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THE GEOLOGY AND ORE DEPOSITS OF THE QUIRUVILCA DISTRICT, PERU

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ABSTRACT

The Quiruvilca copper-lead-zinc district is in the Department of La Libertad in north-central Peru. The only large mine in this area is the Quiruvilca mine, owned and operated by the Northern Peru Mining and Smelting Co. The mine lies in bedded andesitic and basaltic volcanics, which have been intruded by a small plug of andesite. Numerous dikes and breccia pipes cut rocks surrounding the small plug. To the west of the Quiruvilca mine are four dacite plugs enclosed by sandstone, and 7 kilometers to the east slightly metamorphosed Cretaceous sediments crop out.

The ore deposits of the district are mesothermal and epithermal and were formed by fissure filling. Mineralization followed a pre-existing set of tension and shear fractures and the veins form a well-defined oblique grid pattern. Only a few of the many veins in the area are productive. The wider ones, which average a meter in width, are being exploited. On the basis of mineralogy the mineralized area can be divided into four distinct zones. From the center outward these zones are: 1) the Enargite zone, 2) the Transition zone, 3) the Lead-Zinc zone, and 4) the Stibnite zone.

INTRODUCTION

For several years the U. S. Geological Survey, in collaboration with the Geological Institute of Peru, a bureau of the National Institute of Mining Investigation and Development, has been carrying out a systematic appraisal of the lead and zinc resources of northern and central Peru. The work is being done as part of the program of Technical Cooperation (Point IV) under the auspices of the U. S. Department of State. The study of the Quiruvilca mine was planned as part of the general investigation of lead and zinc deposits in the Department of La Libertad, but inasmuch as the area shows an excellent example of hypogene mineral zoning, the study was expanded to include the entire district.

Four months were spent during 1951–1952 in a general reconnaissance of the surface geology and in mapping the Quiruvilca mine. Surface mapping was done on a 1:4,000-scale map provided by the Northern Peru Mining and Smelting Co. The Quiruvilca mine was mapped on 1:500-scale maps furnished by the company, and vein geology was taken from company maps. Over 50 adits and prospects were studied or inspected. Ore samples were collected from all of the stopes and faces in the Quiruvilca mine and from most of the small workings on the surface. More than 120 rock specimens and 130 sulfide samples were collected. From this suite of specimens, 20 polished sections and 60 thin sections were made and studied. All microscopic identification of sulfides were checked by microchemical tests.

I wish to express my gratitude to Guillermo Abele, of the Geological Institute, who assisted me during most of the field work; to Frank S. Simons, of the U. S. Geological Survey for his general assistance and careful editing; and to my colleagues George S. Ericksen and Robert F. Johnson with whom various phases of the work were discussed. Cordial thanks are due the officials of the Northern Peru Mining and Smelting Co. for making this study possible and for providing me with the facilities of their Shorey-Quiruvilca camp. I wish to acknowledge in particular the cooperation and pleasant hospitality of Harvey D. Willeford, former mine superintendent at Quiruvilca. Lawson P. Entwistle, chief geologist of the company, offered many helpful suggestions and ideas about the structure and nature of the ore deposits. Cliff A. Everett, resident geologist, also aided me considerably both in mapping the mine and completing the reconnaissance of the surface geology.

LOCATION AND GENERAL DESCRIPTION

The Quiruvilca copper-lead-zinc district is in the Department of La Libertad in north-central Peru, 80 km east of Trujillo. It may be reached by automobile from Trujillo over 130 km of all-weather road. The district lies in a region of moderate relief, and altitudes range from 3,450 m at the western edge to 4,050 m at the eastern edge. The climate is temperate with a rainy season extending from November until April.

The only large mine in the area is the Quiruvilca copper mine, owned and operated by the Northern Peru Mining and Smelting Co., a subsidiary of the

American Smelting and Refining Co. All other mining operations consist of small-scale exploitation of high-grade lead-zinc and silver-antimony ores.

The Quiruvilca mine consists of about 25 km of workings serviced by the Elvira and Graciela shafts. Less than half the workings are in use, and most of the unused workings are inaccessible because of caving and water. The mine is worked from 11 levels; the lowest is the 220 level, which lies 300 m below the collar of the main (Elvira) shaft. During 1952, mining was carried out along nine semiparallel veins. Copper in the mine water is recovered in a scrap iron precipitation plant at the mouth of the Almirvilca drainage tunnel.

The mine is serviced by a 500 ton flotation mill at Shorey, 5 km to the west. Ore is transported from mine to mill on an aerial tram 2.77 km long with a maximum unsupported span of 1,350 m. Concentrates are shipped over another aerial tram to Samne, the trucking point 40.1 km west of Shorey. A third aerial tram 6.7 km long extends from Quiruvilca to the company's coal mine at Callacuyán.

Although the mine probably has been worked intermittently for more than 150 years, large-scale operations date only from acquisition of the property by the present owners in 1924. The mine has been operated from 1924 to 1931 and from June 1940 to the present time.

During 1951, 121,804 short tons of ore averaging 4.44 percent copper and 3.73 ounces of silver per ton were mined, and 13,951 short tons of concentrate were produced. The Sin Nombre vein yielded about 40,000 tons of ore, the Elvira vein 15,000 tons, and the Morococha vein 23,000 tons. The precipitation plant recovered 389 short tons of cement copper averaging 62.35 percent of copper.

GEOLOGY

The Quiruvilca mine lies in bedded andesitic and basaltic volcanics, which have been intruded by a small andesite plug. The bedded volcanics consist of extensive flows of andesite, andesite flow breccia, irregular and localized basalt flows, and a few beds of tuff and tuffaceous lacustrine sediments. The plug is a mixture of fine- to coarse-grained andesite porphyry. These rocks have been invaded by numerous breccia pipes, dikes and volcanic glass, and dacite dikes.

To the west of Quiruvilca are four plugs of dacite enclosed by tuffaceous sandstone. The dacite and the other volcanic rocks of the district are post-Cretaceous. Quartzites and slates of Cretaceous age crop out 7 km east of Quiruvilca.

Sedimentary Rocks.—The oldest rocks of the area are Lower Cretaceous clastic rocks exposed near Callacuyán, 7 km east of Quiruvilca, where they crop out in a north-trending, asymmetrical anticline and syncline. According to Mr. Victor Benavides (personal communication), three lithologic units here correspond to Lower Cretaceous units described by Stappenbeck (1927) from the southern part of the Department of Cajamarca. At Callacuyán, the lowest unit consists of massive sandstone which corresponds to Stappenbeck's

