pyrite, quartz, and galena.

It is possible that the north vein yielded one or two tons of low-grade lead concentrate before the prospect was abandoned. However, no ore remains in this vein, and the other two veins are essentially barren.

PERLA PROSPECT

The Perla prospect is on the south side and near the head of Quebrada Tanash about 5 kilometers west of the Huanzalá mine at an altitude of about 4,360 meters. The trail distance to Huallanca via Quebrada Tanash and Quebrada Torres is about 23 kilometers.

Several small sulfide veins are exposed in a contact zone between limestone and a diorite intrusive. The limestone in the zone is bleached, recrystallized, and partly replaced by garnet. Beds strike about N. 35° W. and dip nearly vertically. The mineralized contact zone trends east. Three principal veins, ranging from 20 centimeters to a meter in width and 5 to 15 meters in length, and many irregular pods and veinlets crop out along the contact for a distance of at least 100 meters. The larger veins strike N. 75° W. to S. 70° W. and dip 85° N. to vertically.

Sulfide minerals are concentrated along shears and fractures in the limestone which apparently was first recrystallized, then garnetized, and later replaced by pyrite, quartz, galena, and marmatite. Some of the veins contain coarsely crystalline white calcite. It was estimated that most of the veins contained 5 to 10 percent of marmatite and a smaller content of galena; one of the major veins carried 15 to 35 percent marmatite and 5 to 15 percent galena.

The veins have been explored by three or four prospect pits and trenches. A few tons of low-grade galena concentrate may have been mined and shipped.

About 500 meters to the northwest a second mineralized zone appears to be on the north contact of the same dioritic intrusive. However, the intervening area is covered with soil and rock debris, and it is uncertain whether the intrusive is one single body or two isolated dikelike bodies. The attitude of the limestone is the same as to the southeast. The irregular contact zone trends east.

Mineralization is comparable to that already described except that the veins contain more pyrite and less galena. Two major veins were seen: the east vein, striking N. 44° W. and dipping 80° SW., is 1 to 2 meters wide and about 35 meters long; the west vein, striking N. 66° E. and dipping 81° SE., is about 1 meter wide (maximum) and 10 to 15 meters long.

The predominant ore mineral of both zones is dark-brown to black marmatite, which may contain too much iron to be mined profitably. However, selective mining of the zones richer in galena might prove profitable for a small scale operation. Further exploration of the covered contact zones of the intrusive might expose other ore bodies.

PROTECTORA MINE

The Protectora mine is high in the south wall of Quebrada Torres about a kilometer south of Hacienda Torres and near the crest of the ridge between Quebrada Torres and Quebrada Tanash. The portal of the adit is at an altitude of 4,550 meters. Trail distance to Huallanca is about 20 kilometers.

The country rock is silicified limestone near the core of a small anticline whose axial plane strikes N. 35° W. and dips vertically. Beds on the limbs of the anticline dip steeply. Three granodiorite porphyry sills, cropping out on the west limb of the anticline within 30 meters of the axis, range from less than a meter to about 5 meters in thickness. The limestone on the west limb of the anticline has been silicified and serpentinized, but that on the east limb is unaltered, fine grained, and dark gray.

The only vein carrying an appreciable amount of sulfide minerals is near the axis of the anticline and strikes N. 35°–50° W. and dips about 35° SW. An ore shoot 20 to 80 centimeters wide and probably 10 to 15 meters long consists of altered wall rock, barite, calcite, light-brown crystalline sphalerite, and cubic galena. The ore was estimated to contain 20 to 30 percent of sphalerite and galena combined. Ore is localized in short irregular lenses a few millimeters to 30 centimeters thick and as much as 4 meters long. Ore minerals appear to have been deposited both by fissure filling and by replacement of wall rock.

The vein was explored by a 6-meter adit and stoped upwards for about 3 meters. In 1949 the mine was worked intermittently on a small scale, and probably less than 1 ton of galena concentrates was produced per month.

The vein is small, and probably only a few additional tons of ore can be mined from the exposed ore shoot. However, further exploration may expose other small ore bodies.

OTUSCO PROSPECT

The Otusco prospect is near the top of the east wall of Quebrada Chogoracra about 0.5 kilometer west of the Protectora mine. The main prospect pit is at an altitude of 4,530 meters.

The country rock is dark-gray fine-grained limestone, which strikes N. 15°–25° W. and dips about 80° SW. The ore and gangue minerals were deposited in fractures and fissures and replaced the limestone along bedding shears. The main mineralized zone, about a meter wide and at least 12 meters long, is laced with veinlets and pods containing cubic galena and minor amounts of sphalerite and calcite. The zone was estimated to contain about 5 percent of galena. Along the west side of the zone an irregular limestone breccia zone 3 to 6 meters in diameter contains many veinlets and pods of galena, sphalerite, and calcite.

The veins were explored by three or four small prospect pits, and one or two tons of low-grade lead ore may have been mined. The prospect was not being worked at the time of our visit in 1949.

A few other small prospect pits in two or three gouge, breccia, and iron oxide zones to the northwest of the Otusco prospect expose veinlets of pyrite and quartz with minor amounts of galena and sphalerite.

A few tons of ore might be mined from the main vein, but reserves are very small, and the other veins are essentially barren.

REACCIÓN PROSPECT

The Reacción prospect is on the east side of Quebrada Huiscaposada, a small tributary valley on the south side of Quebrada Pucaraju, the westward continuation of Quebrada Torres. The area is about 2 kilometers southwest of Hacienda Torres. The trail from Huallanca to Pachapaqui via Paso Yanashallash passes by the mouth of Quebrada Huiscaposada. The prospect area lies between the altitudes of 4,400 and 4,470 meters.

The country rock is very fine-grained fossiliferous, dark-gray limestone which strikes N. 25°–30° W. and dips 70°–80° SW. At least four veins crop out along the east side of the quebrada over a horizontal distance of about 500 meters. Three of the veins strike N. 60°–75°E. and dip nearly vertically; one strikes N. 10° W. and dips 75° SW. The veins range from 5 to 10 meters in length and in most places are only a few centimeters wide. They contain lenses of calcite, apparently deposited in solution cavities, which range from 1 to 4 meters in length and have a maximum width of about a meter.

Vein material consists of coarsely crystalline, vuggy calcite in rhombs commonly several centimeters in diameter; some cleavage faces are as much as 20 centimeters across. Pyrite, sphalerite, and galena partly fill cavities in the calcite. These druses of sulfide minerals are few in number and seldom are more than 25 centimeters in diameter.

The veins were explored by three small prospect pits, but no ore was encountered, and the prospect was abandoned. The veins are small and nearly barren, and it is doubtful that further exploration is warranted.

CASUALIDAD MINE

The Casualidad mine is on the southeast side of Cerro Huallapata about 1 kilometer northwest of Hacienda Torres. The main workings are between the altitudes of 4,280 and 4,300 meters. The mine is about 300 meters above the level of the pampa in Quebrada Torres.

Irregular veins cut coarse-grained light-gray sandstone which strikes about N. 40° W. and dips 40°–50° NE. The veins are on the east limb and near the crest of a large anticline in sandstone and overlying limestone. The axial plane of the anticline strikes

N. 30°–40° W. and dips nearly vertically. Vein minerals were deposited in fissures, fractures, and breccia cavities along an irregular fault and shear zone trending N. 35° W. Within the fault zone many branching and curving shear planes dip steeply from 65° NE. to 60° SW. The zone is 1 to 2 meters wide and about 60 meters long.

Vein material consists of finely crystalline to massive stibnite, cubic galena, very fine-grained sphalerite, and fine-grained pyrite. Much of the vein material and wall rock is stained with iron oxide. Ore occurs in veinlets and pods which are concentrated in brecciated rock or in rock broken by numerous closely spaced fractures. These bodies are generally 1 to 1.5 meters wide and 1 to 5 meters long.

During 1949 the richest pockets of ore were being mined from small surface pits and three adits ranging from 2.5 to 8 meters in length. Three or four men, working by hand, probably produced between 1 and 3 tons of stibnite and galena concentrate per month.

The ore pockets are small and low grade, and only a few tons of ore are in sight. Unless larger and richer ore shoots are encountered at depth, it is doubtful that mining will continue to be profitable.

VICTORIA MINE

The Victoria mine is at the head of Quebrada Quecurure, a small valley north of Quebrada Pucaraju and about 2.5 kilometers west of Cerro Huallapata. The mine workings are between the altitudes of 4,410 and 4,420 meters.

Several short parallel veins crop out in an area 5 to 10 meters in diameter in a fractured and brecciated shaly limestone. The veins strike N. 70°–80° E. and dip 70°–80° SE. The area is on the east side of a broad anticline near the crest, where the limestone strikes N. 25° E. and dips 26° SE. A 3- to 5-meter dike of altered granodiorite porphyry crops out a few meters east of the mineralized zone and strikes N. 40° W. and dips 70° NE.

The veins range from less than a centimeter to as much as 5 centimeters in width and from a few centimeters to 4 meters in length. They contain bladed stibnite and fragments of soft, altered limestone. Numerous cavities are lined with crystals of quartz. The stibnite blades range from a few millimeters to 5 centimeters in length and form a porous meshwork of crystals and masses of radiating crystals.

The veins were explored by a shallow 4-meter trench and three or four small surface pits. One or two tons of stibnite concentrate may have been shipped. The mine was inactive at the time of our visit in 1949.

Veins are small and apparently disappear within a few meters of the surface. Total reserves of high-grade stibnite ore are probably less than 5 tons.

Another vein area, about 150 meters to the northwest on the floor at the north side of the quebrada, is exposed in two old prospect pits. A fault zone, striking about N. 75° W. and dipping 55° SW., contains a few veinlets of pyrite and quartz. In places the veinlets contain grains of sphalerite and tetrahedrite but not in minable quantities.

BODOQUE MINE

The Bodoque mine is south of a small lake on the west side of Quebrada Retama about 2.5 kilometers northwest of the junction with Quebrada Torres. The main workings are at altitudes of 4,500 to 4,520 meters. The trail distance to Huallanca via Hacienda Torres is about 25 kilometers.

The country rock is interbedded sandstone, limestone, shale, and clay. The attitude of the strata is irregular because of local faulting and crumpling, but in general beds strike about N. 10° W. and dip 85° NE. Several irregular breccia, shear, and gouge zones, trending about N. 25° E. and dipping nearly vertical, are exposed in an area about 50 meters wide by 100 meters long. Much of the area is covered, and the zones are best exposed in the many prospect pits and trenches. One of the zones contained a few veinlets and small pods of crystalline quartz and bladed stibnite, but the other zones seem to be barren.

Inhabitants of the area reported that several tons of antimony concentrate were shipped from this mine but that it was abandoned a few years ago because of lack of ore.

GOTA DE ORO PROSPECT

The Gota de Oro prospect is on the east side near the mouth of Quebrada Retama about 1.5 kilometers southeast of the Bodoque mine. The altitude is between 4,240 and 4,250 meters.

A few veinlets and pods of sulfide minerals occur in a breccia and alteration zone in massive dolomitic limestone. Vein minerals consist of calcite with minor amounts of pyrite, galena, and sphalerite.

This prospect was discovered in August 1949, a few days before we visited the district. No ore is in sight, and it is doubtful that further exploration is warranted.

ISPAC MINE

The Ispac mine is on the northwest side of Nevado Sacra about 6.5 kilometers northwest of Hacienda Torres. Most of the veins and old workings lie south of Lake Ispac between the altitudes of 4,460 and 4,500 meters. This mine, the northernmost of the Huallanca district, is west of the crest of the Cordillera Huayhuash and therefore in the Departamento de Ancash. It is one of the most inaccessible mines in the district. The trail to Quebrada Torres has largely been destroyed by slide rock or has disappeared in the swamps of the quebradas.

When the mine was active, it was also connected by trail to Chavín, about 30 kilometers airline to the northwest, and to Pachapaqui, 15 kilometers to the south.

The country rock is finely crystalline gray to tan limestone with interbedded shale. Much of the limestone has been replaced by quartz and garnet or stained reddish brown with iron oxide, so that from a distance Nevado Sacra looks like a mountain of iron oxide. Regionally the strata strike N. 35° W. and dip 40° NE. At least one altered granitic dike, striking N. 40° W. and dipping 80° SW., passes through the main vein area. Several other dikes can be seen in the walls of the valley around the lake.

Most of the veins are in an area about 100 meters long and 20 to 40 meters wide. Veins strike both northeast and northwest and dip nearly vertically. However, the most persistent veins strike N. 20°–45° E. and dip 65° SE. to vertically. They appear to be replacement zones in the limestone and range from a few meters to as much as 20 meters in length and from 50 centimeters to as much as 2 meters in width. In addition, the area is laced with numerous irregular veinlets of sulfide minerals.

Vein material consists largely of altered wall rock, pyrite, sphalerite, minor amounts of galena, and veinlets and pods of quartz and calcite. Most veins average more than 50 percent pyrite, either in solid masses or as a granular mixture with wall rock. The sphalerite is dark brown to black in color and may be the variety marmatite. It is either mixed with the pyrite and wall rock or forms solid lenses and stringers 10 to 50 centimeters wide and 1 to 4 meters long. The richest vein seen contained many small lenses and stringers of galena in sphalerite and pyrite.

Local inhabitants reported that the area was worked formerly for silver but was abandoned about 1925. Only one of the veins, explored by a shaft, contains enough galena to be mined and sorted by hand.

The mineralized area is fairly large, and reserves may be adequate to support a small mining operation for several years. It is possible that further exploration would expose other galena-rich veins which could be mined and concentrated by hand.

DEPOSITS OF QUEBRADA CASACANCHA

Several prospects and small mines are in the headwater region of Río Vizcarra, along Quebrada Casacancha, and at the heads of small tributary valleys to the west. The region is east of Quebrada Azulmina and therefore is not shown on the sketch map of the Huallanca district (fig. 4). The deposits are accessible from Huallanca. Mr. Frank S. Simons examined the deposits of this region in July 1952 and gave the following data about the mines and prospects.

