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THE LEAD-ZINC VEINS OF THE CHILETE MINING DISTRICT IN NORTHERN PERU[1]

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ABSTRACT

Lead-zinc-silver veins in the Chilete mining district in the Department of Cajamarca in northern Peru have been worked sporadically since the 17th century, but the greatest activity dates only from 1951. The ore deposits are in a thick section of andesitic volcanic rocks that overlie with marked unconformity a sequence of Cretaceous limestone, shale, and quartzite. The volcanic rocks form a gently north-dipping block of apparently simple structure. The Chilete deposits are quartz-sulfide veins consisting essentially of sphalerite, pyrite, and galena in a gangue of quartz and silicified and pyritized andesite. Wall rocks are calcitized, chloritized, pyritized, and sericitized. The veins were formed by fissure filling, breccia filling, and replacement. Veins strike either northwest or east-northeast and dip steeply. They range from a few centimeters to 4 m in width and the longest has a strike length of about 1,700 m. The veins are cut by a number of post-mineral strike-slip faults of small displacement. Thicker sections of the principal northwest-striking vein, Murcielago, tend to occur where the strike swings slightly to the north. Vein intersections are not favorable loci for ore deposition, and several intersections seem to be distinctly unfavorable. All the veins have roughly the same combined content of lead and zinc at all levels, but the proportion of zinc to lead increases notably at the lowest levels of exploration, 200–250 m below the outcrops.

[1] Publication authorized by the Director, U. S. Geological Survey.

INTRODUCTION

LEAD-ZINC veins are being worked in the Chilete mining district, near the town of Chilete on the Rio Magdalena in the Department of Cajamarca in northern Peru. Chilete lies on the main road between Pacasmayo and Cajamarca 108 km east of Pacasmayo. The altitude of Chilete is about 1,100 m and the mountains in the vicinity rise to well over 2,200 m. The district is one of the few lead and zinc producers in Peru whose altitudes are less than 4,000 m. In general the terrain is rugged but relatively easy of access via numerous trails. The climate is warm throughout the year, with temperatures ranging from 15° to 35° C. Annual rainfall is 20–25 cm, most of which occurs from January to April. In general the region is rather arid.

The only mining activity in the district is the operation of the Northern Peru Mining & Smelting Co., a subsidiary of the American Smelting & Refining Co., at Paredones in the San Pablo Valley 4 km north of Chilete. The veins at Paredones have yielded most of the lead, zinc, and silver mined in the district since its discovery in the 17th century.

Eight weeks was spent in the area during 1952 and 1953. Field work included a geological reconnaissance of an area of some 50 sq km and detailed mapping on surface and underground in the Paredones area. Surface mapping was done on aerial photographs and a topographic base of the Paredones area, both furnished by the company, and underground mapping was done on company maps on a scale of 1 : 500. A surface map was compiled from the aerial photographs on a scale of 1 : 10,000 using an Abrams mechanical triangulator kit. Housing and subsistence were kindly provided by the company.

Acknowledgments.—It is a pleasure to acknowledge the wholehearted cooperation of the Northern Peru Mining & Smelting Co. during my study of Chilete. I am especially indebted to Mr. Lawson Entwistle, Chief Geologist of the company, who made arrangements for my work and discussed many of the geological problems with me, and to Mr. Willis Griswold, then General Manager of Operations at Chilete, for much friendly assistance and stimulating discussions.

The study of the Chilete district was undertaken as part of a more comprehensive study of the lead and zinc resources of Peru, which has been carried out by the U. S. Geological Survey in collaboration with the Geological Institute of Peru during the past 7 years. This work is at present done under the auspices of the Foreign Operations Administration of the U. S. Department of State.

GENERAL GEOLOGY

The oldest rocks in the district are a sequence of limestones and quartzites of Cretaceous age, which crop out along and south of the Rio Magdalena (Fig. 1). These rocks were not studied in detail. The upper part of the section consists of thin-bedded dark-gray to black impure limestone and interbedded gray shale that strikes west-northwest and dips 30°–60° south. The limestone is at least 1,500 m thick. The lower part of the section is made