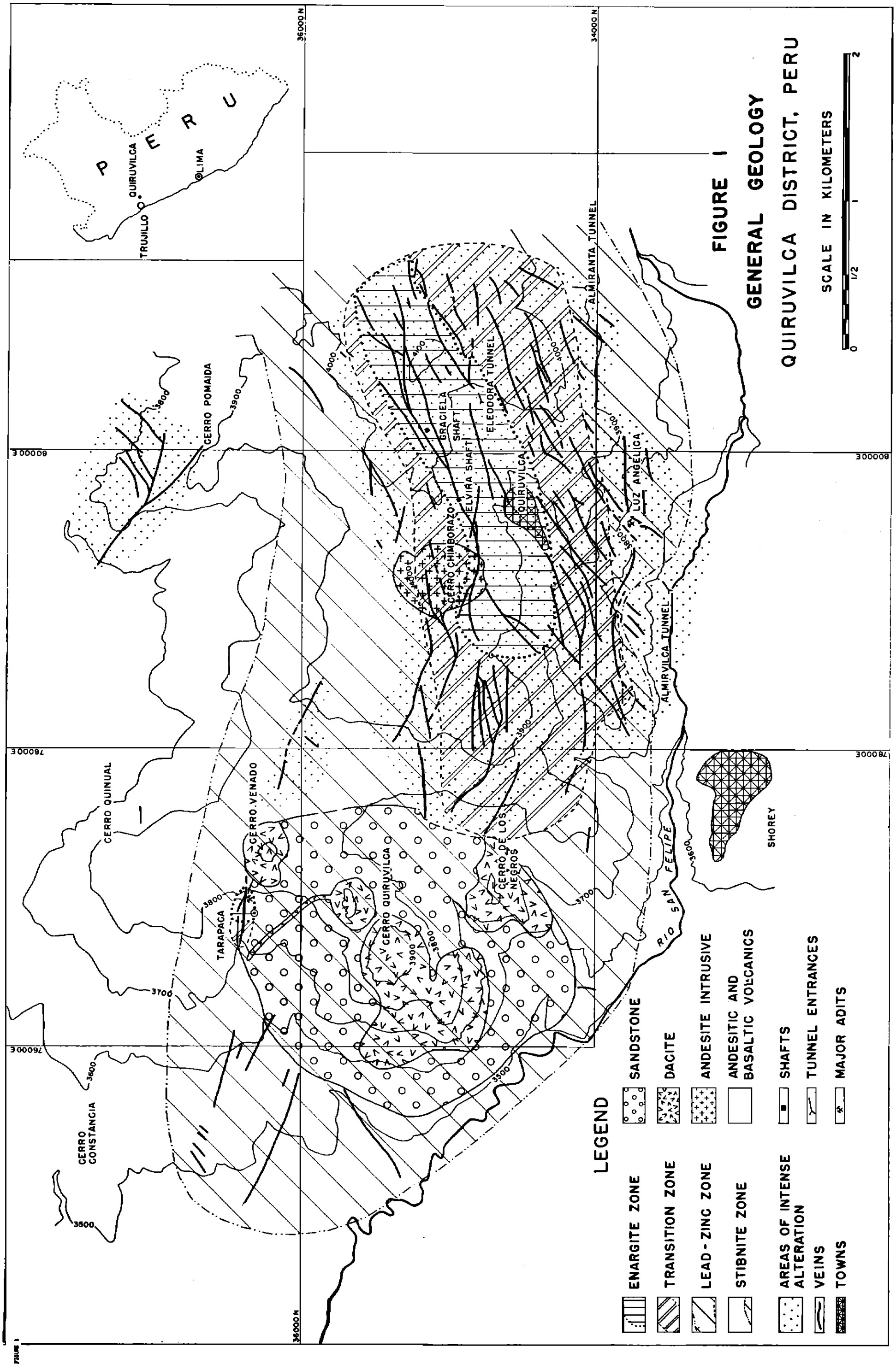


FIGURE I
GENERAL GEOLOGY
QUIRUVILCA DISTRICT, PERU
SCALE IN KILOMETERS
0
1/2
1
2
PERU
QUIRUVILCA
TRUJILLO
LIMA
LEGEND
ENARGITE ZONE
TRANSITION ZONE
LEAD-ZINC ZONE
STIBNITE ZONE
AREAS OF INTENSE ALTERATION
VEINS
TOWNS
SANDSTONE
DACITE
ANDESITE INTRUSIVE
ANDESITIC AND BASALTIC VOLCANICS
SHAFTS
TUNNEL ENTRANCES
MAJOR ADITS
CERRO POMAIDA
CERRO QUINUAL
CERRO CONSTANCIA
CERRO VENADO
TARAPACA
CERRO QUIRUVILCA
CERRO DE LOS NEGROS
CERRO CHIMBORAZO
GRACIELA SHAFT
ELVIRA SHAFT
ELEODORA TUNNEL
ALMIRANTA TUNNEL
QUIRUVILCA
LUZ ANGELICA
ALMIRVILCA TUNNEL
SHOREY
RIO SAN FELIPE
36000 N
34000 N
800000 E
780000 E
760000 E
3500
3600
3700
3800
3900
4000

Fig. 1.

"lower coal-bearing quartzites of the Wealdian"; the middle unit consists of interbedded shales, siltstones, and sandstones equivalent to the Pallares shale; and the uppermost unit is a sandstone equivalent to the Farrat quartzite. Sedimentary rocks of probable Cretaceous age are exposed in a few places in the western part of the area. Contorted black calcareous slate crops out in the east wall of the "explosion crater" northwest of Cerro Venado. Fragments of black shale were noted on many of the small dumps of the abandoned and closed workings on the slope west of Cerro Venado. The shale and calcareous slate are probably equivalent to the Pallares shale found east of Quiruvilca.

The only other sedimentary rocks in the district are the tuffaceous lacustrine sediments encountered in the western and central parts of the area. Most of the sediments are found in the vicinity of Cerro Venado, Cerro Quiruvilca, and Cerro de los Negros and lie in the basin formed by these three hills (Fig. 1). This sandstone is extremely variable in character, grading from a fine-grained tuffaceous sandstone to a pebble conglomerate containing fragments of metamorphic and volcanic rock. Other lacustrine beds were noted northeast, east, and southeast of the town of Quiruvilca, in and amongst the old mine workings. These beds range in thickness from 1 to 10 m and seldom crop out for more than 70 m. These sediments are much finer grained than those found west of Quiruvilca; they consist of mudstones, siltstones, and fine-grained tuffaceous sandstone.

Bedding in some of these lacustrine sediments is well developed but is absent in others. The sorting ranges from very good in the mudstones and siltstones to poor in the pebble conglomerates. The majority of fragments consist of quartz, shale, quartzite, and altered andesite. Minor amounts of magnetite, biotite, chlorite, and oligoclase feldspar were noted. The fine-grained sediments and the matrix of the coarse-grained sediments have been altered to calcite, siderite, clay minerals, and devitrified glass, and all traces of any possible original shard texture have been obliterated. This alteration is particularly intense in sedimentary rocks near the town of Quiruvilca, where these rocks contain pyrite and galena both as disseminations and as 1- to 5-mm seams parallel to the bedding. These sediments are most likely lacustrine deposits of local derivation, deposited in a lake formed by the damming of a stream by lava flows.

Andesitic Rocks.—The predominant rock types of the area are andesite flows and flow breccias, which make up more than 85 percent of the rocks in the area. In the central part of the district the area which contains most of the veins is underlain by interbedded andesite flows and flow breccias. These flows are more or less horizontal and very irregular in form. Interbedded with the andesitic rocks are small basalt flows and a few beds of tuff and lacustrine sediments. No correlation of individual beds has been attempted because of the high degree of alteration and the lack of continuity of the units.

The andesite is dense, blackish green, and megaporphyritic to microporphyritic. In most of the specimens studied all the original minerals except the feldspars, magnetite, and corundum have been altered and the original texture erased. Comparatively fresh specimens show a porphyritic hyalo-

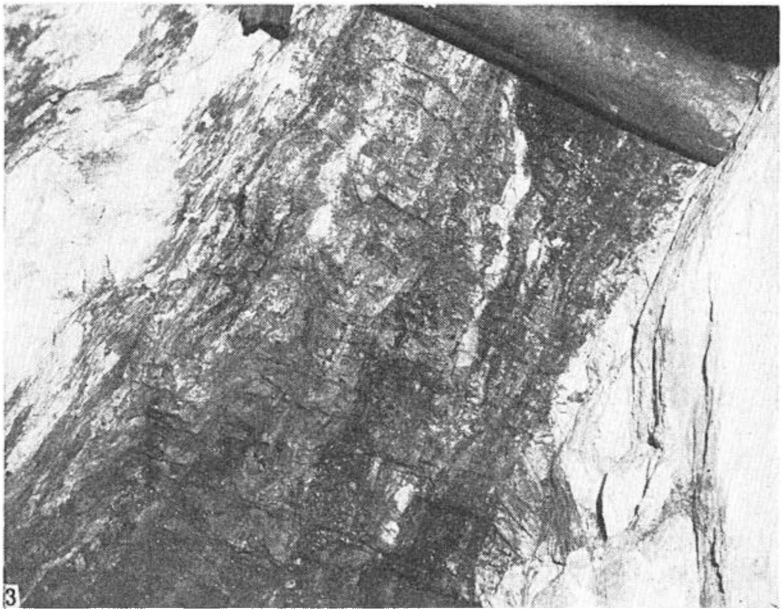


FIG. 2. Weathered surface of an outcrop of the outermost andesite flow breccia. Note the size of the fragments in the background.