Prospects at the head of Quebrada Casacancha.—The high glacier-capped peak (Nevado Tutococha) at the head of Quebrada Casacancha is underlain by an irregular stocklike mass of light-gray rhyolite or dacite porphyry. Along its north and west margin, at an altitude of about 4,800 meters, the porphyry is in contact with gray well-bedded limestone, which strikes north and dips steeply east. Small bodies of pyrite and subordinate galena crop out at several places in the limestone along the contact, and many narrow sulfide veinlets cut the limestone at some distance from the contact. A few of the sulfide bodies have been explored by small prospect pits, but no ore was exposed and the prospect was abandoned. To judge from the size and tenor of the veins in this area, it is doubtful that further exploration would reveal ore.

The area seems to be undergoing a very rapid deglaciation. According to local residents, the deposits were covered by ice until fifteen or twenty years ago; at present the ice has retreated several tens of meters above the deposits. However, a short distance to the south a large tongue of ice extends well below the level of the contact of the limestone and the porphyry.

Pucarodeo prospect.—The Pucarodeo prospect is on the west side near the bottom of Quebrada Casacancha about 1 kilometer south of Hacienda Casacancha and 15 kilometers by trail south of Huallanca. The workings are between the altitudes of 4,050 and 4,060 meters. Country rock is interbedded quartzite and phyllite which strikes N. 30° W. and dips 80° NE.

Two short adits, 10 meters apart vertically, and a raise to the surface from the upper adit have explored a vein striking N. 60° E. and dipping 70° NW. The vein is some 50 centimeters wide and consists of ankerite and minor amounts of pyrite, galena, and tetrahedrite(?). Apparently very little ore was found, and the prospect has been abandoned.

Arteria and Reserva mines.—The Arteria and Reserva mines are on the north slope of Nevado Chaupijanca at the head of Quebrada Churuco about 5 kilometers south of Quebrada Casacancha and 15 kilometers by trail south of Huallanca. The old mine camp is at 4,320 meters, and the veins crop out between the altitudes of 4,440 and 4,580 meters. Rocks of the mine area are limestone cut by an intricate network of dikes composed of gray porphyritic andesite and andesite breccia and light-gray rhyolite or dacite. The limestone strikes east and dips steeply.

The Arteria vein is exposed over a strike distance of about 200 meters and ranges in width from less than 1 centimeter to 3.5 meters; on the average the width ranges from 1.0 to 1.5 meters. The vein strikes east and dips 65°–75° S. In the lower and easternmost exposures the vein consists of a pyritized breccia zone 1.0 to 1.5 meters wide, interlaced with many veinlets of pyrite, galena, and sphalerite. These veinlets are as much as 30 centimeters wide but average less than 5 centimeters. The intrusive rocks north of the vein are andesite, and those to the south are rhyolite or dacite. Rock in the vein walls is heavily pyritized.

Toward the west the vein widens to 3.5 meters and then pinches out. The west half of the vein consists largely of quartz and pyrite with a few small pods or lenses of sphalerite and galena. Wall rocks are andesite, andesite breccia, and limestone.

The Arteria vein probably contains on the average less than 10 percent of combined galena and sphalerite. Sufficient ore is available to support a small operation producing a few tons of hand-sorted lead and zinc concentrate per month. As fresh vein material is well exposed through a vertical zone of 40 meters and over a horizontal distance of 200 meters, the outcrop should give a fair indication of the grade and amount of ore available. The average ore is rather low grade, and the tonnage is inadequate to sustain a large-scale operation.

The Reserva veins are south of the Arteria vein. One vein, about 200 meters south of the west end of the Arteria vein, strikes N. 60° W. and dips steeply southwest. It is 30 to 40 centimeters wide and consists of pyrite with a little galena and sphalerite. The vein cuts through limestone and dikes of rhyolite or dacite. A second vein about 150 meters farther south cuts gray porphyritic andesite. This vein strikes N. 70° W. and dips 80° SW. It is as much as 1.7 meters wide and has an outcrop length of 20 to 30 meters. Vein material is pyrite with considerable sphalerite and minor amounts of associated galena along the footwall. Several other small veins on the Reserva claim appear to be essentially barren.

The Arteria-Reserva group of veins may possibly be worked profitably on a small scale, but grade of ore and possible tonnage are low.

El Sol prospect.—El Sol prospect is on the west shore of Azulcocha Lake in a small cirque at the head of Quebrada Yanajirca, an eastern tributary of Quebrada Churuco. The prospect is about 5 kilometers east of the Arteria-Reserva deposits and is near the altitude of 4,390 meters. Country rock is limestone which strikes N. 10° E. and dips 65° NW. A small opencut exposes irregular pods of sphalerite, pyrite, and minor amounts of galena, which appear to have replaced limestone along the bedding. The mineralized zone crops out for 20 meters along the strike and ranges in width from 60 centimeters to nearly 2 meters; it lenses out to the south and is covered to the north. The largest pod is about 30 centimeters thick. Although some high-grade zinc ore is available, the tonnage is very small, and it is doubtful that additional exploration would reveal much more ore.

Near the outlet of Lake Azulcocha one contact of a small rhyolite intrusive in limestone is marked by a little iron oxide and copper carbonate with small amounts of galena. Neither the carbonate nor the galena occurs in minable quantities.

DEPOSITS AT THE HEAD OF QUEBRADA AZULMINA

Of the following mines located at the head of Quebrada Azulmina, the Danubio-Diamante mine was examined by G. E. Ericksen in 1949, and the others by F. S. Simons in 1952. Mr. Simons also saw veins at the Danubio-Diamante mine in 1952. Location of the Danubio-Diamante mine, as shown in figure 4, is approximate.

Danubio-Diamante mine.—The Danubio-Diamante mine is near the Pachapaqui-Huallanca trail about 1.5 kilometers southeast of Paso Burro and at the extreme western end of Quebrada Azulmina. It lies east of the crest of the Cordillera Huayhuash in the Departamento de Huánuco. By trail the mine is about 15 kilometers from Pachapaqui and about 20 kilometers from Huallanca. The workings are between the altitudes of 4,530 and 4,580 meters.

Principal mineralization occurs within or along the contacts of an irregular porphyritic granite dike several hundred meters long and from 2 to 20 meters thick. The dike trends N. 60°–85° W. and dips nearly vertically. The country rock is thin-bedded fine-grained dark-gray limestone which has been complexly folded. The many large and small folds have amplitudes ranging from a few meters to more than 100 meters. Axial planes trend N. 30° W. and are nearly vertical.

Sulfide minerals are disseminated in irregular replacement bodies 2 to 20 meters long and 0.5 to 3 meters wide, which crop out along the dike for more than 75 meters. One or two of these bodies cut across the dike, but most are near the contact and tend to be nearly parallel to it. The limestone near the dike contains a few veins of sulfide minerals and commonly is crisscrossed with calcite veinlets.

The replacement bodies consist of irregular pods of high-grade lead, zinc, copper, and silver ore separated by intervening areas of low-grade ore. The vein minerals are galena, sphalerite, chalcopyrite, tetrahedrite, realgar, rhodonite, pyrite, and quartz. Of these minerals, galena and chalcopyrite are most common, tetrahedrite occurs in minor amounts, and realgar was seen in veinlets of only one mineralized body. Disseminated grains of rhodonite give the ore bodies a pinkish color. During the deposition of the minerals, vugs as much as 20 centimeters in diameter were lined with massive rhodonite and then filled with crystalline quartz.

A short distance from the dike galena, chalcopyrite, and sphalerite, in a gangue of quartz and rhodochrosite, replace limestone along an irregular vertical fracture zone which trends roughly N. 15° W. The limestone strikes N. 30° W. and dips vertically. Tetrahedrite and realgar associated with coarse-grained milky quartz occur sporadically along the walls of the mineralized zone. The ore body was explored and mined by means of a shallow inclined shaft and an adit (now caved) about 10 meters below the head of the shaft. The ore in this vein is moderately high grade, but the amount in sight and reasonably expectable is very small.

The present operation was begun in 1948, and the veins were worked by hand entirely from surface pits. The owner employs three to six men, and production between 1948 and 1952 was about a ton of hand-sorted lead-copper-silver concentrate per month. The area had been explored previously by means of two or three adits which were inaccessible in 1949 and 1952.

Parts of the mineralized bodies are amenable to hand mining and concentrating. It seems probable that the reserves throughout the Danubio-Diamante area are large enough to support the present operation for several years.

Eureka mine.—The Eureka mine is at the head of Quebrada Azul mina several hundred meters south of the Danubio-Diamante mine.

A number of veins crop out on the lower slopes of Cerros Portachuela and Inca at altitudes ranging from 4,670 to 4,760 meters. These veins cut limestone that strikes N. 20°–30° W. and dips steeply northeast. They range in width from less than a millimeter to about 1 meter, but most are 10 to 20 centimeters wide. Vein material consists of pyrite, chalcopyrite, reddish-brown sphalerite, and galena in a gangue of quartz, calcite, rhodonite, and rhodochrosite; late veinlets of manganiferous calcite and pyrargyrite(?) occur in one vein. Two short adits and one moderately long adit expose the veins. The longest adit, at an altitude of 4,760 meters, was driven south to explore the veins at depth. Two veins were cut, at 90 and 93 meters from the portal. Both veins strike N. 70°–80° E. and dip 75°–80° S. The northern vein ranges from a few centimeters to about a meter in width. The widest part of the vein, exposed in a drift to the east of the adit, was stoped, and apparently considerable amounts of high-grade copper-lead-zinc ore were extracted. The southern vein and other veins tend to be narrow but locally contain small bodies of minable material.

Although the mine was inactive in July 1952, enough ore is available and inferred to sustain a small-scale operation for several years. However, the veins in general are very narrow, and the possibilities of obtaining large amounts are remote.

Excelsior prospect.—The Excelsior prospect is about 3 kilometers southeast of Paso Burro near the summit of Cerros Portachuelo and Inca, between the altitudes of 4,880 and 4,920 meters. Limestones striking N. 30° W. and dipping steeply northeast largely have been converted to pale-green garnet in the prospect area.

The Excelsior vein strikes east and its dip is vertical. It is exposed over a strike distance of about 120 meters and attains a maximum width of two meters. The vein pinches out to the east and is covered by ice to the west. Vein material is largely coarse-grained calcite cut by veinlets of quartz, rhodonite, and pyrite with small amounts of chalcopyrite, galena, and sphalerite. Although the vein is persistent and moderately wide, the tenor is too low to warrant further exploration.

OTHER DEPOSITS

In addition to the mines and prospects already described a few others, whose names are unknown and which have not been worked for several years, are described briefly in the following section and are given numbers for purpose of reference.

Prospect 1.—A small prospect lies about 100 meters northeast of a small lake in the east wall of Quebrada Pucaraju Pampa at an altitude of 4,360 meters. Sandstone striking N. 35° W. and dipping 85° SW. is cut by a mineralized fracture zone striking N. 85° W. and dipping 85° S. The zone is about 50 centimeters wide and is exposed for about 10 meters. It is stained with iron oxide and contains a few veinlets of galena averaging less than 2 millimeters in width and 10 centimeters in length.

There is no ore in sight, and it is doubted that further exploration will reveal minable material.

Mine 1.—An old silver mine is on the south side of Cerro Huallapata, about 250 meters south of the Casualidad mine and about a kilometer northwest of Hacienda Torres. The portal of the lowest major adit is at an altitude of 4,200 meters and is 50 to 100 meters above the pampa in Quebrada Torres. The workings are old and the mine has been abandoned for many years.

A single fissure vein, striking about N. 30° W. and dipping 85° NE., is parallel to bedding of light-gray sandstone on the east limb of the anticline of Cerro Huallapata. The vein contains gouge and breccia with disseminated crystals and veinlets of pyrite but seems to be barren of ore minerals. A careful search of the dumps revealed a few specimens containing crystals of proustite and galena.

The vein was mined and explored by means of 4 major adits and several shorter adits and surface pits through a horizontal distance of about 100 meters and a vertical distance of 50 meters. The major adits are from 10 to 30 meters long and are now partly caved or filled with water. An upper adit is stoped to the surface, a distance of 10 to 20 meters, and possibly a shoot of enriched silver ore was mined. The lower adits are smaller and have no stopes; they may have been driven to explore the vein at greater depth.

The vein appears to be barren, and the adequate exploratory work indicates little chance of finding more ore.

Mine 2.—A small group of workings of another old mine is on the south side of Quebrada Torres about 500 meters southwest of Hacienda Torres and about a kilometer southeast of mine 1. The workings lie between altitudes of 4,140 and 4,150 meters and are 65 to 75 meters above the pampa.

Several small mineralized zones crop out in sandstone on the east limb of the same anticline as is exposed at Cerro Huallapata. They contain much gouge and breccia with veinlets of pyrite and quartz. One principal zone strikes N. 40° W. and dips 55° SW., and the other, 10 meters to the north, strikes N. 70° E. and dips 80° SE. No ore minerals were observed in place, but a few specimens on the dumps contained veinlets of galena.

The area was explored by a 7-meter inclined shaft with a 7-meter drift, a 10 meter adit, and a few prospect pits. Apparently no ore was encountered.

PACHAPAQUI MINING DISTRICT

The Pachapaqui mining district is in the northeast part of Bolognesi Province in the Departamento de Ancash. The district takes its name from the town of Pachapaqui at the south edge of the area, 22 kilometers airline north of Chiquián. The main trail from Chiquián to Huallanca via Quebrada Burro passes through Pachapaqui. The trail distance to Chiquián is 30 to 35 kilometers, and that to Huallanca via Quebrada Tunacancha and Quebrada Torres is 35 to 40 kilometers.

The area lies west of the Cordillera Huayhuash at the headwaters of the Río Pativilca. Three major valleys lying to the north join at Pachapaqui, and their streams join to form the Río Pativilca. The northwestern valley, Quebrada Piscapaccha, heads on the eastern slope of the Cordillera Blanca near Nevado Raria and trends southeast about 16 kilometers to Pachapaqui. The central valley, Quebrada Tunacancha, trends approximately south and is about 11 kilometers long. The eastern valley, Quebrada Cara, is 3 to 4 kilometers long and trends southwest. At the east end of Quebrada Cara is the junction of three smaller valleys, Quebrada Burro, Quebrada Nupocuta, and Quebrada Shicra Shicra. Most of the mines and prospects are in these three smaller valleys (fig. 5).

Most valleys of the district are U-shaped. Their heads are cirque-like and contain much recent morainal material. A small lake has formed behind a recent recessional moraine at the head of Quebrada Burro. The higher peaks along the crest of the Cordillera Huayhuash are covered with active glaciers, and tongues of ice extend down into the mine areas. Nevado Burro, one of the highest peaks in the northern part of the Cordillera Huayhuash, rises sharply from the north end of Quebrada Burro.

The sedimentary rocks are complexly folded, and it was not possible to work out details of the stratigraphy. Most of the folds are in a medium- to thick-bedded fine-grained dark-gray limestone that is underlain by medium-grained light-gray sandstone. Between these units is a sequence of interbedded shale, limestone, and shaly sandstone, which may be several hundred meters in thickness. On the whole the rocks seem to be similar to those in the Huallanca district.

The only igneous rocks are irregular dikes and stocks of granite porphyry, which occur in greatest number near the crest of the Cordillera Huayhuash.

Many small faults appear to have caused only minor displacement of the rocks. Most of them appear to be steeply dipping normal faults and contain veins of sulfide minerals.

Both fissure and replacement veins are found. The predominant minerals of the fissure veins are quartz and pyrite with lesser amounts of galena, sphalerite, chalcopyrite, and tetrahedrite. The replacement veins contain much quartz, rhodochrosite, and rhodonite with pods, veinlets, and disseminated grains of galena, sphalerite, chalcopyrite, and pyrite.

Some of the fissure veins might be worked profitably on a small scale for several years. However, the future of the district depends on the possibility of large-scale exploitation of one or two large low-grade replacement veins; at present we do not know whether these veins can be mined profitably.

Mines showing most promise for future production are:

Patria, Esperanza, and Otito: low-grade lead-zinc-copper ore, largest mineralized zones in the four southern mining districts. Detailed sampling and diamond drilling might disclose very large reserves of low-grade ore.

Sinchi Roca: lead-zinc-copper ore, reserves may be large enough to support a small scale operation for a few years.

San Antonio and Abandonada: lead-zinc copper ore, moderately large but low-grade mineralized zone, worthy of further exploration.

San Judas Tadeo: lead-zinc-copper ore, reserves may support a small-scale operation for several years.

PACHAPAQUI CONCENTRATION PLANT

The Pachapaqui concentration plant is on the north side of Pachapaqui at an altitude of 3,800 meters.

The mill, rated at 30 tons per day, is owned and operated by the Compañía Minera Argenta Bolognesi. Construction was completed early in 1949, and operation began in March 1949. In August 1949 the plant was operating at less than one-half capacity because of shortage of ore. Five to ten men were employed, and production was about three-fourths of a ton of lead-copper-silver concentrates per 8-hour day. However, only two or three mines were furnishing ore, and the mill operated less than four days per week; probably output was less than 10 tons of concentrate per month.

The plant is powered by a 75-horsepower Frances turbine which furnishes direct (pulley) power to the machines. Water for the turbine comes from the stream in Quebrada Cara and is brought to the plant by a canal about 1 kilometer long. Other equipment of the mill included a Risdon Iron Works jaw crusher rated at 100 tons per 24 hours, a Krupp ball mill rated at 30 tons per 24 hours, a Dorr Simplex classifier, and 6 wooden flotation cells, Denver type No. 15.

PATRIA, ESPERANZA, AND OTITO MINES

Two large, nearly parallel mineralized zones along the east side of Quebrada Piscapaccha have been explored and worked at the Patria, Esperanza, and Otito mines. The principal workings of the northernmost mines, Patria and Esperanza, are in Quebrada Quenhuaracra between the altitudes of 4,320 and 4,350 meters. Patria is on the eastern zone and Esperanza on the western zone about 300 meters distant. These mines are about 9 kilometers airline and 12 kilometers by trail north of Pachapaqui. Two prospect areas of the Otito mine are on the eastern mineralized zone 2.5 and 3 kilometers southeast of Patria. The Otito workings are between the altitudes of 4,330 and 4,510 meters.

The mineralized zones are in brecciated limestone on two sides of a complexly folded structure which in Quebrada Quenhuaracra consists of two anticlines separated by a syncline. At most places the zones are 10 to 30 meters thick, but at Otito the eastern zone attains a thickness of nearly 50 meters. The zones have an outcrop length of more than 4 kilometers and an exposed vertical extent of at least 200 meters. They are underlain by light-gray sandstone and overlain by a sequence of alternating beds of limestone and shale. At Patria the beds strike N. 15° W. and dip 70°–85° NE., and at Esperanza they strike N. 20°–30° W. and dip about 80° SW., whereas at Otito bedding is more irregular, striking N. 25°–55° W. and dipping 45°–75° NE.

It is probable that a limestone bed resting on sandstone was irregularly faulted and brecciated during folding and later was mineralized. The resulting mineralized zones have a sinuous outcrop and regionally are parallel to beds but locally cut across beds of the underlying sandstone. Irregular brecciated areas and veins of sulfide minerals within the principal zones trend parallel to them.

Much of the limestone is silicified and contains finely disseminated pyrite. At places the zones are capped with porous and cavernous gossan, which may be several meters thick, and at other places weathered surfaces are encrusted or stained with iron oxide, so that it is difficult to examine the zones except in prospect pits or in valleys where streams have kept the surfaces clear of iron oxide. The more intensely brecciated areas contain pyrite, calcite, siderite, and quartz with blebs, veinlets, and disseminated grains of sphalerite, galena, and chalcopyrite. Unbrecciated limestone contains scattered grains and veinlets of these minerals. Apparently minerals were deposited both by fracture filling and by replacement of the limestone.

The degree of mineralization varies considerably at the different mines. The richest lead ore is exposed at Patria and is mixed with pyrite and altered limestone. Several veins and lenses of pyrite and sphalerite with lesser galena are exposed at Esperanza. The zone at Otito contains much pyrite, ankerite, and minor amounts of galena and sphalerite.

In the underlying sandstone at Patria and within 30 meters of the principal zone a few small irregular galena veins crop out along fracture and breccia zones parallel to bedding. At Esperanza a vein in the sandstone strikes N. 45° E. and dips 35° SE. and contains 10 to 20 centimeters of quartz and pyrite with a few blebs of chalcopyrite.

Veins at the three mine areas have been explored and mined in pits, trenches, and short adits. The vein in sandstone at the Esperanza mine was explored by means of several inclined shafts up to 5 meters long and a drift about 10 meters long. At the time of our visit in 1949 the Patria mine was being worked by two men, and the other mines were inactive.

These mineralized zones are the largest and most persistent seen in the region. On the whole they are of low grade, and detailed sampling would be necessary to determine the quantity and grade of minable material. If blocks of the zones could be mined in toto, the reserves should be very large. Some small veins of galena can be mined profitably by hand, but selective mining on a larger scale would not be profitable.

PACIENCIA PROSPECT

The Paciencia prospect lies near the mouth of a small tributary valley extending southward from Quebrada Cara. In airline distance the prospect is 4.1 kilometers east of the Pachapaqui concentration plant, and the trail distance is 6 to 7 kilometers. The prospect is at the level of the stream at an altitude of 4,120 meters.

Two veins about 10 meters apart are exposed in a 3-meter adit and a pit in an area covered by slide rock and soil at the south side of the stream. The north vein strikes N. 45° W. and dips 85° NE., and the south vein strikes N. 65° W. and dips 80° SW. The veins range from 50 to 80 centimeters wide and contain breccia fragments, quartz, and white coarsely crystalline calcite with pods and veinlets of pyrite, sphalerite, and galena. Because of the poor exposures, the horizontal and vertical extent of the veins could not be determined, but they are probably not more than a few meters long.

The content of galena and sphalerite is insignificant, and it is doubtful that further exploration would reveal minable material.

ARABIA MINE

The Arabia mine is on the west side of Quebrada Burro 4.9 kilometers airline distance northeast of the Pachapaqui concentrator. The main workings are between the altitudes of 4,310 and 4,430 meters. The trail distance to Pachapaqui is 8 to 10 kilometers.

The country rock is coarse-grained light-gray sandstone striking N. 40° W. and dipping 80° NE. to vertically. Several irregular fissure veins 20 to 40 centimeters wide and 10 to 50 meters long crop out in a fault or shear zone 5 to 10 meters wide and more than 150 meters long. The veins strike N. 10°–45° W. and dip 80° NE. to vertically, nearly parallel to bedding. Vein material consists of vuggy white quartz with some rhodonite and with small lenses, irregular pods, veinlets, and disseminated grains of pyrite, chalcopyrite, sphalerite, galena, and tetrahedrite.

According to local inhabitants the mine was worked during Colonial times, and throughout the area are many surface pits, shafts, drifts, and open stopes. The main adit, more than 300 meters long, is the lowest and the easternmost opening. It exposes several pyrite-quartz veins that in places contain disseminated chalcopyrite. Although there is no record of production, the size of the workings indicates that several thousand tons of vein material were removed.

It is probable that the mine was operated for a number of years and that most of the ore has been mined. The remaining vein material seems to be of low grade, and reserves are small.

VETILLA MINE

The Vetilla mine is on the east side of Quebrada Tunacancha, near the crest of the ridge between Quebrada Tunacancha and Quebrada Burro and about a kilometer northwest of the Arabia mine. The main workings lie between the altitudes of 4,300 and 4,400 meters. The trail distance to Pachapaqui via Quebrada Tunacancha is 6 to 7 kilometers.

The country rock is thin-bedded dark-gray quartzite with interbedded phyllite, striking about N. 35° W. and dipping 85° SW. The vein area is largely covered with slide rock and waste material from several adits. Almost all the waste material consists of barren quartzite, and a careful search of the dumps revealed only a few fragments of vuggy, crystalline quartz with disseminated grains of pyrite, galena, sphalerite, and tetrahedrite.

A few veinlets of quartz and pyrite trending parallel to the strata are exposed in one adit 75 meters long. Several short crosscuts intersect a bedding fault zone as much as a meter wide containing altered wall rock and gouge with veinlets of pyrite. The drifts along this zone are completely caved.

Local inhabitants could not give any information about the mine, but the workings are old, and the area may have been explored at the time the Arabia mine was operating. There are at least three caved or flooded adits which, to judge by the size of the dumps, were from 50 to 100 meters long.

No lead, zinc, or copper minerals were observed in the exposed veins, and the small quantity of sulfide minerals on the dumps suggests that practically none were encountered during mining.

ABANDONADA PROSPECT

The Abandonada prospect is about 150 meters north of the Arabia mine, in the west wall of Quebrada Burro. The altitude at the adit is 4,340 meters.

The country rock is massive gray limestone which strikes about N. 15° W. and dips nearly vertically. Several irregular replacement bodies and veinlets of quartz, rhodonite, and rhodochrosite are in a zone up to 15 meters wide and more than 50 meters in horizontal and vertical extent. The replacement bodies tend to be elongate parallel to the bedding of the limestone. Both ends of the mineralized zone are covered with slide rock.

Most lenses are not more than 1 to 2 meters wide and 5 to 10 meters long. They consist of compact and tough masses of intermixed wall rock, white quartz, and pink rhodonite and rhodochrosite, with disseminated grains of pyrite, chalcopyrite, sphalerite, galena, and tetrahedrite.

The area was explored by a prospect pit and a 6-meter adit. The prospect was abandoned prior to 1949, and it is doubtful that any ore was shipped.

The veins are low grade and visible reserves small. However, this zone may be a continuation of the San Antonio vein and might warrant further exploration. The vein material is too low grade to be mined and concentrated by hand.

SANTA ELENA MINE

Two veins have been worked on the Santa Elena property. Santa Elena I, the southern vein, is on the west side of Quebrada Burro 300 meters east of the Arabia mine, and Santa Elena II is 250 meters to the northeast. The adit at Santa Elena I is at an altitude of 4,200 meters, and that at Santa Elena II is 4,170 meters.

The country rock at Santa Elena I is light-gray crystalline limestone which strikes N. 30° W. and dips nearly vertically. Sulfide minerals occur in a main vein a few centimeters to a meter wide and about 20 meters long as well as in a shorter off-shoot vein. The major vein strikes N. 45° W. and dips 90°, and the off-shoot strikes N. 70° W. and dips 65° SW. The veins contain vuggy quartz and pyrite with veinlets and pods of galena, sphalerite, and tetrahedrite. The ore is banded and crustified and contains open cavities lined with calcite crystals.

The principal vein was worked from a 10-meter adit, and possibly several tons of ore were extracted. Although small-scale mining might produce an additional few tons of ore, reserves appear to be very small. The mine was inactive at the time of our visit.

The country rock at the Santa Elena II vein is gray crystalline limestone striking N. 40° W. and dipping 70° SW. The vein minerals were deposited in fissures along a fault zone striking N. 35° W. and dipping 50°–75° SW. The zone has an average width of 1 meter and horizontal and vertical ranges of more than 30 meters. It consists largely of limestone breccia, gouge, and pyrite, with pods and grains of galena, sphalerite, chalcopyrite, and tetrahedrite. At places it contains bodies of moderate- to high-grade ore, ranging from one to two meters long and as much as one meter wide. Much of the vein is webbed with veinlets of quartz and calcite.

An adit 25 meters long was driven on the Santa Elena II vein, and probably several tons of copper-lead-silver ore were extracted. The mine was not operating in 1949, but it seems likely that small scale hand mining of the vein would be profitable for a few years.

PRIMAVERA PROSPECT

The Primavera prospect is in a small gorge cut by the main stream near the center of Quebrada Burro, 4.5 kilometers northeast of Pachapaqui. The altitude of the adit is 3,960 meters.

A mineralized fault and shear zone, striking N. 20° W. and dipping 55° SW., crops out near the stream level in a light-gray sandstone which strikes N. 35° W. and dips 55° SW. The most persistent vein in the shear zone, about 5 centimeters wide and 10 meters long, contains quartz and pyrite with minor amounts of galena and sphalerite. Small stringers and pods of these minerals also occur in the shear zone within 1 meter above and below the vein. The zone was explored by a 2-meter adit, but no ore was encountered and the prospect was abandoned.

A second vein is exposed in a small outcrop about 75 meters to the southwest. The vein is about 20 centimeters wide and contains calcite with disseminated sulfides. It is largely covered but at the outcrop strikes N. 65° W. and dips 75° SW.

Both veins are small and nearly barren, and further exploration does not seem justified.