FIG. 3. Face of the Sin Nombre vein in a stope below the 50 level. Note the well-developed banding of pyrite (gray) and enargite (black) and the small horses of wallrock (white).

pilitic texture with unoriented phenocrysts set in a groundmass of unoriented feldspar microlites, altered pyroxene, and interstitial glass. The ratio of phenocrysts to groundmass averages 1:1.5. Most of the phenocrysts are slightly zoned plagioclase with an average composition of An_{45}, but larger phenocrysts are zoned from An_{65} in the center to An_{45} at the borders. Some of the completely altered phenocrysts were probably pyroxene. Minor amounts of magnetite, apatite, corundum, and skeleton crystals of ilmenite were noted.

The flow breccias have textures and compositions identical with the andesite flow rock. They consist of fragments of andesite cemented by more andesite of the same or finer grain size. The fragments range from 10 cm to 3 m across, the average size being about 20 cm. The abundance of fragments varies considerably, and for mapping purposes in the mine the breccia was defined as a rock composed of more than 20 percent fragments. A gradation from massive andesite through fractured andesite to breccia with 50 percent or more of fragments often takes place within tens of meters. Gradational contacts and identity of composition and texture indicate that the andesite flows and flow breccias of the central part of the district are contemporaneous.

The extensive flow breccias that surround the central area where most of the veins are located differ slightly in texture and composition from the andesitic rocks of the central area. The matrix is green microporphyritic hyalo-ophitic andesite with feldspar of An_{28-38} composition, and the fragments consist of at least two different types of dark-green to purple megaporphyritic andesites, one containing phenocrysts of composition An_{35-45} and the other phenocrysts of composition An_{55-68}. Textures of the fragments range from trachytic to hyaloophitic and hyalopilitic. The fragments range in size from 1 to 100 cm and compose 60 to 90 percent of the rock. Because of the marked contrast in color between the fragments and matrix, this flow breccia is usually easily recognized in the field (Fig. 2) and possibly could be mapped as a distinct unit. This rock is probably the oldest igneous rock exposed in the area. Its full extent is not known, but it is believed to underlie the surrounding terrain for several kilometers in all directions.

An andesite plug which intrudes the andesitic volcanics of the central area crops out 250 m west of the Elvira shaft. The outcrop is about 500 m in diameter and forms the central part of Cerro Chimborazo (Fig. 1). The rock is a dense, dark-green, megaporphyritic basaltic andesite. The percentage of mafic minerals is higher in this rock, and the feldspars, averaging An_{50}, are slightly more calcic than in the andesite flow rocks.

Basaltic Rocks.—Flows of basalt are interbedded with the andesite flows and flow breccias in the central part of the area. The outcrops range in thickness from 1 to 15 m and seldom are more than 150 m long. The rock consists of two generations of plagioclase feldspar phenocrysts set in a hyalopilitic or intersertal groundmass. The larger phenocrysts have an average composition of An_{60} and are often strongly zoned from An_{80} in the cores to An_{55} at the rims. The later phenocrysts and the groundmass microlites are An_{55-65} in composition. A few phenocrysts of pigeonite and hypersthene are scattered through the rock; the groundmass pyroxene is too altered for positive identification. Minor amounts of magnetite, apatite, corundum, skeleton crystals of ilmenite, and chlorite pseudomorphing an amphibole were noted. These rocks are always less altered than the surrounding andesitic rocks, probably because of selective alteration due to compositional differences. Basalt was cut at depth in several diamond-drill holes north of the Graciela shaft.

Dacite.—Cerros Quiruvilca, Venado, and de los Negros are all composed of a light-gray porphyritic dacite which was intruded in pluglike masses and as series of contiguous parallel dikes. A wall-like dike of dacite extends 225 m northwest from the north side of the northernmost Cerro Quiruvilca plug. The dacite contains inclusions of sandstone and has baked the sandstone along several of the contacts. Within the Quiruvilca mine area several occurrences of dacite porphyry were noted within the mine, especially in the east-central section, as well as on the surface around and to the north of the mouth of the Eleodora Tunnel.

The rock is composed of abundant phenocrysts of oligoclase and a few grains of biotite, quartz, and altered amphibole imbedded in a pilotaxitic groundmass of feldspar microclites, devitrified glass, and iron oxides. The ratio of phenocrysts to groundmass is about 1:1.5. Oligoclase occurs in two generations, an early generation of crystals averaging 1.5 mm in length and An_{27} in composition and a second generation of 0.5 mm crystals with An_{20} composition. Groundmass microlites have a composition of An_{17}. A few of the largest phenocrysts show zoning from An_{44} in the center to An_{27} on the edge; most of them have myrmekitic intergrowths of albite and show evidence of resorbtion.

The principal bodies of dacite found within the mine lie along veins or extensions of vein structures. In addition several vertical northtrending dikes 50 to 200 cm wide were seen. The rock is characterized by subhedral to euhedral quartz crystals and a coarse-grained texture. The quartz grains may be as much as 4 mm in diameter, but average 2 mm. The feldspar phenocrysts are mostly 3 to 4 mm in length. Some fine-grained varieties of dacite were also seen. Alteration of the dacite in the mine has been so intense that the groundmass texture and mafic minerals have been completely obliterated.

A welded dacite tuff crops out at one place on the southern slope of Cerro de los Negros, and a great deal more may be hidden under the alluvium, especially around the bases of the dacite plugs. Several small bodies of tuff were noted in and around the mine, but the high degree of alteration prevented positive identification.

Dikes of Volcanic Glass.—Throughout the mine and at a few places on the surface, small dikes of a green to light-purple aphanitic material were observed. This rock has been so thoroughly altered that it is impossible to say what the original material was. As these dikes fill small and irregular cracks, the original melt must have been highly fluid. This rock was probably an andesite or basalt glass.

Explosion Crater.—About 500 m northwest of Cerro Venado is an explosion crater which was formed during the present erosion cycle. The crater is

350 m long and about 250 m wide. The western side is open and the eastern side is bounded by cliffs of andesite breccia 100 m high. Instead of forming a typical crater the explosion removed a large piece from the side of the hill and scattered debris down the hill for half a kilometer. The depression has an extremely irregular floor and is filled with large blocks of breccia. Although no evidence was found that this youngest volcanic phenomenon ejected any lava or ash, it probably had the same sources as the older volcanic activity. Perhaps late gasses working up along a fracture became concentrated in one spot and caused a minor explosion.

Some Geologic Features of the Quiruvilca Mine.—The majority of the workings of the Quiruvilca mine lie in the interbedded andesite flows and flow breccias. These rocks are particularly well exposed in the eastern and far western sections, where large amounts of flow breccia were seen. Around and to the east of the Elvira shaft lies a large expanse of andesite in which neither breccia nor bedding of any sort was observed. Despite the lack of conclusive evidence, this body seems to be the underground equivalent of the andesite intrusive that crops out on Cerro Chimborazo, east of the Elvira shaft. In the mine this body of andesite is 600 m long and 300 m wide and extends 450 m to the east of the Elvira shaft. Although the alteration of the rocks nearly obscures the contact, the boundaries have been traced from the 50 to the 220 level (Fig. 3). This intrusive appears to be a mixture of fine to coarse-grained andesite. No direct connection between the intrusive and the ore deposits was observed.

Many small breccia pipes and dikes of volcanic glass were noted in the mine. They are mostly in the andesite intrusive near its contact with the bedded volcanics, within the bedded volcanics near the contact between the flows and flow breccias, and in intensely fractured zones. Most of the dikes are less than 5 cm wide, but some are as much as half a meter wide. They are very irregular and seldom extend for more than a few meters. The breccia pipes are irregular and weak; they rarely are more than 10 cm in diameter or more than a few meters long. These pipes consist of altered volcanic glass enclosing fragments of andesite. Larger dikes and breccia pipes are found in the intrusive and the bedded volcanics at some distance from their contact. These dikes average 20 to 40 cm in width and are more or less vertical. The breccia pipes are from 1 to 3 m in diameter and also are nearly vertical. The breccia pipes generally have a matrix of clay or clay and altered volcanic glass with fragments of andesite and, in three examples, numerous fragments of quartzite. A breccia pipe along the footwall of the Number 3 vein on the 50-level contains quartzite fragments as much as half a meter across. On the surface, a small breccia pipe carrying quartzite fragments was noted in the far eastern part of the area. The quartzite fragments are subrounded to well-rounded and were probably derived from sedimentary rocks below the volcanics. Possibly the quartzite is the same age (Cretaceous) as the quartzite found 7 km east of Quiruvilca.