DOS COMPADRES PROSPECT

The Dos Compadres prospect is on the east side of Quebrada Burro about 700 meters northeast of the Primavera prospect. Several small prospect pits are between the altitudes of 4,100 and 4,110 meters.

The prospect is a new discovery and was being explored by three or four small pits at the time of our visit. The vein seems to be a tabular body 25 to 40 centimeters thick and 5 to 15 meters long, parallel to bedding of silicified limestone striking N. 25° W. and dipping 45° SW. The vein parallels a dip slope and is covered with about 50 centimeters of limestone which is cut by veinlets. Vein material is predominantly pyrite, calcite, and gouge with pods and disseminated grains of galena, sphalerite, and chalcopyrite.

The vein is small and low-grade and probably cannot be worked at a profit.

SINCHI ROCA MINE

The Sinchi Roca mine is on the east side of Quebrada Burro 400 to 600 meters east of the Primavera prospect. The main lower adit is at an altitude of 4,050 meters, 75 to 100 meters above the pampa.

The country rock is gray crystalline limestone which strikes N. 25° W. and dips 80° SW. Vein minerals were deposited in fissures and also replace wall rock along an irregular fault zone which strikes N. 25°–45° W. and dips 45° SW. to nearly vertically. The vein is more than 150 meters long and has an exposed vertical range of about 125 meters. Ore shoots are lenticular, generally 10 to 20 meters long, and have a maximum width of 1 to 1.5 meters. The areas between ore shoots are altered and contain veinlets of sulfide minerals.

The ore shoots contain much pyrite, gouge, quartz, and calcite with pods and disseminated grains of galena, sphalerite, and chalcopyrite. Much of the vein material is stained red-brown with iron oxide. Outcrops show some copper stain, and numerous open cavities contain crystals of azurite and malachite. The ore shoots were estimated to contain 5 to 15 percent of combined lead, zinc, and copper sulfides.

The main adit is 15 meters long, and the vein has been stoped upwards for 2 to 3 meters. A second adit about 150 meters southeast is 5 meters long, and stopes extend upward about 3 meters to the surface.

Probably as much as 100 tons of vein material were mined, but the grade of the ore and amount of concentrate shipped are not known.

The Sinchi Roca vein is one of the more accessible of the district, and reserves are probably large enough to support a profitable small-scale operation for several years.

SANTA BENITA PROSPECT

The Santa Benita prospect is near the head of Quebrada Burro about 200 meters southeast of Laguna Burro. The altitude of the adit is 4,320 meters.

Many veinlets of sulfide minerals are in closely spaced, parallel fractures and in breccia along a fault zone striking N. 35° W. and dipping 90°. The wall rock is recrystallized and silicified limestone that strikes N. 55° W. and dips 55° S.

The veinlets are vuggy and consist largely of pyrite and quartz with minor amounts of galena, sphalerite, chalcopyrite, and tetrahedrite. Many of the vugs are lined with quartz and tetrahedrite crystals. On the average, the mineralized zone is 20 centimeters wide and has a horizontal and vertical extent of more than 20 meters. The richest part was explored by a 4-meter adit, but the vein material appears to be too low in grade to be mined.

RASCACIELO MINE

The Rascacielo mine is on the east side of Quebrada Burro, 300 meters south of the Santa Benita prospect. At the portal of the adit the altitude is 4,360 meters. The main trail from Pachapaqui to Huallanca passes by the mine.

Minerals were deposited in a gouge and breccia zone, striking N. 70° W. and dipping 55° N., in silicified limestone which strikes N. 45° W. and dips 80° NE. Much of the area is covered with soil, and the zone is best exposed in an old adit about 40 meters long. Here it ranges in width from 50 centimeters to a meter and extends more than the full length of the adit.

Irregular fractures along the fault zone contain calcite and quartz with disseminated grains of sulfide minerals. A few larger bodies of sulfide minerals, as much as a meter wide and 1 to 3 meters long, consist largely of pyrite with lesser amounts of chalcopyrite, galena, and sphalerite.

The adit appears to be very old, but the face was extended a few meters in recent years. The mine was not being worked at the time of our visit in 1949. Most of the vein is barren, but a few tons of ore are exposed in the richer sulfide bodies.

SOCORRO PROSPECT

The Socorro prospect is at the northeast end of Quebrada Burro near the Pachapaqui-Huallanca trail, about 0.5 kilometers west of Paso Burro and 7 kilometers northeast of Pachapaqui. The altitude of the lowest adit is 4,400 meters.

Thin-bedded gray limestone striking N. 40° W. and dipping 45°–70° SW. is cut by at least three small mineralized shear zones. One of the zones strikes N. 45° W. and dips 55° NE., and the other two are parallel to bedding. The zones, ranging from 5 to 30 meters in length and a few centimeters to 75 centimeters in width, are within an area less than 35 meters long and 10 meters wide. Vein material consists largely of rubbly, soft, reddish iron oxide and shattered gray limestone with veinlets and pods of galena, sphalerite, pyrite, and quartz. A few crystals of tetrahedrite were seen in specimens on the dumps.

The area was explored by 3 adits ranging in length from 5 to 7 meters, and it is possible that a few tons of low-grade lead-silver ore were mined before the prospect was abandoned. There is no ore in sight, and further exploration is not warranted.

RIQUEZA MINE AND PRADO PROSPECT

The Riqueza mine is about 200 meters west of the crest of the Cordillera Huayhuash, on the east side of Quebrada Burro. The workings are between the altitudes of 4,650 and 4,700 meters. The Prado prospect is about 400 meters to the southwest and 50 to 100 meters lower in altitude. A trail about 700 meters long, which originally connected the Riqueza mine with the Pachapaqui-Huallanca trail near the Rascacielo mine, has been largely destroyed by rockslides.

The country rock is silicified and pyritized limestone which in the Riqueza area strikes N. 55°–75° E. and dips nearly vertically and in the Prado area strikes about N. 30° W. and dips 70° SW. A small irregular intrusive of porphyritic granite crops out southeast of the vein areas near the crest of the cordillera.

At Riqueza the main vein is along a bedding shear or fault zone striking N. 60° E. and dipping nearly vertically, which is 40 to 70 centimeters wide and is exposed throughout the length of a 70-meter adit. The vein minerals, consisting of vuggy quartz and rhodonite with veinlets and disseminated grains of pyrite, chalcopyrite, tetrahedrite, galena, and sphalerite, were evidently deposited in fissures and cavities in the zone. A second vein cropping out about 200 meters to the southwest is on another shear zone striking N. 75° E. and dipping 85° N., nearly parallel to bedding in the silicified limestone. This vein was opened by a trench 10 meters long and 5 meters deep, from which a lens of lead-copper ore seems to have been mined. The vein now exposed in the trench is as much as 70 centimeters wide and consists of many irregular veinlets in silicified limestone. The minerals are essentially the same as in the vein to the northeast but occur as both wall rock replacements and cavity fillings.

At Prado three small irregular fissure filling and replacement veins crop out; one is parallel to the bedding of the limestone, and the others strike nearly east and dip 80° to 90° S. The veins, ranging from a few centimeters to a meter wide and 1 to 10 meters long, contain stringers and irregular bodies of quartz, calcite, and pyrite with disseminated grains and pods of chalcopyrite, galena, and sphalerite.

The veins at Prado were explored by small prospect pits, and a few hundred pounds of ore were extracted and stockpiled at the mine. Several tons of ore were probably extracted from the Riqueza workings.

The area is one of the most inaccessible of the Pachapaqui district, and transportation of ores and supplies would be difficult and expensive. No ore was in sight at the time of our visit, but further exploration, especially around the contacts of the intrusive body, might expose pockets of ore which could be mined on a small scale.

SAN ANTONIO PROSPECT

The San Antonio prospect is 100 to 200 meters north of the ridge between Quebrada Burro and Quebrada Nupocuta and 800 meters southeast of the Sinchi Roca mine. The workings are between the altitudes of 4,370 and 4,380 meters.

The country rock is metamorphosed and silicified limestone which strikes N. 40° W. and dips 85° SW. Ore and gangue minerals form irregular replacement lenses and veins, ranging from a few centimeters to 2 meters in width and less than a meter to 15 meters in length, along irregular fractures within a large shear zone. The general trend of the lenses and veins is N. 40° W., and average dip is 80° NE. These lenses are restricted to a zone about 5 meters wide which can be traced northwestward about a kilometer, almost to the pampa in Quebrada Burro. The zone, if projected northwest, would include the Abandonada prospect, and mineralization at both mines is similar.

Between the San Antonio workings and a second area of strong mineralization 400 to 500 meters northwest the zone contains only a few mineralized lenses and irregular pods. This second area is near the west contact of a small intrusive body of granite.

The vein material is largely an altered limestone and consists of calcite, rhodochrosite, rhodonite, and quartz with veinlets, disseminated crystals, and blebs of pyrite, chalcopyrite, galena, and sphalerite. Some of the lenses contain a moderate amount of sulfide minerals, whereas others are almost barren. Many cavities in the veins, as large as 20 centimeters in diameter, are lined with quartz crystals.

Prospect pits have been opened on several of the mineralized bodies, and one of the largest lenses was explored by a short inclined shaft. Most of the vein material appears to be too low in grade to be mined and concentrated by hand, and it is doubtful that concentrates have been shipped.

This mineralized zone is more extensive than most and contains moderately large tonnages of vein material. Mining of isolated lenses probably would be expensive, and the tenor may be too low to pay mining costs. However, if roads are built into the Pachapaqui district, the San Antonio and Abandonada areas should be worthy of further investigation.

SANTA CLARA MINE

The Santa Clara mine lies on the north side of Quebrada Nupocuta 5.2 kilometers east of the Pachapaqui concentration plant. The workings on the main vein lie between the altitudes of 4,200 and 4,210 meters.

At least three small quartz-sulfide fissure veins crop out in silicified limestone which is nearly horizontal. Only one vein, with an outcrop length of about 25 meters and a maximum width of 75 centimeters, contains an appreciable amount of sulfide minerals. It strikes east and dips 75° S. Vein material consists of massive quartz with small irregular pods of pyrite, galena, and sphalerite. Most sulfide bodies are not more than 0.5 meter long and 20 to 30 centimeters wide. Two other quartz veins are exposed in prospect pits about 200 meters to the west. One vein strikes N. 25° W. and dips 75° NE., and the other strikes N. 65° E. and dips 85° SE. They contain iron oxide and quartz but practically no sulfide minerals.

During 1949 the sulfide pockets in the main vein were mined from small surface pits, and a few tons of concentrate was shipped to the Pachapaqui concentrator. It is doubtful that the hand-sorted ore contained enough lead and silver to pay mining and shipping costs. The remaining vein material is low-grade, and the reserves are small.

SAN MIGUEL I AND II PROSPECTS

The two San Miguel properties are near the pampa in Quebrada Nupocuta about 5 kilometers east of the Pachapaqui concentration plant at altitudes near 4,000 meters.

At San Miguel I a few small prospect pits explore the top of a low hill on the south side of the valley. The country rock is massive dark-gray limestone cut by a mineralized fault or shear zone striking N. 70° E. and dipping nearly vertically. Numerous veinlets and small lenses of calcite and pyrite with pods and disseminated grains of galena and sphalerite fill cavities and partly replace the sheared and brecciated limestone along the fault and irregular fractures and shears on both sides of the fault. The mineralized zone is 5 to 10 meters wide and more than 20 meters long. The largest mineral lens has a maximum width of about a meter and is several meters long. The other lenses are less than 30 centimeters wide and 1.5 meters long.

At San Miguel II a 43-meter adit on the north side of the valley 400 meters north of San Miguel I exposes a fault zone striking N. 20°–30° W. and dipping from 85° to 90° NE. The zone contains sheared and brecciated limestone and gouge with veinlets and pods of calcite, pyrite, galena, and sphalerite.

Both areas are largely covered with alluvium and soil. No ore was seen in the workings, and it is doubtful that further exploration would disclose minable material. Probably no ore has been shipped.

FORTUNA MINE

The Fortuna mine is in the west side of Quebrada Shicra Shicra about 600 meters southeast of San Miguel I. The portal of the adit is at an altitude of 4,200 meters.

Two veins crop out in silicified dark-gray limestone which strikes N. 20° W. and dips 85° NE. The principal vein, striking N. 70° W. and dipping 70° SW., contains quartz and sulfide minerals which have filled irregular fissures and replaced wall rock along a fault zone. This vein is more than 50 meters long and ranges from 10 centimeters to a meter in width. It contains pyrite, quartz, chalcedony, and sphalerite with minor amounts of galena and arsenopyrite. Limestone in the footwall is silicified and contains disseminated sulfide minerals.

The second vein, exposed in a prospect pit to the east of the main vein, strikes N. 55° E. and dips 70° NW. This vein is about 40 centimeters wide and contains veinlets and disseminated grains of pyrite and sphalerite.

The principal vein was explored and mined from an adit 19 meters long. The mine was opened around 1940, and probably several tons of lead-silver concentrate were shipped. The mine was not operating in 1949. Ore is low grade, and reserves are small.

LUÍS ADOLFO PROSPECT

The Luís Adolfo prospect is about 200 meters northeast of the Fortuna mine on the east side of Quebrada Shicra Shicra. The vein is exposed between the altitudes of 4,120 and 4,130 meters.

A mineralized shear and breccia zone in massive dark-gray limestone strikes N. 35°–75° E. and dips 65° SE. to vertical. The zone has a maximum width of a meter and can be traced on the surface for 15 to 20 meters. Minerals were deposited in fractures and cavities and also appear to have replaced part of the limestone. The zone contains much sheared and brecciated limestone and pyrite with lesser marmatite and minor amounts of galena. Locally it is webbed with veinlets of calcite and quartz.

The zone was explored by two or three prospect pits, but no ore was encountered, and further exploration would probably not be remunerative.

GABY PROSPECT

The Gaby prospect is on the ridge between Quebrada Shicra Shicra and Quebrada Nupocuta about 1 kilometer east of the Fortuna mine. One prospect area is north of the ridge crest at an altitude of 4,270 meters, and the other is 400 meters to the south in Quebrada Shicra Shicra between the altitudes of 4,220 and 4,230 meters.

The country rock is thin-bedded dark-gray limestone with shaly and sandy layers, striking N. 35°–60° W. and dipping 20°–25° SW.

Some of the limestone beds have been silicified and serpentinized. A dike or irregular intrusive body of porphyritic granite, cropping out near the south prospect area, is as much as 8 meters wide, strikes about N. 20° W., and dips nearly vertically.

At the north prospect an irregular replacement body about 2 meters in diameter, of serpentine, quartz, and sulfide minerals, is exposed in an adit 2.5 meters long. The ore body is in the footwall of a normal fault striking N. 40° W. and dipping 55° SW. Slickensides on the fault plunge 40° SW. In the replacement body veinlets of calcite strike N. 40° W. and dip vertically; they appear to have formed along tear fractures in the footwall of the fault. The ore consists of serpentinized limestone with disseminated crystals, pods, and veinlets of chalcopyrite, pyrite, galena, sphalerite, and pyrrhotite.

At the southern prospect several irregular replacement bodies and veins crop out in limestone near the west contact of the granite intrusive. The three largest veins are 5 to 10 meters long and 25 centimeters to 3 meters wide. They appear to have formed by fissure filling and partial replacement along irregular shear and fracture zones striking N. 5°–55° E. and dipping nearly vertically. The mineralization is similar to that at the northern prospect, but veins contain more sphalerite and less galena.

During 1949 the northern prospect was worked, and a few tons of hand-sorted ore were sent to the Pachapaqui concentration plant. The southern prospect was explored and mined from 4 or 5 pits, and a few tons of hand-sorted ore may have been shipped.

The veins may contain enough chalcopyrite and galena to support the present scale of operation for a year or two. However, individual lenses contain only a few tons of ore, and once the surface area is mined, exploration costs may be prohibitive.

LUCERO PROSPECT

The Lucero prospect is near the mouth of a small valley on the east side of Quebrada Shicra Shicra about 500 meters southeast of the Gaby property. The workings lie between the altitudes of 4,320 and 4,330 meters.

Silicified limestone striking N. 85° W. and dipping 80° N. is cut by a fissure vein which strikes N. 70° W. and dips nearly vertically. The vein contains much soft iron oxide, quartz, and rubbly and crystalline calcite. Within this material are disseminated grains of pyrite, galena, and tetrahedrite. The vein is about 70 centimeters wide and 60 meters long.

The prospect area is largely covered with talus, but the vein is exposed in an 8-meter shaft and several small prospect pits. No minable material was seen.

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EXITO PROSPECT

The Exito prospect is about 400 meters to the east of the Lucero prospect and in the same valley. A single prospect pit in the area is at an altitude of 4,350 meters.

A fissure vein, exposed in a vertical cliff of silicified limestone, strikes N. 35° W. and dips nearly vertically. The vein has a maximum width of 25 centimeters and a vertical range of at least 30 meters. It contains quartz and pyrite with disseminated grains of tetrahedrite, galena, and sphalerite. Apparently no ore was encountered in the prospect pit. The vein is too small and the mineral content too low to warrant further exploration.

PERÚ MINE

The Perú mine is in cliffs about 200 meters southeast of Exito. The portal of the upper adit is at an altitude of 4,450 meters, and a lower adit is 30 to 40 meters below.

Country rock is silicified limestone near the west edge of a complexly folded area along the crest of the cordillera. At the mine the limestone strikes N. 15° W. and dips 80° SW. A fissure vein of massive and crystalline quartz, about 40 meters long, strikes N. 85° W. and dips nearly vertically. The vein was explored and mined from two adits 7 and 10 meters long respectively. In the lower 7-meter adit the vein is about 10 centimeters wide and contains only quartz, whereas in the upper adit the vein is 35 to 40 centimeters wide and contains minor amounts of pyrite, galena, sphalerite, and tetrahedrite.

Local inhabitants stated that this mine was worked for silver, and it is possible that several tons of low-grade concentrates were shipped. The material now exposed in the vein cannot be mined profitably.

TRES REYES MAGOS PROSPECT

The Tres Reyes Magos prospect is at the east side of Quebrada Shicra Shicra 600 meters south of the southern workings at the Gaby prospect. The main prospect pit is at an altitude of 4,240 meters.

The mineralized area is along the north contact of a granitic dike cutting dark-gray metamorphosed limestone. The limestone strikes N. 40° W. and dips nearly vertically, and the dike strikes east and dips 65° N. A small lens of sulfide minerals was mined from a pit about 2 meters deep. The vein exposed in the pit is about 10 centimeters wide and contains quartz with disseminated crystals of pyrite. One or two tons of vein material on the dump is largely pyrite and quartz with lesser sphalerite and minor galena. A smaller pit about 10 meters to the east along the dike exposes a few quartz veinlets.

No ore has been shipped from the prospect. The veins are very small and barren, and no additional exploration is justified.

SAN JUDAS TADEO PROSPECT

The San Judas Tadeo prospect is at the south end of Quebrada Shicra Shicra about 600 meters south of the Tres Reyes Magos prospect. It is the southernmost mine in the district and is about 7 kilometers southeast of Pachapaqui. The workings on the veins are between the altitudes of 4,350 and 4,420 meters.

Several mineralized shear and fault zones occur on both sides of a contact between recrystallized limestone and an overlying sequence of thin- to medium-bedded phyllites and quartzites. Beds strike N. 45° W. and dip 60° SW., and most veins are nearly parallel to bedding. One major cross vein strikes N. 80° E. and dips nearly vertically. Sulfide minerals occur in pods, irregular veins, and well-defined lenses along shear zones in the phyllite and quartzite and apparently were deposited in open fissures and cavities. Sulfide minerals in the limestone occur as pods, veinlets, and scattered grains in irregular zones up to 5 meters in diameter, and most apparently were deposited by replacement. The bodies of sulfide minerals crop out over an area 1 to 10 meters wide and at least 300 meters long.

The ore minerals are sphalerite, galena, and chalcopyrite in a gangue of wall rock, quartz, pyrite, and calcite. Dark-brown to black sphalerite, possibly the variety marmatite, is the most common ore mineral, and in a few places forms nearly solid lenses 1 to 2 meters long and as much as a meter thick. Galena appears to be more abundant in replacement bodies in limestone than in the fissure veins. The mineralized zones in limestone have associated irregular patches and disseminated crystals of epidote, and at places the limestone is transected by veinlets of white crystalline calcite, which locally make up 30 to 40 percent of the rock. The calcite was evidently the last mineral to be deposited.

Several veins along the zone have been explored by small prospect pits, but no ore has been shipped. The prospect was inactive at the time of our visit in 1949.

Although the area has not yet been prospected adequately, small-scale mining of the richer pockets of galena and chalcopyrite should be profitable for several years. Further exploration, especially of the limestone zones now covered with glacial debris, may reveal additional ore bodies.

OTHER DEPOSITS

Prospect 1.—This prospect is reported to have been explored in 1948 or 1949, but the name was not known to the inhabitants of the district. For purposes of reference it is designated Prospect 1. The prospect is on the north side of Quebrada Nupocuta, about 500 meters north of the Santa Clara mine. The workings are between the altitudes of 4,240 and 4,270 meters.

Two veins occur along shear zones in a dark-gray metamorphosed limestone which strikes N. 25° W. and dips 70° SW. On one vein, striking N. 30° W. and dipping 75° SW., a lens of sulfide minerals about 5 meters long and 1 to 1.5 meters wide was mined from a small trench. Ore on the dump consists of quartz and rhodonite with 5 to 15 percent of chalcopyrite, galena, and sphalerite. A 5-meter crosscut to the vein 8 meters below the trench does not expose sulfide minerals.

Another shear zone, about 50 meters to the northeast, strikes N. 85° W. and dips 75° NE. It contains two lenses of vein minerals, each about 5 meters long and a meter in maximum width, which consists of rhodonite, quartz, and pyrite with minor amounts of galena, chalcopyrite, sphalerite, and tetrahedrite.

It is possible that a few tons of copper and lead concentrates were shipped. The tenor of the remaining ore is low, reserves are small, and it is doubtful that further mining would be profitable.

PACLLÓN-LLAMAC MINING DISTRICT

The Pacllón-Llamac mining district is about 20 kilometers southeast of Chiquián in the southeastern part of Bolognesi Province in the Departamento de Ancash. Most of the mines are on the ridge between Quebrada Pacllón on the south and Quebrada Llamac on the north. Five kilometers east of the mine area the Pacllón-Llamac ridge intersects the Cordillera Huayhuash about 5 kilometers north of Nevado Yerupajá. The buildings of Hacienda Palca are near the east end of Quebrada Llamac and at an altitude of approximately 3,660 meters; the east end of Quebrada Pacllón is somewhat higher. A trail from Hacienda Palca to Quebrada Pacllón crosses the Pacllón-Llamac ridge at an altitude of nearly 4,570 meters. Fig. 6 shows the location of mines in the district.

The mining district is accessible from Chiquián by a trail which passes through the towns of Llamac and Pocpa to Hacienda Palca, a distance of about 35 kilometers. From Palca the mines are all within 2 hours' ride on horseback.

The major valleys of this area are U-shaped, as is best shown in Quebrada Llamac (fig. 19), and trend westerly to drain into the Río Pativilca. A small pampa at Palca appears to be a filled-in glacial lake, and several small glacial lakes still exist in Quebrada Pacllón. Nevado Yerupajá and surrounding peaks of the Cordillera Huayhuash are covered with active glaciers.

The sedimentary rocks exposed in the Pacllón-Llamac ridge consist of sandstones of early Neocomian age; a sequence of limestones, shales, and sandy shales of Barremian age; and more massively bedded limestones with minor amounts of shale, which probably represent the Machay and Jumasha. The base of the lower Neocomian was not seen but exposed beds are several hundred meters thick. A massive limestone immediately overlying the sandstone, probably the lower unit of Steinmann's Barremian sequence, is about 200 meters thick. The heterogeneous sequence is considered as the middle unit of the Barremian and is of the order of several hundred meters thick. The upper limestone unit of the Barremian was not differentiated in the field from the more massive overlying Machay and Jumasha limestones. Most of the veins occur in the lower limestone unit, directly overlying the lower Neocomian, but several are also found in the lower Neocomian sandstone and in the shales and shaly sandstones of the middle unit of the Barremian.

Throughout the entire region southeast of Chiquián few igneous rocks are visible. The only intrusions seen in the mine area were a diorite dike, an andesite sill, and a rhyolite sill. At a distance Nevado Yerupajá and nearby peaks appear to consist of folded and steeply dipping sedimentary rocks (fig. 11), and prominent igneous masses seem to be absent.

The outstanding features of the regional structure are large upright anticlines and synclines characterized by sharp crests and troughs and steeply dipping limbs. The axial planes trend N. 20°–30° W. and dip nearly vertically. On the Pacllón-Llamac ridge, faults cutting across the strata are rare, whereas bedding faults are many. Fissure veins are on cross faults, and most replacement veins are along bedding faults.

The predominant vein minerals are pyrite, marmatite, and quartz. A little galena occurs in nearly all veins, and chalcopyrite is found in many. A few veins contain tetrahedrite and arsenopyrite, and one or two others have pyrrhotite or magnetite. Limestone near most replacement veins is silicified and garnetized.

Most of the veins have a surface coating of iron oxide. Rocks on the Pacllón-Llamac ridge contain enough red iron oxide to give them a prominent reddish color. In the Susana mine area streams and springs have deposited iron oxide in the alluvium, forming breccialike masses 1 to 3 meters thick and as much as 50 meters in diameter.

The mines in the Pacllón-Llamac district most worthy of further exploration are:

Susana—low-grade zinc-lead ore, many short veins and mineralized zones, large mineralized area.

San Samuel—low-grade zinc-lead ore, two principal veins 50 to 100 meters long.

BONANZA MINE

The Bonanza mine is in a small gully in the cliffs at the south side of Quebrada Llamac about 0.5 kilometer south of the buildings of Hacienda Palca and 4 kilometers east of Pocpa. The principal workings are between the altitudes of 3,970 and 4,010 meters.

The gully is cut in a thin sequence of black shales and argillites within light-gray sandstone. The strata, striking N. 25°–30° W. and dipping 60°–65° NE., are on the east limb of a large upright anticline whose crest lies between this mine and the Susana mine about 1 kilometer to the southwest. A single outcrop of a narrow sill of altered andesite in the shale was seen at the north end of the mine area. The sill is covered with soil and talus elsewhere in the gully.

Several irregular fault and shear zones containing short sulfide veins crop out in the sandstone below the shale. Most of the veins contain gouge and breccia, and sulfide minerals appear to have been deposited in cavities and fissures. A major vein strikes N. 65°–80° E. and dips from 50° to 90° SE. Other small mineralized shear zones strike N. 35°–60° W. and dip 55° SW. to vertically. The veins occur through an area about 50 meters wide and 75 meters long.

Only the major vein, 20 to 50 centimeters wide and 25 meters long, contains a significant quantity of sulfide minerals. This vein consists of crystalline to massive quartz and pyrite with veinlets, pods, small lenses, and disseminated grains of marmatite, galena, and tetrahedrite. The vein material is banded and contains many small cavities lined with quartz crystals. The more massive lenses of ore minerals are webbed with quartz veinlets. Other veins of the area are small and nearly barren.

Six adits ranging in length from 6 to 35 meters and a few surface pits have been opened on the veins. Of the three adits on the major vein, the middle one exposes the widest part of the vein and the highest grade ore. The size of workings on this vein indicates that nearly 100 tons of vein material were extracted, and it is possible that this material yielded several tons of hand-sorted concentrate. Apparently most of the ore had been extracted in these workings when the mine was abandoned.

A few more tons of lead-silver concentrate might be mined at a profit from the present workings, but the reserves appear to be small, and it is doubtful that new ore bodies will be found.

SUSANA MINE

The Susana mine is in a broad gully in the south wall of Quebrada Llamac, 3.5 kilometers southeast of Pocpa and about 1.5 kilometers southwest of Hacienda Palca. Veins are exposed in the Susana claims over an area about 900 meters long and 200 meters wide between the altitudes of 4,000 and 4,500 meters (pl. 11). Veins also crop out for at least an additional 500 meters to the southeast of the Susana area and can be traced into the veins at the Monte Cristo mine. A trail from the mine meets the Pocpa-Hacienda Palca trail 2 to 3 kilometers east of Pocpa.