Rock Alteration.—All the volcanic rocks in the district have been altered to some degree, but only in the vein areas has the alteration been intense. Five general types of alteration were recognized; chloritization, propylitization,

propylitization-argillization, argillization, and silicification. Chloritization is the weakest type of alteration and grades into propylitization upon approaching the vein areas. Propylitization-argillization is found in the center of the district around the main vein system; the outer limit of this alteration is the limit of strong alteration shown in Figure 1. The same alteration is also found near isolated veins and vein groups to the north and west of Quiruvilca. Argillization is the highest grade of alteration in the area and is found adjacent to veins or along faults. Silicification, with the exception of the two silicified hills east of Cerro Venado, is closely associated with propylitization and is found only adjacent to veins or vein structures.

Chloritization is shown by some of the basalts and to some extent by the dacite. This type of alteration is characterized by partial alteration of pyroxenes to chlorite-antigorite, the complete alteration of hornblende to iron oxides, devitrification of any glass present, and slight alteration of the larger feldspar phenocrysts to albite, sericite, and kaolin clays.

Propylitization, the common alteration of the basalt flows, is characterized by complete conversion of all mafic minerals to chlorite-antigorite, magnetite, hematite, sphene, leucoxene, and some aragonite. The larger feldspar phenocrysts are partly converted to albite, sericite, epidote, and aragonite. In the groundmass, the feldspar microlites remain unaltered, but the glass and pyroxenes have been converted to quartz, clay, iron oxides, and minor amounts of sphene and leucoxene. Tiny stringers and blotches of epidote and hematite are characteristic. The outermost flow breccias are also strongly propylitized but without the formation of epidote and large amounts of hematite. Commonly the alteration of the feldspars in the breccia is more advanced and in some specimens the breakdown of the feldspar microlites has started.

Propylitization-argillization of the rocks becomes more intense as the veins are approached. In general this alteration constitutes a conversion of all minerals to quartz, kaolin clays, hydromica, aragonite, and varying amounts of chlorite, iron oxides, and introduced silica. Near the outer limits of this alteration the feldspars have not been completely altered and chlorite is still abundant so that the original texture of the groundmass is still recognizable. As alteration becomes more intense antigorite-chlorite and the iron oxides disappear, the feldspars are completely converted to kaolin clays, hydromica, and aragonite, and the original groundmass becomes a mass of clay and quartz. In general, the aragonite occurs only in aragonite-kaolin pseudomorphs after feldspar. Although most of the quartz is residual, some has been introduced. The apparent differences in rock types are mostly due to variation in abundance of the alteration products, particularly aragonite, which accentuates the feldspar phenocrysts, and of iron oxides, which bring about marked color differences.

The rocks near veins and faults are almost completely argillized, and all minerals have been converted to kaolin clays, hydromica, and quartz. Enough of the hydromica is concentrated in pseudomorphs of feldspar phenocrysts to preserve the original porphyritic texture, but the groundmass texture has been completely eradicated. Immediately adjacent to veins and faults argillization is so intense that the rocks have been completely altered to kaolin clays and hydromica, making the rocks soft and white.

ORE DEPOSITS

The ore deposits of the district are mesothermal to epithermal and were formed by fissure filling. Ore deposition probably closely followed the emplacement of the dacite porphyry dikes and is genetically related to them. Mineralization has followed a set of tension and shear fractures, and the veins form a well-defined oblique grid pattern. The veins in the center of the district are characterized by enargite and are mesothermal deposits. The peripheral veins contain mineral assemblages characteristic of epithermal deposits. On the basis of mineralogy, the mineralized area of about 24 sq km may be divided into four distinct zones. From the center outward these zones are: 1) the Enargite zone, 2) the Transition zone, 3) the Lead-Zinc zone, and 4) the Stibnite zone. In general, the vein material is coarsely crystalline and fairly massive. The veins are locally vuggy, and in many places well-developed banding was seen. Contacts between vein and wall rock are usually sharp and slightly slickensided.

The veins at Quiruvilca form a well-defined oblique grid pattern. One set of veins trends N 60°–70° E and the other N 85° W to S 85° W; most of the veins belong to the N 60°–70° E set. Most of the veins lie along faults which dip at least 70°. Apparently, horizontal movement along a set of east-striking premineral fractures caused the formation of tension or gash fractures striking N 60°–70° E. Several unmineralized east-striking faults were found just north of the Río San Felipe along the southern edge of the vein system, suggesting that the valley of this river may be the site of one of the major east-striking shear zones. Movement took place along a series of small, parallel strike-slip faults.

Most of the sulfides were deposited in fissures of the N 60°–70° E system of gash fractures. The veins of this system are characterized by massive, slightly fractured, banded sulfide ore. Contacts between sulfides and wallrock are sharp and marked by little gouge. Horses and stringers of wallrock within the vein are common (Fig. 3).

The veins of the east-striking system usually branch out and cut across the veins of the N 60°–70° E system, but in several places a N 60°–70° E vein terminates against an east-striking vein. The fact that many of the east-striking veins cut across the other veins without offset indicates that their formation was probably contemporaneous with the other set. The ore-bearing solutions filling the tension fractures also entered and filled this pre-existing set of shear fractures. Renewed movement along the east-striking shears during later stages of mineral deposition is indicated in the eastern part of the Quiruvilca mine, where the veins of both systems have been broken up into a series of en echelon segments connected by diagonal crossings of ore.

Evidence of post-mineral movement along mineralized and unmineralized shears is abundant within the Quiruvilca mine, particularly in the Morococha vein. The highly friable condition of the ore in this vein and the large