Most veins are in a fine-grained dark-gray limestone and a hydrothermally altered limestone having a thickness of more than 150 meters. This sequence is underlain by coarse-grained light-gray sandstone and grades upward into a sequence of interbedded calcareous shales, phyllites, and shaly sandstones. The sedimentary rocks are locally crumpled but in general strike N. 35°–40° W. and dip 65°–85° SW.

A rhyolite sill 1 to 4 meters thick was intruded into the upper part of the limestone. Although this intrusive is essentially parallel to the strata, it is somewhat irregular in strike and locally cuts across limestone beds. The rhyolite consists of feldspar crystals and quartz grains as much as a centimeter in diameter in a microcrystalline groundmass. Feldspars have been bleached and partly altered to clay. Mafic minerals are completely decomposed, and their former presence is indicated only by small cavities filled or stained with limonite.

The upper part of the limestone and lower part of the overlying sequence are silicated and contain much garnet, quartz, and epidote. Limestone was most intensely altered near the sill. Some of the altered rock is pale green and only partly replaced, whereas some consists entirely of green massive and crystalline grossularite garnet and quartz or epidote and quartz. Stringers and pods of unreplaced but recrystallized limestone are preserved within the altered limestone. The most conspicuous body of this type is an irregular stringer from 2 to 10 meters wide which crops out a few meters west of the sill and extends nearly the length of the mine area (pl. 11).

Mineralized zones containing lenses, pods, veinlets, and scattered grains of sulfide minerals occur in the altered limestone near the sill and along the contact between limestone and underlying sandstone. Although the zones are irregular in attitude, most tend to parallel the strata. They range from less than a meter to as much as 80 meters in length and from a few centimeters to 2 meters in width. Apparently most of the sulfide minerals were deposited by replacement of the altered limestone along bedding shears.

The contact between the limestone and the underlying sandstone is marked by a layer of altered thin-bedded calcareous shale 2 to 3 meters thick, as is shown in fig. 29. This layer, as well as material along bedding planes and cross fractures in the overlying limestone, is partly replaced by sulfide minerals (figs. 30 and 31).

The vein material consists largely of pyrite, sheared and brecciated wall rock, limonite, and marmatite with minor amounts of quartz and galena. At places lenses and irregular bodies of marmatite with finely disseminated grains of pyrite and galena are 1 to 2 meters wide and several meters long. A small mass of magnetite crops out at the limestone-sandstone contact near the south end of the area.

FIGURE 29.—Mineralized zone at contact between sandstone and overlying limestone, Susana mine.

All of the veins are covered with a crust of iron oxide, which ranges from a few millimeters to several centimeters in thickness. Beneath the crust the pyrite, and to a lesser extent the marmatite, are altered to limonite. At most places oxidation does not extend to depths of more than 1 or 2 meters.

According to local inhabitants several of the pits and small adits date from Colonial times. These are now largely caved or filled with rock debris. It is not known whether any ore was shipped from the older workings. The Northern Peru Mining and Smelting Company explored the area in 1948 and opened the four adits shown in fig. 32 but did not ship any concentrate.

Probably several thousand tons of low-grade lead ore are available in the Susana property, but ore shoots are mostly small and isolated, and underground mining would be expensive. The galena is disseminated and would be almost impossible to concentrate by hand. The principal ore mineral is marmatite, generally intermixed with pyrite, and it might contain too much iron to yield a saleable zinc concentrate.

If this region were made accessible by road, the Susana mine, and several other mines of the district probably could supply a small mill with lead ore for a number of years.

FIGURE 30.—Sulfide minerals replacing limestone along bedding planes, Susana mine. Veins near right side of photograph are about 5 cm. thick.

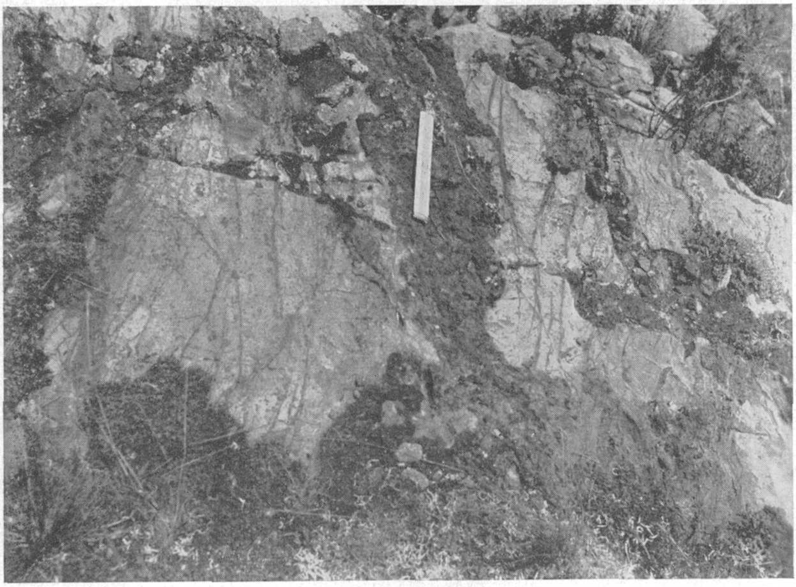


FIGURE 31.—Sulfide minerals replacing limestone along cross fractures, Susana mine. Scale is 22 cm long.

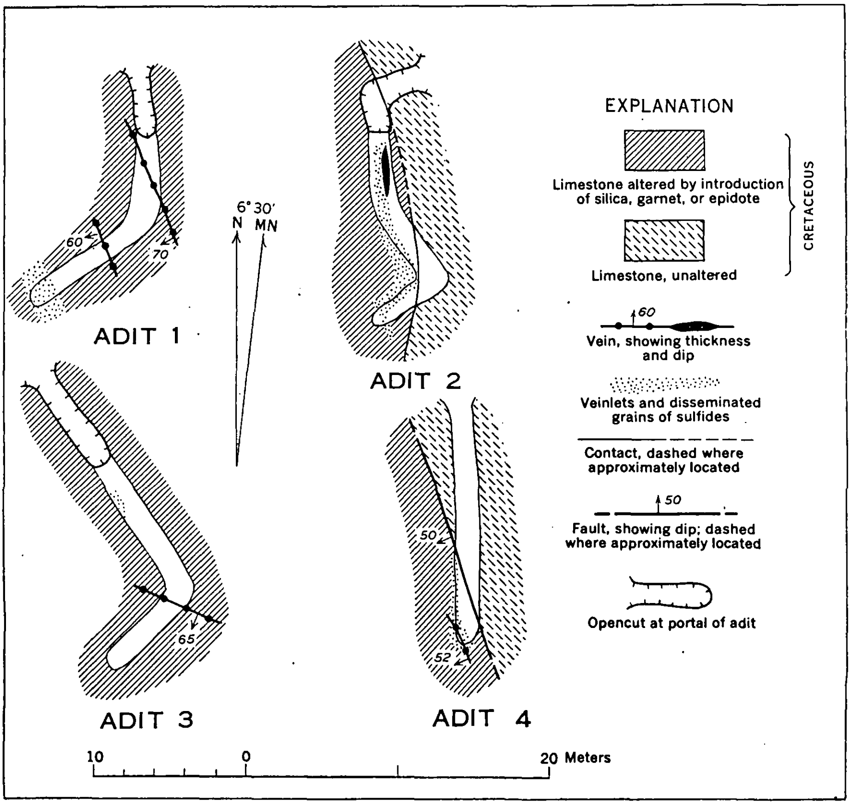


FIGURE 32.—Geologic sketch maps of exploratory adits at Susana mine, Pacll6n-Llamac district.

MONTE CRISTO MINE

The Monte Cristo mine is about 500 meters south of the Susana mine and near the top of the Pacllón-Llamac ridge. Two mineralized zones lie at altitudes of about 4,570 and 4,700 meters. The trail distance to Hacienda Palca is 4 to 5 kilometers.

The principal sulfide vein, apparently along the southern extension of the western mineralized zone at Susana, strikes N. 35° W. and dips 55° SW. This vein is lenticular in shape and ranges from less than a meter to about 7 meters wide and from 70 to 80 meters long. Wall rock is garnetized limestone or calcareous shale striking N. 25°–35° W. and dipping 65°–75° SW. The rhyolite sill of the Susana mine area crosses the ridge 30 to 50 meters to the northeast.

The second mineralized zone southeast of the principal vein and at the lower altitude (fig. 6) consists of several short veins and irregular bodies of sulfide minerals extending through an area 15 to 20 meters wide and 25 to 30 meters long. Most of the veins strike N. 15°–30°

W. and dip 65°–90° SW. The veins range from less than a meter to about 5 meters long, and most are less than 50 centimeters wide. The country rock is dark-gray fine-grained limestone striking N. 15° W. and dipping 65° SW. An anticline and a syncline, exposed in a cliff 100 meters south of the vein area, have vertical axial planes which strike N. 25° W. These folds seem to be on the southern extension of the large anticline between Susana and Bonanza mines, and they continue southward, passing through the Aida and San Samuel mine areas.

The Monte Cristo veins seem to have resulted from replacement of limestone along bedding faults and irregular shear zones. The vein material, consisting largely of a granular mixture of pyrite and wall rock, contains pods and irregular bodies of marmatite with disseminated grains of galena and is similar to the material of the Susana veins. The weathered outcrops of the veins are pitted and encrusted with dark-red to black iron oxide.

A pit on the principal vein, said to date from Colonial times, is about 10 meters long, 5 meters wide, and 5 to 7 meters deep. A few veins in the second area have been explored more recently by a pit and a room, each about 5 meters in diameter. The main vein is large but contains no ore, whereas the veins of the eastern mineralized zone contain low-grade ore but are small. It is doubtful that any of the veins could be worked at a profit.

AÍDA MINE

The Aída mine is on the south side of the Pacllón-Llamac ridge, about 500 meters south of the pass. The main workings are at an altitude of 4,490 meters. The trail from Hacienda Palca passes through the mine area.

The veins are on the east limb of a small open anticline in fine-grained light- to dark-gray limestone striking N. 10°–25° W. and dipping 50°–65° NE. A syncline and a second anticline are exposed a short distance to the east. The axial planes of the folds strike N. 15°–20° W. and dip nearly vertically.

Several short veins and irregular bodies of sulfide minerals crop out in an area 15 to 20 meters wide and 120 meters long parallel to the strike of the limestone. These veins strike N. 25°–80° W. and dip 45° to 90° NE. Most are small, but one irregular body is about 20 meters long and as much as 4 meters wide. A few zones of limestone breccia and iron oxide lie parallel to the bedding, the largest 1 to 2 meters thick and about 30 to 50 meters long.

Mineralization is similar to that at the Susana and Monte Cristo mines. The sulfide bodies range from pure pyrite to a granular mixture of limestone and pyrite containing irregular pods and lenses of marmatite with disseminated grains and veinlets of galena. One of the veins contains pyrrhotite. The iron oxide and breccia zones appear to contain no sulfide minerals.

Recently several veins have been explored and mined in surface pits. One of the owners reported that a few tons of galena concentrate was extracted from one vein.

One or two of the galena-bearing ore bodies might be mined and concentrated by hand and probably would yield a few additional tons of concentrate. However, most of the veins are of too low-grade to be mined at a profit.

SAN SAMUEL MINE

The San Samuel mine is on the south side of the Pacllón-Llamac ridge about 500 meters southeast of Aída mine. The main vein area lies between the altitudes of 4,370 and 4,400 meters. Two major veins with associated splits and irregular replacement bodies crop out in an area 50 to 60 meters wide and more than 100 meters long.

The veins are in the same folded limestone complex as those at the Aída mine and strike N. 15°–30° W. nearly parallel to the bedding and dip 70°–90° SW. The crest of an anticline lies along the east side of the vein area; its axial plane strikes N. 20° W. and dips 65° NE.

The two principal veins are about 60 meters apart, and range in width from less than a meter to as much as 4 meters. Part of the limestone in and near the veins is brecciated, suggesting that the minerals were deposited along bedding faults. Some of the vein material may have been deposited in fissures, but irregular and gradational contacts with wall rock and irregular patches of limestone along the veins indicate that mineralization took place largely by replacement.

Most of the vein material is a granular mixture of pyrite and altered limestone which contains irregular bodies of marmatite with disseminated grains and veinlets of galena. The western vein contains many lenses, pods, and disseminated grains of marmatite and was mined in trenches and shafts throughout its exposed length. The east vein at its northern end consists of pyrite and altered limestone with almost no ore minerals; the southern extension is iron-stained recrystallized limestone with disseminated pyrite. The north ends of the two veins curve toward each other, and between them are several irregular replacement bodies of sulfide minerals. One of these bodies, 5 to 7 meters wide, contains many veinlets and small pods of galena associated with marmatite, forming the richest lead ore seen at the mine.

The veins were explored by short shafts, pits, and trenches. The largest working, a shaft on the west vein, is about 10 meters deep. Twenty to thirty meters east of the main mine area surface pits and an inclined shaft, 10- to 15-meters long, explore a breccia and iron oxide zone striking north and dipping 40° E. This zone appears to be barren of sulfide minerals. All the workings are old and are said to date from Colonial times.

The veins are mostly low grade but are more persistent than most others of the district, and together with the Susana veins might furnish ore for a small concentration plant. The galena from one or two of the sphalerite bodies probably could be concentrated by hand, but in most of the veins the galena is too finely disseminated for hand concentration.

FABULOSA PROSPECT

The Fabulosa prospect is on the south side of the Pacllón-Llamac ridge about 500 meters west of San Samuel. Veins crop out in an area about 100 meters long and 40 meters wide between the altitudes of 4,470 and 4,490 meters. Trail distance from the mine to Hacienda Palca is about 6 kilometers.

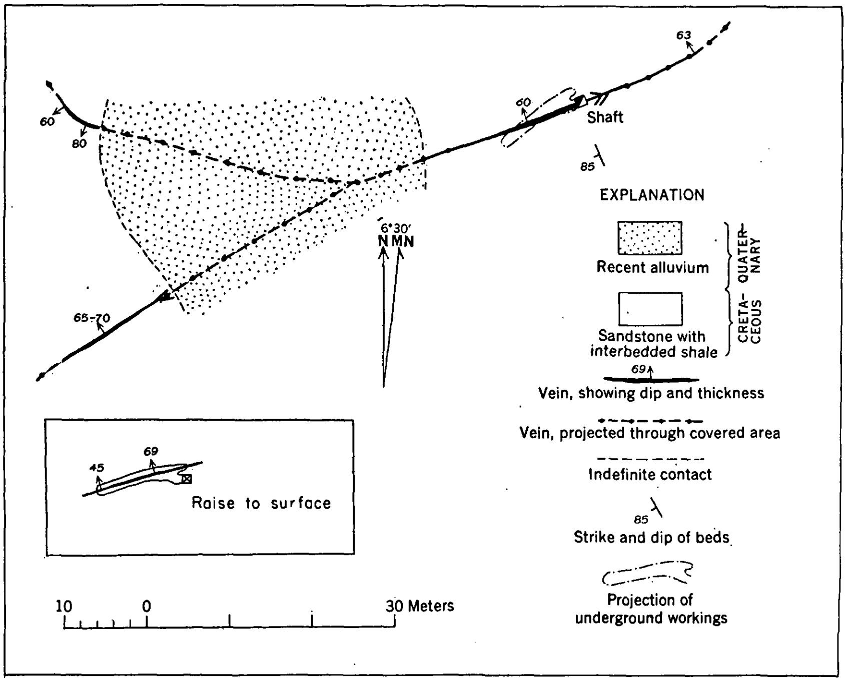
Many short veins and lenses are enclosed in limestone near the contact with overlying thin-bedded metamorphosed shales and sandstones. The sedimentary rocks strike N. 0°–35° W. and dip from 75° to 90° SW. Most veins lie nearly parallel to the strata. The veins range from a few centimeters to as much as 2 meters wide and from less than a meter to 10 meters long. Most veins are near the south end of the property and are scattered through a thickness of 30 to 40 meters of limestone along a strike distance of 15 to 20 meters. The veins contain pyrite, quartz, and altered limestone with minor amounts of marmatite, galena, chalcopyrite, arsenopyrite, and calcite. The mineralization is similar to that at the Aída mine. Much of the limestone near the veins has been silicified and garnetized.

Parts of the veins have been explored recently by pits and trenches, but no ore was encountered and the prospect was abandoned.

LA ESPERANZA MINE

La Esperanza mine is on the south side of the Pacllón-Llamac ridge about 200 meters west of the Fabulosa prospect. The workings are between the altitudes of 4,480 and 4,490 meters. The main trail from Hacienda Palca to Quebrada Pacllón passes by the mine.

Two fissure-filling veins crop out in fine- to medium-grained gray sandstone interbedded with thin shale layers. The strata strike N. 25° W. and dip 85° SW. The major vein, striking N. 55°–70° E. and dipping 60°–70° NW., appears to intersect or cut off the second vein which strikes N. 60° W. and dips 60° SW. However, the junction of the veins, as shown in fig. 33, is covered, and their true relationship is not known. Vein material consists principally of clear crystalline quartz with well-crystallized pyrite, arsenopyrite, rhodochrosite, and calcite. Crystalline light-brown sphalerite and fine-grained argentite are the only ore minerals; galena appears to be absent. The vein material is vuggy and porous, consisting of a mesh



Surveyed with compass and tape by D. Brambilla and U. Petersen, September 1949

FIGURE 33.—Geologic sketch map of La Esperanza mine, Pacllón-Llamac mining district.

of quartz crystals with lesser amounts of sulfide minerals. Crystals range from less than a millimeter to 2 centimeters in length.

The main vein is at least 80 meters long and from 20 to 70 centimeters wide. The other vein is exposed only in the cliffs about 50 meters west of the mine workings. The ore shoot on the major vein pinches out a few meters east of the workings, but an irregular shear zone continues eastward for at least 200 meters. A small vein at the north end of the Fabulosa mine area appears to be in this zone.

The main vein was worked from pits and an open stope about 5 meters deep, which bottoms at a 10-meter drift. A few tons of hand-sorted silver concentrates were shipped before the mine closed down in 1942. It appears that the richest ore has been mined, but further exploration might show other small ore shoots which could be worked profitably by hand mining methods.

MISERICORDIA PROSPECT

The Misericordia prospect is on the south side of the Pacllón-Llamac ridge about 500 meters north of La Esperanza mine. The workings lie between the altitudes of 4,620 and 4,650 meters.

Sulfide minerals occur in two small irregular shear zones and along a diorite dike south of these zones. The country rock consists of interbedded fine-grained iron-stained sandstones and dark-gray shales striking N. 25° W. and dipping 80° SW. The mineralized part of the eastern shear zone, as much as a meter wide and 10 to 15 meters long, strikes N. 85° E. and dips 60° S. It contains many quartz veinlets with associated pyrite and arsenopyrite. The second shear zone, about 200 meters to the west, strikes N. 80° W. and dips 80° S. It contains a lens 3 meters long and up to 60 centimeters wide consisting largely of an open mesh of small quartz crystals with cavities partly filled by crystalline pyrite, rhodochrosite, argentite, galena, and sphalerite. The diorite dike is about 2 meters wide and strikes N. 65° E. and dips 85°–90° NW. Small irregular fractures at the contacts of the dike contain crystals of sulfide minerals.

The shear zones and the dike contacts have been explored by small prospect pits, but apparently no ore was found and the prospect was abandoned. The veins are small, and it is doubtful that further exploration would reveal ore bodies.

BLANQUITA PROSPECT

The Blanquita prospect is about 100 meters south of La Esperanza and about 30 meters lower in altitude.

Two small irregular bodies of quartz and arsenopyrite occupy shear zones in sandstone. The shears are parallel, striking N. 65° W. and dipping 80° SW., and are about a meter apart. The mineral bodies are from 20 to 60 centimeters wide and, although largely covered, seem to be only a few meters long.

Both veins were exposed in a small prospect pit, but ore minerals appear to be absent.

AGUSTÍN PROSPECT

The Agustín prospect is about 300 meters southwest of La Esperanza, at an altitude of 4,440 meters.

Two small parallel quartz veins, striking N. 75°–80° W. and dipping from 85° NE. to vertical, are exposed in an outcrop of light-gray sandstone in a slide rock area. The veins, each from 10 to 40 centimeters wide and from 10 to 20 meters long, are about 4 meters apart and appear to have formed by fissure filling within a fault zone. The quartz contains a minor amount of arsenopyrite and lesser pyrite and galena.

During prospecting, part of the weathered surfaces were stripped from the veins, revealing them to be essentially barren of sulfide minerals. It is doubtful that further exploration would reveal ore.

ROSITA PROSPECT

The Rosita prospect is 150 to 200 meters southwest of the Agustín prospect and near the east rim of a broad, deep canyon on the south side of the Pacllón-Llamac ridge. The main prospect pit is at an altitude of 4,400 meters.

Veinlets and lenses of sulfide minerals fill fissures and partly replace altered limestone along a zone nearly 150 meters long. The veins and lenses are parallel to the bedding of the limestone which strikes N. 15°–20° W. and dips 70°–80° SW.

Most veins and lenses are less than 50 centimeters wide and 3 meters long. The largest lens has a maximum width of 60 centimeters and is about 15 meters long. It contains up to 50 percent marmatite with lesser amounts of pyrite, galena, and chalcopyrite. Other lenses and veins are similar but contain less sulfide minerals and more altered wall rock. The altered limestone and fractures near the veins contain crystals of grossularite garnet. On the whole, mineralization is similar to that at the Susana mine.

The veins have been explored by three or four pits and trenches, but probably no ore has been shipped. A few small pockets of high-grade galena within the marmatite might be mined and concentrated by hand. Otherwise, the veins are too small and too low-grade to be mined at a profit.

CCORIDELIA MINE

The Ccoridelia mine is near the head of a small valley north of Quebrada Llamac. The mine is about 2 kilometers airline distance northeast of Hacienda Palca and 5 to 6 kilometers by trail. The workings are between the altitudes of 4,400 and 4,450 meters.

The country rock is medium- to thick-bedded fossiliferous fine-grained gray limestone which overlies medium-bedded fine-grained gray sandstone. Bedding strikes N. 25°–35° W. and dips 55°–65° SW. At least ten small fissure veins are along faults, striking N. 20°–60° E. and dipping from 55° to 90° SE., which cut the limestone. Most of the faults cut across the contact of the limestone and the sandstone and displace it from a few meters to as much as 40 meters. They seem to persist in the limestone for distances of 50 to 200 meters, but most die out in the sandstone within a few meters of the contact.

The veins consist of lenses, irregular pods, and veinlets of crystalline stibnite and calcite, most of which lie within 50 meters of the contact. The larger bodies are from 5 to 30 centimeters wide and 30 centimeters to 1.5 meters long. Stibnite forms either radiating masses or open meshworks of crystals which developed in open cavities. The larger crystals are as much as a centimeter in diameter and 20 centimeters long. Large radiating stibnite crystals in one vein appeared to have penetrated the silicified limestone wall rock, indicating that they had grown by replacement of the limestone. White coarsely crystalline calcite fills spaces between stibnite crystals and along the faults. One vein yielded calcite rhombs 5 to 10 centimeters across cleavage faces.

The veins crop out along the limestone-sandstone contact for a distance of nearly a kilometer. In the lower workings the veins contain less stibnite than in the upper workings, and the few veins which continue to the floor of the valley about 50 meters below contain only calcite.

The veins have been explored and mined from small pits, trenches, and three adits 2 to 6 meters long. The mine has been worked intermittently for several years, although it was not operating at the time of our visit. Ore is mined and concentrated by hand, and several tons of high-grade stibnite concentrates have been shipped. Several tons of high-grade ore in the exposed veins could probably be mined at a profit. However, mineralization extends only to a shallow depth, and possible reserves are small.

TUCO-CHIRA MINING DISTRICT

The Tuco-Chira mining district is at the south end of the Cordillera Blanca about 20 kilometers airline northeast of Conococha. The district has been named for the two major quebradas of Tuco and Chira which drain the area. (See fig. 7.) The north end of the pampa in Quebrada Tuco at the old smelter is at an altitude of 4,330 meters, and the bottom of the valley near the Chira mine in Quebrada Chira is at about 4,230 meters. The trail from Quebrada Tuco to Quebrada Chira crosses the ridge between the quebradas at an altitude near 5,000 meters. Nevado Tuco, at the north edge of the district, reaches an altitude of 5,487 meters.

The ridge separating Quebrada Tuco from Quebrada Chira trends parallel to the main mass of the Cordillera Blanca and forms the local drainage divide between the Río Santa and Río Pativilca. Quebrada Tuco drains southwestward into the Río Santa near the outlet of Laguna Conococha, whereas Quebrada Chira drains southeastward into the Río Pativilca. Both quebradas originate on the flanks of Nevado Tuco, and glaciers furnish most of the water to the streams.

The sedimentary rocks consist of a sequence of interbedded shaly sandstones, shales, calcareous shales, and a few beds of limestone, overlain by massive limestone. Part of the shaly sandstones have been metamorphosed to quartzite, and shales and calcareous shales to phyllite or hornfels; some of the limestone has been recrystallized. We believe that the heterogeneous sequence of shales, sandstones, and calcareous shales are equivalent to the middle unit of the Barremian of Steinmann. In Quebrada Tuco the exposed sequence is several hundred meters in thickness. Because of complex folding the thickness of limestone which overlies the Barremian sequence could not be estimated. However, several hundred meters of massive limestone are exposed and may be equivalent to the upper limestone unit of the Barremian, the Machay, and part of the Jumasha.

These sedimentary rocks have been intruded by a large granodiorite stock, several small irregular granite porphyry stocks and dikes, rhyolite porphyry sills, and andesite sills and dikes.

The sedimentary rocks have been complexly folded, as is shown in fig. 13, and time was not available to make a complete study of the structure. However, large folds with complex secondary folds are the most prominent structural features, and most faults appear to be small. The regional strike of sedimentary beds is about N. 30° W.

The most common vein minerals are pyrite and quartz with lesser amounts of galena, sphalerite, chalcopyrite, tetrahedrite, calcite, barite, and fluorite. Most veins are vuggy, and the minerals are well crystallized.

Some of the veins were mined extensively during the early part of the present century, when the smelter at the north end of Quebrada Tuco was in operation. Two of the mines were worked in 1949 by small-scale hand-mining methods. Yearly production from the district probably averages less than 35 tons of lead-silver-copper concentrate. Output could be increased by more extensive mining, but most of the veins are small and low grade. Unless larger ore bodies are discovered, it is doubtful that reserves are large enough to maintain increased production for more than a few years.

Of the mines and prospects of the district, only the Cosmos mine has possible reserves of lead-zinc-copper ore to sustain a small-scale operation for more than a year or two.

COSMOS MINE

The Cosmos mine, the largest in the district, and the Cascajal mine probably were the principal sources of ore for the smelter. The mine is on the west side of Quebrada Tuco 200 to 270 meters vertically above the pampa and 1.5 to 2 kilometers southwest of the smelter. The principal workings are between the altitudes of 4,550 and 4,620 meters. A trail leads directly from the smelter to the mine.

Veins occur along a recrystallized limestone bed in a metamorphosed shale-sandstone sequence near the contact with massive limestone. The area is on the upper or west limb of an overturned syncline (pl. 12), so that older shale rests on younger limestone. Massive limestone cropping out about 100 meters northeast of the map area (pl. 12) is near the axis of the syncline. The axial plane of the syncline strikes N. 20°–30° W. and dips 2°–12° SW., and strata on the overturned limb strike N. 10°–30° W. and dip 24°–60° SW. Three andesite sills, which strike about N. 30° W. and dip 50°–60° SW., crop out 75 to 130 meters west of the recrystallized limestone bed. Sills of similar lithology crop out on the east limb of the syncline several hundred meters east of the vein area. It is possible that these sills are continuous through the syncline and that therefore they were intruded before the sequence was folded.

Many fissure filling and replacement veins occur over a distance of more than a kilometer in or near a layer of light-gray recrystallized limestone which averages about 10 meters in thickness. However, this layer is somewhat irregular in thickness and, as exposed in one of the principal adits (pl. 12), consists of two stringers separated by a lens of impure limestone, giving an aggregate thickness of nearly 20 meters. At some places the contact between the recrystallized limestone and surrounding rock is gradational, whereas in other places the contact is sharp. Irregular breccia zones are found at many places within the recrystallized limestone and at the contacts, suggesting in part that the irregularity in thickness is due to faulting. It seems possible that the recrystallized limestone represents a relatively pure limestone layer in the shale-sandstone sequence that was shattered and recrystallized during folding and metamorphism.