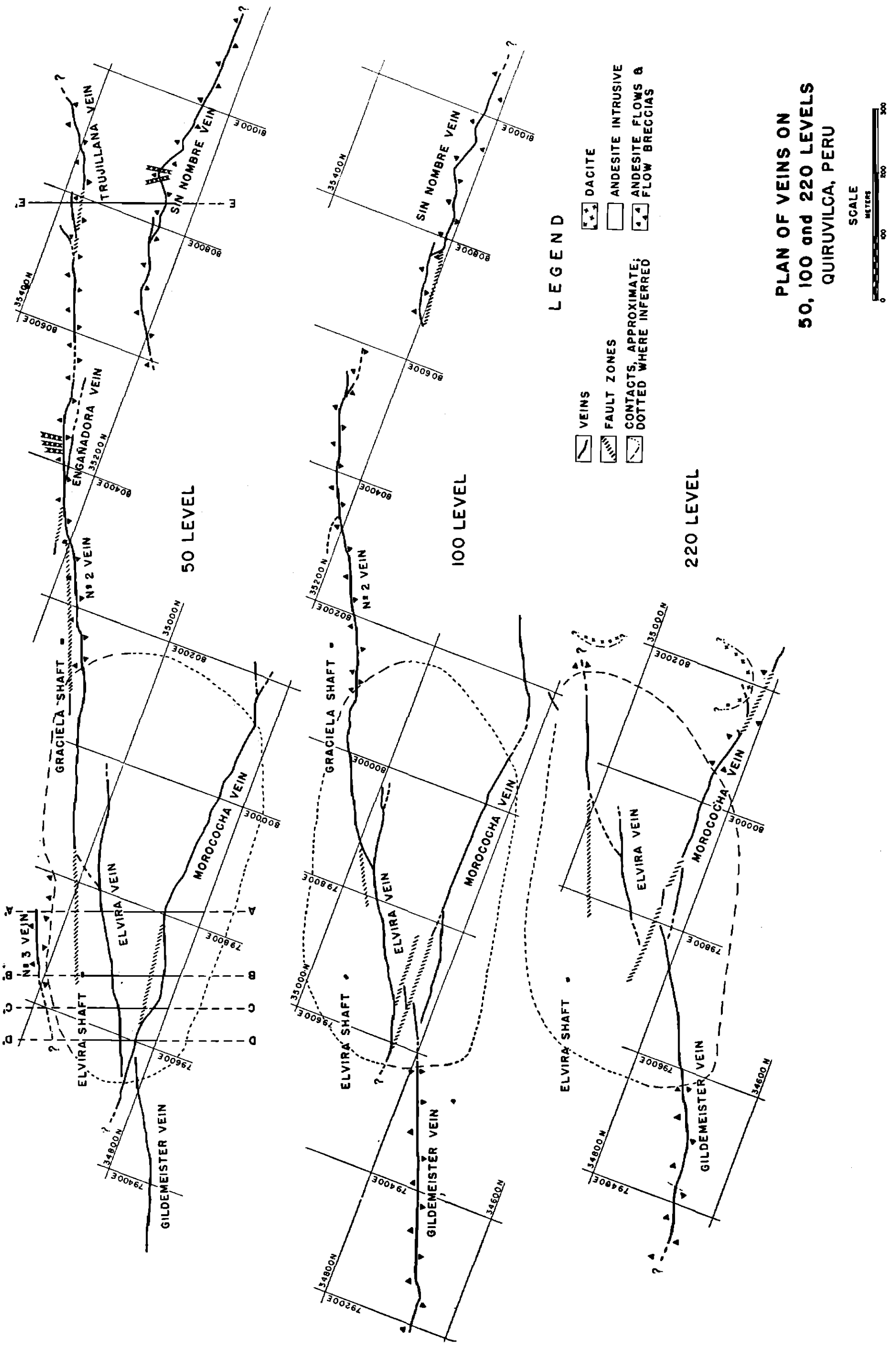


FIG. 4. Plans of 50, 100, and 220 levels showing geology and veins.

amounts of gouge along the walls indicate considerable post-mineral movement. The vein lies in one of the major east-striking shear zones. Post-mineral movement along this zone has cut the Gildemeister-Elvira vein, which occupies one of the N 60°–70° E fractures, and displaced the Elvira vein 60 m to the west (Fig. 4).

The Morococha fault or shear zone is not a simple fracture but a complex series of steeply dipping, semiparallel faults, veins, and breccia and shear zones (Fig. 5). The Morococha vein does not follow consistently the plane of one fault, nor does it have a constant width, strike, or dip but instead has followed several semiparallel faults. Thus, the vein swings, splits, and pinches out as it changes its course from one fault to another. The split in the Morococha vein below the 100 level (Fig. 5, section A-A′) is a typical example of the changes in the vein course. Here the vein switches from one fault to another by means of a diagonal crossing.

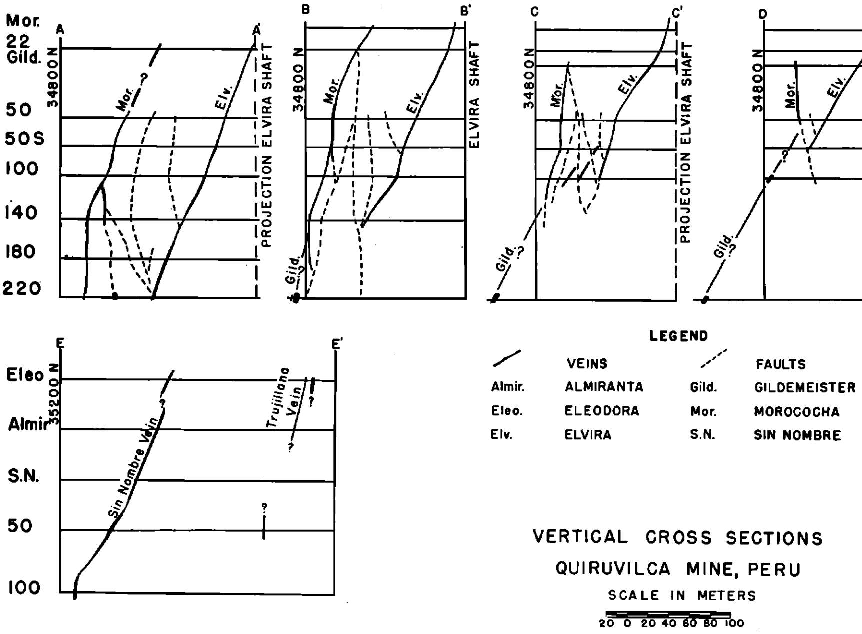


FIG. 5. Cross sections of veins in Quiruvilca mine.

ZONING

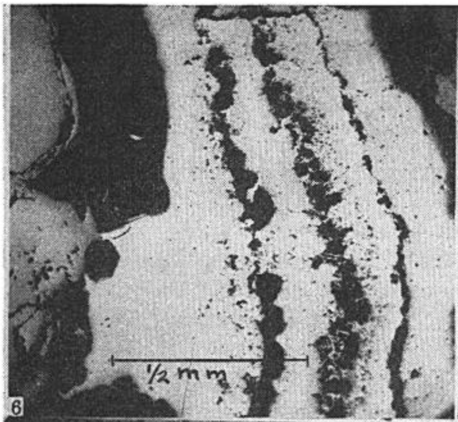
Enargite Zone.—The Enargite zone is located at Quiruvilca and embraces most of the workings of the Quiruvilca mine. At the surface this zone has the shape of an elongated oval, 2800 m long and 700 m wide. The zone is defined by the presence of enargite. Associated sulfides are pyrite, tetrahedrite-tennantite, wurtzite, sphalerite, chalcopyrite, realgar, and galena. Non-sulfide minerals are quartz, calcite, and gypsum.

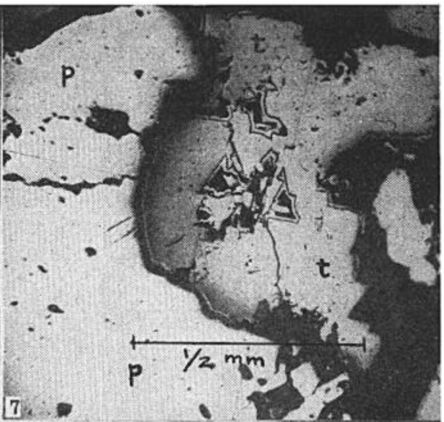
The enargite is generally massive and coarsely crystalline; individual crystals average 1 cm in width and 4 cm in length. The development of enargite crystals in many of the vugs is phenomenal; nearly perfect prismatic crystals of enargite as much as 20 cm in length and 5 cm in width have been found. Many clusters of slightly smaller crystals have also been discovered, and large clusters of crystals 1 to 3 cm long are fairly common. The crystals in the smaller clusters are usually coated with small crystals of enargite and pyritohedrons of pyrite. The enargite is remarkably pure and contains only 0.5 percent of impurities. A spectrographic analysis of the enargite made in the Geological Survey laboratory showed XX percent of copper, sulfur, and arsenic; 0.X percent of antimony; 0.0X percent of silver, molybdenum, tin, zinc, cadmium, chromium, and barium; and 0.00X percent of iron, titanium, calcium, manganese, and magnesium. An analysis made by the Northern Peru Mining and Smelting Co. showed 0.5762 percent of impurities, including 0.22 percent of antimony, 0.19 percent of tellurium, and traces of selenium, gold, bismuth, lead, indium and germanium but did not show any molybdenum, cadmium, barium, titanium, calcium, manganese, or magnesium.

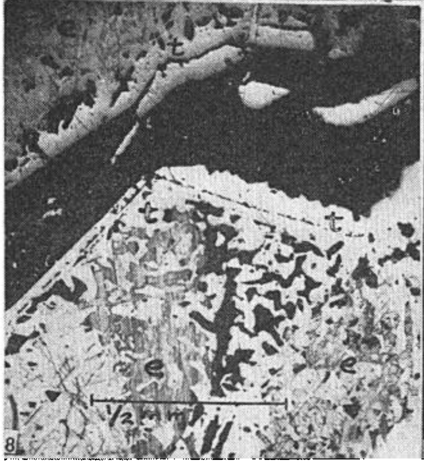
Enargite follows pyrite in the sulfide sequence and two stages of deposition have been recognized. The first stage is replaced by tetrahedrite-tennantite. The second stage of enargite replaces the first stage tetrahedrite-tennantite and in turn is replaced by late tetrahedrite-tennantite.

Pyrite is the most abundant sulfide in the Enargite zone. It is both massive and coarsely crystalline; the crystals are as much as 15 cm across and have both pyritohedral and dipyramidal habits. The crystals are generally coarser at depth and are commonly coated with an iridescent red to blue film of enargite. The larger crystals commonly show well-developed growth rings, indicating the pulsating nature of the pyrite deposition (Fig. 6). Large pyrite crystals in vugs are commonly coated with tiny crystals of enargite and late pyrite. Pyrite was the earliest sulfide to be deposited and in subsequent repetitions of the sulfide sequence it was in all cases the first sulfide to be formed. Three stages of pyrite deposition were recognized and most of the pyrite seems to have been deposited in the third stage after the formation of most other sulfides. Much of the early pyrite has been replaced by other sulfides, especially enargite and tetrahedrite-tennantite, and the remaining crystals show pitted surfaces and corroded edges suggesting that they have been partly dissolved by circulating solutions. Late pyrite replaces the other sulfides and commonly forms large massive bands in the veins. Small crystals of pyrite are disseminated throughout most of the rocks in the zone, but only in small amounts. Whereas the vein pyrite always has a pyritohedral or dipyramidal habit, the disseminated pyrite is always cubic. Sheets of secondary pyrite and calcite 1 to 2 cm thick coat the walls of some of the older workings.

Tetrahedrite-tennantite occurs throughout the Enargite zone but appears to be more abundant in the eastern veins. Two stages of deposition have been recognized (Fig. 7). Early tetrahedrite-tennantite replaces enargite, forming either myrmekitic-like intergrowths of the two minerals or pseudomorphs after enargite (Figs. 8, 9). Late tetrahedrite-tennantite is found in veinlets in the enargite and pyrite. These veinlets are generally concentrated







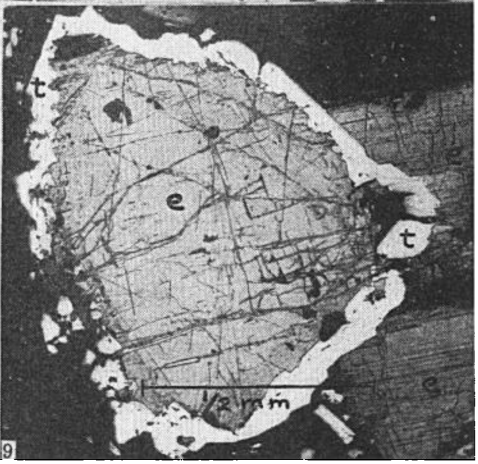


FIG. 6. Microphotograph showing growth rings in pyrite. Note corroded condition of contacts between bands.

FIG. 7. Two generations of tetrahedrite-tennantite (t) deposition, late stage deposited in solution pits in early stage tetrahedrite-tennantite. Pyrite (p).

FIG. 8. Tetrahedrite-tennantite (t) pseudomorphing enargite (e) and replacing it in myrmekitic-like intergrowths. Note second generation of tetrahedrite lining cavity. Section stained with KCN.

FIG. 9. Enargite (e) partly replaced by tetrahedrite-tennantite (t). Section stained with KCN.

near the center of the veins and are more common near the outer edge of the enargite zone.

Wurtzite is the usual form of zinc sulfide in the Enargite zone. It has a distinctive honey-orange color and is found in small stringers near the vein walls. Only one stage of deposition, following the first stage tetrahedrite-tennantite, was recognized. Marmatitic sphalerite was seen in several places, in all cases associated with late galena and quartz.

Chalcopyrite is found in small amounts throughout the zone. It is invariably present in wurtzite as small rounded blebs, which are commonly aligned in stringers. It also occurs along the contacts of the various copper sulfides with one another and with wurtzite. It was deposited along with and just after the wurtzite.

Galena occurs in very small amounts in the wurtzite and also has been seen in late fractures. The Morococha vein is reported to have carried some galena along the footwall in the upper part of the vein. Galena is associated with sphalerite and quartz in small fractures and encrustations in the outer part of the zone. The galena associated with the wurtzite is an early stage sulfide deposited just after pyrite and largely replaced by other sulfides that followed. Late galena was deposited following the third stage of pyrite and is probably epithermal, contemporaneous with the first stage of galena in the deposits of the outer zones.

Realgar is found in a few places in the central part of the Quiruvilca mine in small stringers associated with disseminated pyrite in the wallrock near the veins. The gangue minerals occur in small amounts in open spaces in the sulfides.

The paragenesis of a typical vein is as follows. Pyrite was the earliest sulfide to be deposited and was followed by galena. These sulfides were nearly completely replaced by enargite. Tetrahedrite-tennantite then partly replaced the enargite. Wurtzite was deposited next and was accompanied by chalcopyrite, which partly replaced the wurtzite as well as the enargite and tetrahedrite-tennantite. A second generation of pyrite was then deposited and subsequently was nearly completely replaced by a second generation of enargite. Tetrahedrite-tennantite again followed the enargite, partly replacing it. A third generation of pyrite was followed by a deposition of quartz, calcite, and rare galena.

The Tarapacá vein is a small outlier of the main Enargite zone that lies a few hundred meters northwest of Cerro Venado. This vein contains enargite with associated pyrite, tetrahedrite-tennantite, sphalerite, alabandite, and rhodochrosite. West of this small enargite center is a zone of tetrahedrite-tennantite and sphalerite, and farther west lies the lead-zinc area of Constancia. Thus, it appears that the Tarapacá area shows in miniature the general zoning found in the district.

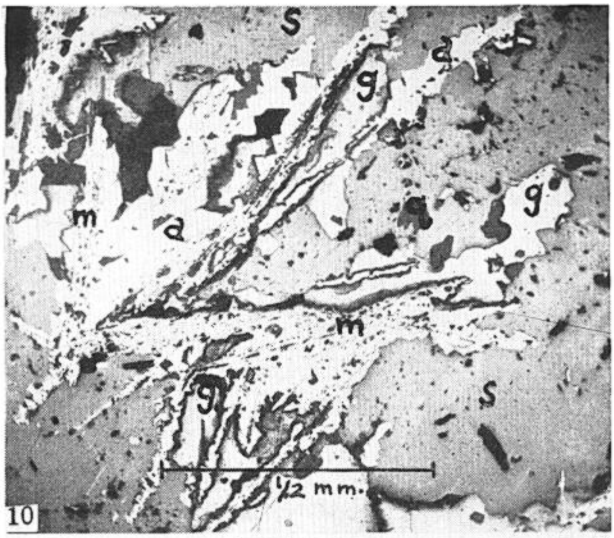
Transition Zone.—The Transition zone lies between the Enargite and Lead-Zinc zones. Its boundaries are delineated by the disappearance of enargite on the inside and the appearance of megascopic galena on the outside. In many places the exact boundaries could not be located precisely because of lack of information. The zone is most prominent to the west of the Enargite zone, where it is as much as 1,200 m wide, but it was recognized also to the south and north; it appears to be missing along the eastern edge of the district. The inner boundary of the zone is nearer the center of the Enargite zone on the surface than it is underground, so that the Enargite zone has the shape of a flattened cone. The conical shape of the zone is borne out by the fact that diamond drill holes in the Luz Angelica area show vertical zoning from galena-sphalerite at the surface to copper-pyrite at depth. Although most of the sulfides occur as massive aggregates, well-developed banding was observed in several places.

Pyrite and sphalerite are the most abundant sulfides. The pyrite is mostly massive and commonly shows well-developed growth rings and bands (Fig. 6). The sphalerite is dense and black and occurs in stringers, bands, and masses in the veins. Wurtzite is not abundant and is restricted to the inner parts of the zone. One stage of wurtzite and at least three of sphalerite have been recognized in this zone. In all cases the zinc sulfide follows tetrahedrite-tennantite in the sulfide deposition sequence. Tetrahedrite-tennantite is the principal copper mineral of the zone, although chalcopyrite was noted in several veins. The tetrahedrite-tennantite generally forms masses and stringers in the veins, but it also occurs interlayered with late-pyrite in colloform aggregates. Chalcopyrite is generally present as tiny blebs in sphalerite, but small masses of the mineral were seen in several places. Galena occurs in small amounts interlayered with late pyrite or associated with sphalerite and quartz in encrustations and veinlets. Marcasite and arsenopyrite were found in several of the larger workings in the zone. Arsenopyrite replaces marcasite and they always occur together associated with covellite. Two generations of marcasite and arsenopyrite were recognized. The first generation consists of a mosaiclike mixture of these minerals replacing pyrite. Second generation marcasite occurs as needles in sphalerite and is coated with late arsenopyrite (Fig. 10). Covellite fills innumerable tiny fractures in sphalerite, giving it an iridescent blue color. The mode of occurrence indicates that the covellite is a secondary mineral, probably derived from tetrahedrite-tennantite. Gangue is more abundant in the Transition zone than in the Enargite zone. Massive quartz is the principal gangue mineral, but small amounts of calcite and rhodochrosite were also noted.