Most of the veins strike N. 20°–30° W. and dip 35°–70° SW. They contain breccia and gouge with irregular to lenticular sulfide bodies, most of which are less than a meter wide and 5 to 10 meters long. These bodies consist largely of pyrite with irregular pods and veinlets of galena and sphalerite, but many of them also contain minor amounts of chalcopyrite, tetrahedrite, calcite, barite, and fluorite. The veins in the main Cosmos area have been worked from several inclined shafts and adits, many of which are now either caved or flooded. The total length of underground workings probably exceeds 600 meters.

About 500 meters south of the main Cosmos area shown in the map (pl. 12) and between the altitudes of 4,610 and 4,620 meters two other veins crop out in the recrystallized limestone layer. One is a zone of iron oxide and limestone breccia from 1 to 1.5 meters wide and about 50 meters long, striking N. 80° W. and dipping vertically. It contains pods and veinlets of malachite and azurite. The second vein, about 10 meters to the north, strikes N. 80° W. and dips 80° S.; it consists of pods and stringers of iron oxide and galena in a shear and fracture zone 50 to 75 centimeters wide and about 10 meters long.

A third mineralized zone about 150 meters east of the main Cosmos area was explored by an adit more than 50 meters long. Here an irregular zone of iron oxide and silicated limestone contains a few veinlets of galena and sphalerite.

During 1949 two or three men were hand-mining ore pockets in the old workings and may have been producing as much as 2 to 3 tons of low- to medium-grade hand-sorted lead-copper-silver concentrates per month. Enough ore is probably available to sustain this operation for several years, but as the ore bodies are small and generally low grade, it is doubtful that potential reserves could support a larger operation.

CASCAJAL MINE

The Cascajal mine is on the west side of Quebrada Tuco about a kilometer south of the main Cosmos area. Several old workings lie between the altitudes of 4,510 and 4,600 meters. The trail distance from the old smelter is about 3 kilometers.

Veins in the Cascajal area are associated with the same layer of recrystallized limestone exposed at Cosmos. However, here the beds swing around the nose of the overturned syncline, as shown in figure 12, and the strata are in normal position, striking N. 55°–85° W. and dipping 40°–75° NE. About 50 meters northwest of the uppermost vein, beds are overturned and strike N. 20°–30° W. and dip 50°–70° SW.

Several old dumps and pits extend along the limestone layer for a distance of more than 200 meters northeast from the nose of the syncline. All the old workings are caved, and most of the vein outcrops are covered with slide rock or waste. An upper vein, exposed near the nose of the syncline, strikes N. 65°–70° W. and dips 65° NE. and appears to be a replacement zone within the recrystallized limestone. The mineralization, similar to that at Cosmos, shows predominant pyrite and quartz with minor tetrahedrite, galena, and sphalerite. At a caved adit 150 to 200 meters to the northeast another vein in the recrystallized limestone trends east and dips 40°–60° N., nearly parallel to the bedding. It consists of soft, crumbly pyrite and altered limestone with a few disseminated crystals of sphalerite.

A few other prospect pits and two small adits to the northeast on the same limestone layer lie within 400 meters of the principal Cascajal mine area. The prospects expose small irregular veins or pods of sulfide minerals.

The Cascajal mine was probably worked at the same time as the Cosmos mine. The production of the mine is unknown, but the size of the dumps indicates that several thousand tons of rock were removed. It is possible that the veins were worked out and then abandoned.

VENUS MINE

The Venus mine is on the east side of Quebrada Tuco, almost due east of the Cascajal mine. The portal of the main adit is at an altitude of about 4,430 meters and is about 100 meters above the pampa.

A mineralized fault zone striking about N. 60° W. and dipping 20°–40° NE., cuts metamorphosed calcareous shale striking N. 75° E. and dipping 30° NW. The zone, 20 centimeters to 1 meter wide and more than 50 meters long, consists largely of gouge, breccia, and quartz with disseminated grains of pyrite, chalcopyrite, arsenopyrite, and calcite. A fine-grained andesite dike cropping out in the mine area strikes N. 50° W. and dips 20° NE.

Four small adits have been opened on the vein. The two lower adits are caved, the main adit is 50 meters long, and the upper adit is 9 meters long. The main adit has two small raises but no stopes. Production from the main adit could not have been more than a few tons of copper concentrates. The upper adit and dumps of the lower adits are barren. The mine was not operated in 1949. No ore is in sight, and it is doubtful that further exploration would reveal new ore bodies.

MERCEDES MINE

The Mercedes mine is on the east side of Quebrada Tuco 1.5 to 2 kilometers south of the Venus mine and about 200 meters above the pampa. The altitude at the portal of the main adit is 4,530 meters. A one-half kilometer trail connects the mine with the road about 4.5 kilometers south of the old smelter.

Several veins crop out in light-gray recrystallized limestone above the contact with the granodiorite stock. Bedding in the limestone is obscure but seems to be nearly horizontal. The contact of the limestone and the granodiorite strikes N. 55° E. and dips 10°–20° NW.

The veins appear to have formed both by fissure filling and by replacement along short irregular fractures in the limestone along the contact for a distance of 75 to 100 meters. Veins strike N. 60°–75° E. or N. 30°–75° W. and dip either 15°–45° N. or 55°–65° S. The major vein is arcuate, striking from N. 75° E. to N. 75° W. and dipping 55°–65° S. It has a maximum width of 50 centimeters and is more than 20 meters long. The predominant mineral is calcite which contains small pods and veinlets of galena, sphalerite, and pyrite. Mineralogy of the other veins is similar.

During 1949 the ore was hand-mined and concentrated by three or four men, and a few tons of galena concentrates were shipped. The veins were worked from a 22-meter adit and several small pits. The veins are small, and most are low grade, but small scale mining of richer pockets may continue to be profitable for a few years.

SIBERIA MINE

The Siberia mine is in the low hills along the west side of Quebrada Tuco about 4 kilometers south of the old smelter. Mine workings are near the floor at the west side of the quebrada between the altitudes of 4,300 and 4,320 meters.

Several small veins cut recrystallized and partly silicated limestone near the contact with the granodiorite stock. Beds strike N. 15°–25° E. and dip 20°–30° NW. One or two small aplite dikes have been intruded into the limestone.

Veins appear to replace altered limestone along irregular fractures and faults occurring along the contact for a distance of 50 to 75 meters. The most prominent veins lie nearly parallel to the limestone beds and range from 5 to 60 centimeters in width and 1 to 10 meters in length. Many of the veins consist only of altered limestone with disseminated grains of pyrite and chalcopyrite, but a few contain small pods and lenses of high-grade galena and sphalerite.

The veins have been explored and worked in several small pits and two or three adits ranging from 2 to 15 meters in length. Sulfide pockets may have yielded a few tons of lead concentrates, but the remaining material appears to be too low in grade to be mined profitably.

RUSIA PROSPECT

The Rusia prospect is on the east side and near the mouth of Quebrada Tuco, about 7 kilometers south of the old smelter. The workings are between the altitudes of 4,420 and 4,430 meters. The trail distance from the Quebrada Tuco road is about 1 kilometer.

A narrow vein in altered sandstone near the contact with the granodiorite stock strikes about N. 50° E. and dips 70° SE. Bedding planes of the sandstone strike N. 60° W. and dip 30° SW. The vein is largely covered but may be as much as 50 meters long. It consists of wall rock and quartz with disseminated crystals and veinlets of pyrite and is essentially barren of other sulfide minerals. Only a few grains of galena were seen in specimens on the dumps. A few pits and three small adits are now completely caved, and the prospect has been abandoned.

CHIRA MINE

The Chira mine is on the west side of Quebrada Chira about 3.5 kilometers east of the old smelter in Quebrada Tuco. The workings lie between the altitudes of 4,240 and 4,420 meters. A trail about 6 kilometers long connects the mine to the smelter.

Many irregular veins, short thick lenses, and irregular pods of quartz and pyrite are found in a contact-alteration zone between limestone and the granodiorite stock. This zone is from 25 to 50 meters wide and can be traced westward from near the floor of the quebrada for more than a kilometer. The limestone in the zone, striking N. 40° E. to east and dipping 10°–15° N., has been silicified, garnetized, pyritized, and partly recrystallized, and in places it contains irregular pods and disseminated crystals of wollastonite. One bed near the contact is schistose and originally may have been shaly limestone or shale. Within the granodiorite are several small aplite dikes.

Most of the larger veins and lenses of quartz and pyrite, ranging from 5 to 15 meters in length and 1 to 2 meters in width, strike east and dip 15°–25° N. A few are 15 to 20 meters long and as much as 4 meters wide. Apparently the bodies formed both by replacement and by fissure-filling along fractures and cavities in the altered limestone. Some of the veins are a granular mixture of fine-grained quartz and pyrite, whereas others are massive quartz dotted with 1- to 2-centimeter cubes of pyrite. A few of the veins contain minor amounts of chalcopyrite and sphalerite.

The contact zone has been explored thoroughly by prospect pits and short adits over a width of about 25 meters and a length of about 150 meters. Four major adits range from 20 to 25 meters in length. Also along the deposit to the west of this area for a distance of several hundred meters are several other prospect pits and short adits. The mine has been abandoned for several years, and as the veins appear to be nearly barren, it is doubted that further exploration will discover minable material.

OTHER DEPOSITS

Two prospects not previously discussed are on the east side of Quebrada Tuco. They are 300 and 450 meters north of the Venus mine and slightly higher in altitude.

At the southern prospect two parallel replacement veins, ranging from 50 centimeters to 2 meters in width and from 50 to 70 meters in length, strike N. 50°–60° W. and dip 50°–60° NE. The veins contain pyrite, iron oxide, and altered limestone. The wall rock is very fine-grained dark-gray limestone which strikes N. 35° W. and dips 45°–60° NE. The veins were explored by a 21-meter adit, but no ore was encountered.

The northern prospect was explored by a 30-meter adit which exposes recrystallized limestone and one or two small veinlets of pyrite.

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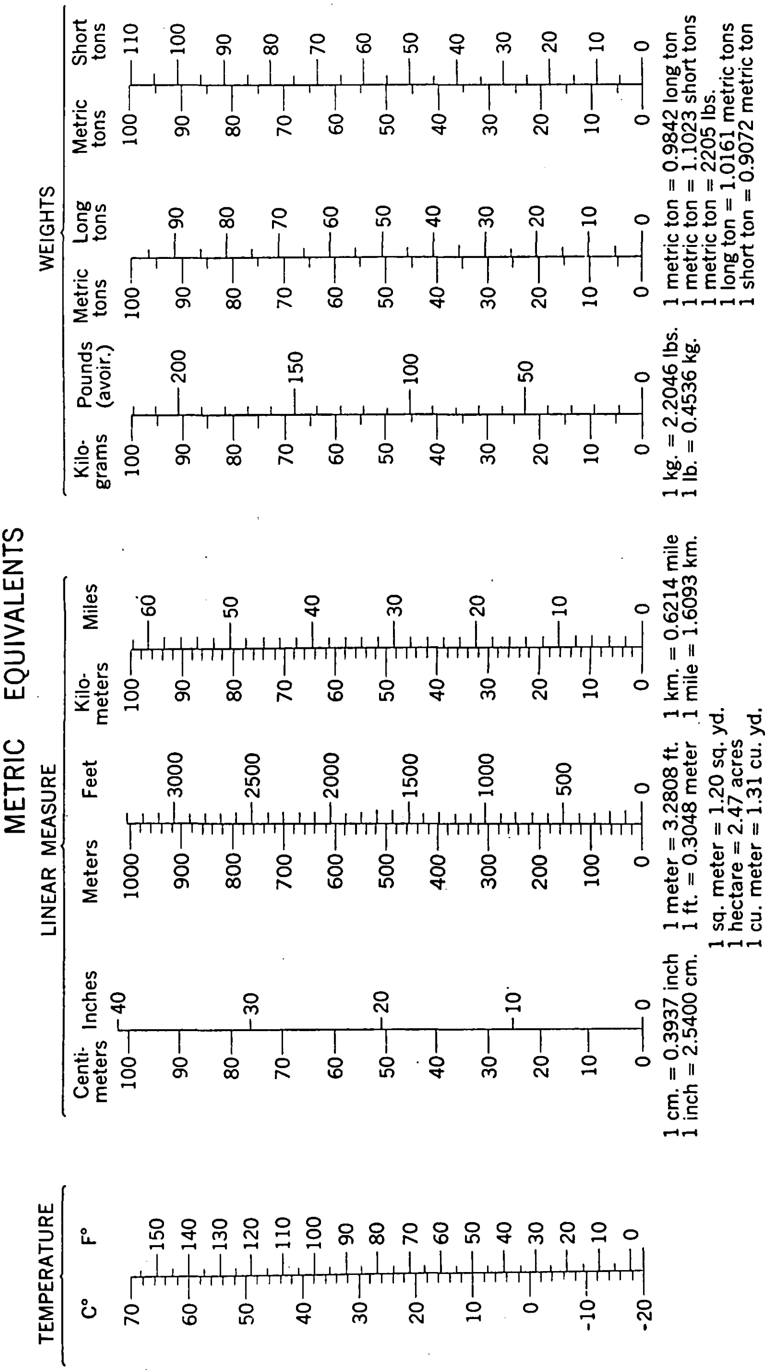
METRIC EQUIVALENTS
LINEAR MEASURE
Centi-meters
Inches
1 cm. = 0.3937 inch
1 inch = 2.5400 cm.
Meters
Feet
1 meter = 3.2808 ft.
1 ft. = 0.3048 meter
Kilo-meters
Miles
1 km. = 0.6214 mile
1 mile = 1.6093 km.
1 sq. meter = 1.20 sq. yd.
1 hectare = 2.47 acres
1 cu. meter = 1.31 cu. yd.
WEIGHTS
Kilo-grams
Pounds (avoir.)
1 kg. = 2.2046 lbs.
1 lb. = 0.4536 kg.
Metric tons
Long tons
Metric tons
Short tons
1 metric ton = 0.9842 long ton
1 metric ton = 1.1023 short tons
1 metric ton = 2205 lbs.
1 long ton = 1.0161 metric tons
1 short ton = 0.9072 metric ton
TEMPERATURE
C°
F°

INDEX