The order of deposition in a typical vein is two sequences of pyrite, galena, tetrahedrite-tennantite, sphalerite, chalcopyrite, quartz, marcasite, and arsenopyrite followed by rhodochrosite and calcite. The number of stages of pyrite and tetrahedrite-tennantite is unknown, but this pair of minerals appears to have been repeated at least three times.

Lead-Zinc Zone.—The Lead-Zinc zone lies outside the Transition zone. Its sulfide minerals include galena, sphalerite, pyrite, chalcopyrite, tetrahedrite-tennantite, marcasite, arsenopyrite, and gratonite (?). The zone is 700 to 1,000 m wide to the north of Quiruvilca, 200 to 1,000 m wide to the south, and over 3,000 m wide to the west. Like the Transition zone, it is missing along the east side of the district. The active mines in the zone are in the Luz Angelica area south of Quiruvilca and the Constancia area to the west.

Marmatitic sphalerite is the only abundant zinc sulfide mineral, but some wurtzite was found near the inner edge of the zone. Galena forms either pods within the sphalerite or minute crystals intimately mixed with it. Pyrite is massive and is commonly found banded with sphalerite. Chalcopyrite in all cases occurs as small blebs and seams in and around sphalerite. Small amounts of tetrahedrite-tennantite were seen in many veins in seams and the interstices of quartz grains. Occurrences of marcasite and arsenopyrite, similar to those in the Transition zone, were noted in places. Arsenopyrite also occurs in comblike masses of prismatic crystals. Tiny prismatic crystals of gratonite (?) are present throughout the zone in small amounts as drusy coatings in small vugs, in interstices of quartz crystals, or replacing galena.



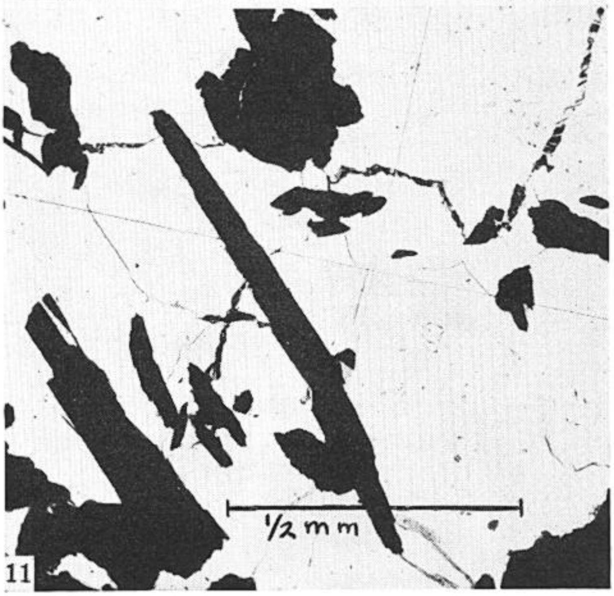


FIG. 10. Needles of marcasite (m) coated with arsenopyrite (a) and cutting across galena (g). Sphalerite (s) has replaced most of galena. Quartz (q).

FIG. 11. Thin section of quartz-stibnite vein. Note second generation stibnite along contacts between quartz grains.

Nonsulfide minerals are quartz, dolomite, rhodochrosite, and calcite. Quartz is abundant and generally occupies cavities. The gossan of many of the veins in this zone carries large amounts of quartz. Dolomite forms prismatic crystals in vugs and thin seams in the veins. Rhodochrosite is restricted to veins near the outer limit of the zone. Calcite is widely distributed, filling cracks and small cavities.

Sulfide deposition can be divided into three distinct stages. The first stage consists of pyrite, galena, tetrahedrite-tennantite, sphalerite, and chalcopyrite in that order. The pyrite-to-chalcopyrite sequence is repeated in the second stage of deposition and is followed by quartz, marcasite, and arsenopyrite. The third stage is a repetition of the pyrite-to-arsenopyrite series and is terminated by gratonite (?), rhodochrosite, and calcite. The first two stages of galena are nearly completely replaced by sphalerite, and the late galena is partly replaced by sphalerite, tetrahedrite-tennantite, and gratonite (?). Pyrite is replaced by sphalerite, marcasite, and arsenopyrite. Early sphalerite and arsenopyrite are replaced by later sphalerite and to a lesser degree by quartz.

Stibnite Zone.—The Stibnite zone, outermost of the four mineral zones, is characterized by the antimony sulfide, stibnite. This zone has been recognized throughout the periphery of the district, except possibly on the east, and is of unknown width. Stibnite first makes its appearance as a component of lead-zinc ores. The galena and sphalerite of these ores are mostly massive, whereas the stibnite shows its typical habit of radiating prismatic crystals. It is also found in masses of acicular crystals set in quartz or carbonate (Fig. 11), or in thin veinlets of fibrous crystals. Two separate stages of stibnite have been recognized, both of which succeed quartz and precede rhodochrosite in the deposition sequence; first generation stibnite may be partly replaced by second generation quartz. Arsenopyrite also appears and is either massive or, more commonly, in bands of short prismatic crystals. Pyrite and minor amounts of tetrahedrite-tennantite and chalcopyrite have been reported. One mine contained large amounts of native arsenic in colloform masses, associated with pyrite, sphalerite, galena, chalcopyrite, and tetrahedrite-tennantite. The nonsulfides consists of quartz and rhodochrosite and may be either banded or massive. Rhodochrosite replaces quartz and was the last major mineral to be deposited. The order of deposition is as follows: pyrite, quartz, tetrahedrite-tennantite, arsenopyrite, stibnite, rhodochrosite, pyrite, tetrahedrite-tennantite, quartz, stibnite, and rhodochrosite. Most of the active small mines and prospects are in the inner part of the Stibnite zone, as the galena-sphalerite-stibnite ores contain large amounts of silver in the form of argentiferous galena and possibly as freibergite.

PARAGENESIS

Paragenesis of minerals has been discussed in the description of the various mineral zones and is summarized in Figure 12. The mesothermal deposits are those of the Enargite zone and part of the Transition zone, and the three outer zones are epithermal in character. Two major pulsations of ore deposition are recognized in the mesothermal deposits and four pulsations in the epithermal veins.

VEIN DESCRIPTION

Quiruvilca Mine.—Nine different veins were being exploited in the Quiruvilca mine in 1951–1952. The major production was from the Elvira Number 2, Morococha and Morococha Number 2, Trujillana, and Sin Nombre veins. The Gildemeister, Bolognesi, Engañadora, and 477 veins also were being worked.

The Gildemeister vein, the westernmost in the mine, trends N 65° E and has an average dip of 75° S. To the east it terminates against the Morococha vein, and it narrows to the west although the end has not been reached. Workings on the vein extend over 250 m down dip and 400 m along the strike. Most of the ore has been extracted, and only one stope was active during 1951–1952. The vein is reported to have been between 1 and 1.5 m wide throughout most of its extent. Although the vein width increases on the deeper levels, the percentage of copper decreases; on the 220 level the vein is 2 to 2.5 m wide but is almost entirely pyrite. The vein consists of alternating stringers of pyrite and enargite, ranging from 3 to 20 cm in width. The sulfides are massive, containing only a few vugs, and are only slightly fractured. The vein contacts are sharp and marked by only a few centimeters of gouge. Small stringers of late pyrite are found in the wallrock in the immediate vicinity of the vein.

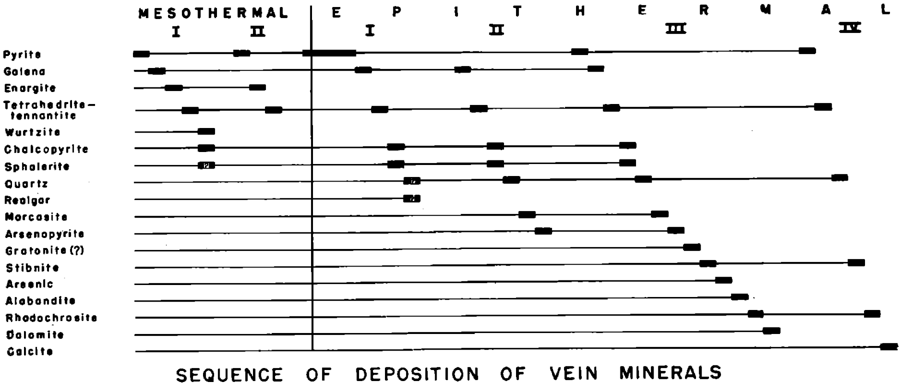


FIG. 12. Sequence of deposition of vein minerals.

The Elvira vein is actually a faulted segment of the Gildemeister vein. It is offset to the northwest of the east end of the Gildemeister vein (Fig. 4, 5), and has the same attitude and appearance. The Elvira vein segment is about 550 m long and has been worked for 275 m vertically. It has an average width of 1.4 m. The upper levels of this vein were the richest in the mine. In character the Elvira segment is similar to the Gildemeister, having massive slightly fractured ore with sharp and only slightly slickensided vein walls. It differs from the Gildemeister in having more vugs, small horses of wallrock within the vein, and wider bands of sulfides. The average sulfide band is 10 cm wide, but a 1- to 3-m band of massive pyrite is found on the footwall on the lower levels.

The Morococha vein, which intersects the Gildemeister and Elvira veins at an angle of 20°, trends N 85° W and has an average dip of 70° S from the 22 level to the 100 level; below the 100 level the dip changes to nearly vertical. This vein has been worked for more than 350 m laterally and 330 m vertically. Most of the workings lie to the east of the Gildemeister vein. The Morococha vein averages 1.10 m in width and is distinctive in appearance. Contacts have as much as 20 cm of gouge and the ore is extremely friable. Vugs and horses of wallrock are missing, but banding is well developed. The bands average 15 cm in width and are commonly separated by stringers of gouge. To the east, away from the Gildemeister-Elvira-Morococha juncture, the ore becomes less friable. The vein does not have a constant dip but appears in sections as a series of steps (Fig. 5). Apparently the thicker parts of the vein were the vertical segments, indicating that the hangingwall has moved down with respect to the footwall. Changes in dip and strike indicate that the vein follows no single structure but instead a series of semiparallel mineralized faults connected by diagonal crossings of ore. The so-called Morococha number 2 vein, which strikes N 82° E and is nearly vertical throughout most of its extent, is actually the southernmost of these mineralized faults. The Morococha Number 2 vein is considered here as the lower eastern part of the Morococha vein, even though the principal Morococha structure is mineralized for several tens of meters beyond where the vein splits and crosses over to the Morococha number 2 structure.

The Number 2 vein in 30 m north of the Elvira vein. It has the same strike and dip as the Elvira vein, N 65° E and 75° S, and is connected to the Elvira vein by a diagonal crossing whose intersection with that vein plunges 70° S. The average vein width is 1.10 m. As the 220 level is approached the width increases to an average of 1.15 m but the values decrease. Contacts between vein and wallrock are sharp and slightly slickensided. Sulfides are fractured and pyrite is commonly coated with an iridescent film of enargite; on the lower levels this film is so widely distributed throughout the pyrite that several stopes had to be closed down because of difficulties in concentrating this ore. Enargite commonly occurs in well-developed crystals and tends to be concentrated near the hanging wall on the lower levels of the vein. Banding is evident but ordinarily only three to six bands are present. Horses of wallrock are missing and the bands are not separated by seams of gouge. At the eastern end of the Number 2 vein the Engañadora vein splits off to the south. The Engañadora vein has an average width of 0.90 m. The Number 2 vein dies out a short distance to the east of the split, but its structure continues eastward and becomes the Trujillana vein.

The Trujillana vein is actually a series of en echelon veins which are often connected by very lean stringers. It strikes N 65° E and dips 67° S. The average width is 0.70 m. Workings on the vein extend from near the surface down to the 50 level. The vein is strongly banded and contains small horses of wallrock and thin stringers of gouge. Vein walls are highly sheared but the ore is not notably fractured. Near the surface tetrahedrite-tennantite is most abundant copper sulfide but on the lower levels enargite predominates.

The Sin Nombre vein, which was the principal producer during 1951–1952, is in the eastern section of the mine, south of the Number 2 and Engañadora veins. It strikes approximately east and dips 75° S. The width averages 1.15 m. The vein has been worked for 400 m laterally and from the surface to the 100 level. In the high-grade sections the vein is massive and well banded but contains many slices of wallrock and seams of gouge (Fig. 3). In the leaner sections wallrock in the vein is so abundant that the vein is reduced to a group of parallel stringers. The vein contacts are sharp and highly slickensided, often having 10 to 15 cm of gouge. The ore is quite friable and locally the sulfides are vuggy. The vein is actually made up of a series of en echelon veins, which trend N 85° W, connected by diagonal crossings that strike N 45° W. On the Eleodora level, three major segments of this vein are completely separated and have accordingly been named the Sin Nombre, Ojos Negros, and Bolognesi veins. On lower levels these segments are joined into one vein, herein considered the Sin Nombre, but the structures of the segments can be traced through all of the levels. En echelon structure in a vertical plane has also been noted in this vein. Overlapping of the en echelon segments is practically nonexistent in both the hoziontal and vertical planes. The main vein segments commonly change strike and the majority of ore is concentrated where these segments change strike slightly just before making a diagonal crossing. These concentrations form actual ore shoots that can be traced from level to level. Individual sulfide bands and stringers average 5 cm in width. The only persistent occurrence of wurtzite in the Quiruvilca mine is in this vein; the wurtzite forms 2- to 5-cm stringers near both the footwall and hangingwall. Tetrahedrite-tennantite also occurs in small bands, which tend to be concentrated near the center of the vein.

About 40 m north of the Number 2-Engañadora split is the 477 vein, which strikes N 80° E and dips 70° N. It has been worked for 160 m laterally on the Eleodora, Sub-Eleodora and, 22 levels. The vein averages 0.85 m in width. It consists of alternating stringers of pyrite and enargite about 5 cm wide. Locally the vein is vuggy. In many places disseminated sulfides and numerous small and localized splits make the vein-wallrock contact very vague.

Other Veins.—The veins of the Transition and Lead-Zinc zones can be divided into three major groups: 1) veins whose dominant mineral is pyrite, 2) veins whose dominant minerals are metallic sulfides other than pyrite, and 3) veins whose dominant minerals are nonsulfides. In general all of these veins have well-defined contacts and slightly slickensided walls. The average width is about 0.75 m.

In the Transition zone the pyritic veins of the first group predominate. In these veins the pyrite is generally massive and locally vuggy, and banding is essentially absent. The other sulfides are either disseminated through the pyrite or found as aggregates within it; these sulfides include only marmatitic sphalerite and small amounts of galena and tetrahedrite-tennantite.

The sulfide veins of the second group are found in both zones but are more common in the Lead-Zinc zone. In the Transition zone the dominant sulfide is marmatitic sphalerite, whereas in the Lead-Zinc zone both sphalerite and galena are abundant. These veins are mostly massive and banding is generally poorly developed. However, several examples of well-developed repetitive banding of sphalerite, pyrite, and galena were seen in veins with complex mineral assemblages.

The veins with predominant gangue minerals are common to both zones. Some veins are brecciated and in all a regular distribution or banding of the sulfides can be distinguished. Quartz is the most abundant gangue mineral and rhodochrosite is second.

The veins in the Stibnite zone are of two types. Veins of one type are composed solely of a mass of intergrown quartz and stibnite crystals, whereas veins of the other type contain large amounts of other sulfides, mainly sphalerite, pyrite, tetrahedrite, galena, and arsenopyrite, and show evidence of brecciation. Most veins of the latter type contain considerable quartz and a few contain rhodochrosite.

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c/o AMERICAN EMBASSY,
LIMA, PERU,
July 26, 1955

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