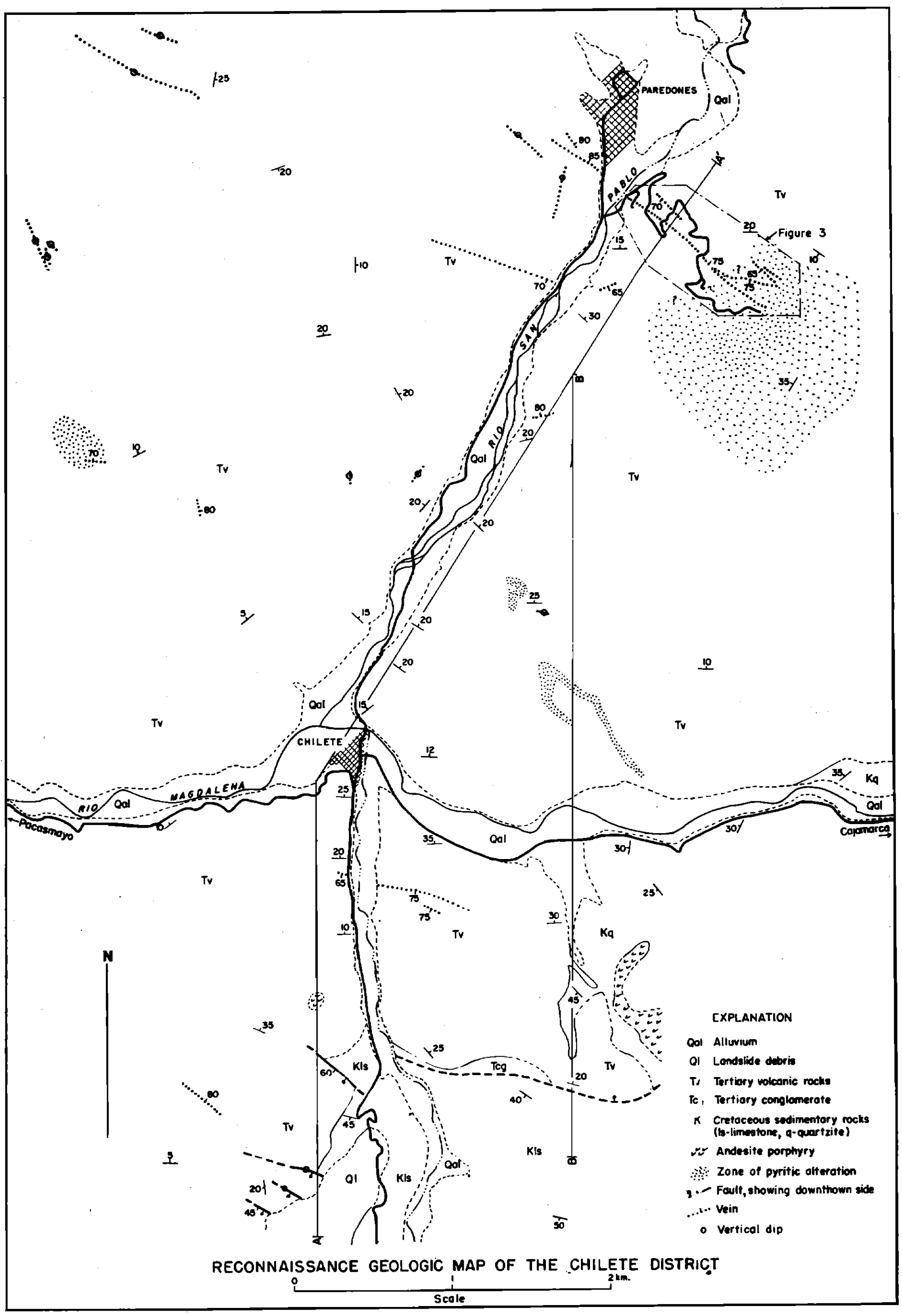
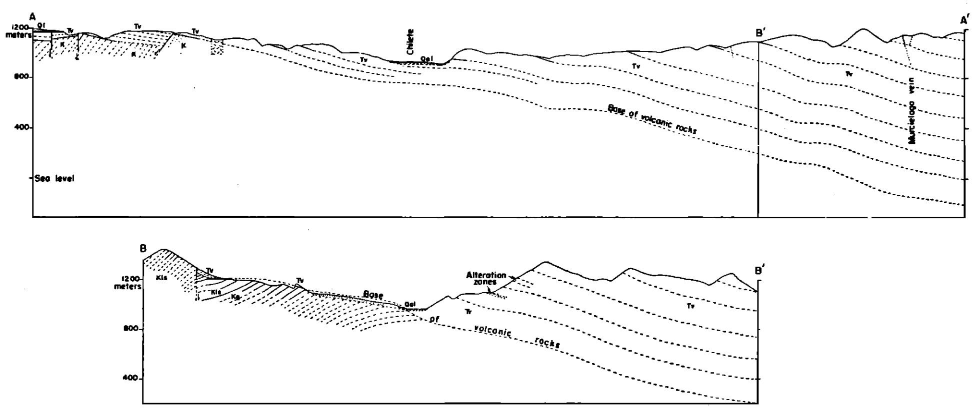

PAREDONES
Qal
Tv
Figure 3
RIO SAN PABLO
CHILETE
RIO MAGDALENA
←Pacasmayo
Cajamarca→
Kq
Kls
Ql
Tcg
N
EXPLANATION
Qal Alluvium
Ql Landslide debris
Tv Tertiary volcanic rocks
Tc Tertiary conglomerate
K Cretaceous sedimentary rocks (ls-limestone, q-quartzite)
Andesite porphyry
Zone of pyritic alteration
Fault, showing downthown side
Vein
o Vertical dip
RECONNAISSANCE GEOLOGIC MAP OF THE CHILETE DISTRICT
0
2 km.
Scale

FIG. 1.

up of thick-bedded white quartzite at least 500 or 600 m thick. No mineralization of any kind was noted in the sedimentary rocks.

The sedimentary section is overlain with marked angular unconformity by a thick section of volcanic rocks, which underlie almost the entire area shown in Figure 1 north of the Rio Magdalena. The thickness of this section is estimated from the generalized structure sections (Fig. 2) to be 1,500 m or more. The lower 300–400 m is composed of interlayered andesite flows, andesite and dacite tuffs, and quartzite conglomerates with only very minor quantities of flow breccia. In contrast, above this layered sequence, the rocks are almost entirely andesitic flow breccias and lavas that show little or no layered structure. Although attitudes of the volcanic rocks are variable, the section in a general way forms a homocline dipping gently north. All the ore deposits of the district are enclosed in volcanic rocks.



STRUCTURE SECTIONS, CHILETE DISTRICT

FIG. 2.

In spite of their rather fresh appearance, all the volcanic rocks are notably altered. The most common alteration product is calcite, followed by chlorite, sericite, and kaolin clay in that order. In most of the rocks examined in thin section, the original plagioclase feldspars have been converted to an aggregate of calcite, epidote, sericite, and albite, and almost invariably the pyroxenes are strongly chloritized. No explanation for this widespread alteration was offered by field observations at Chilete.

The volcanic rocks are overlain, perhaps conformably, to the north of the area shown in Figure 1 by an unstudied sequence of conglomerates and red beds.

Andesitic and dacitic intrusive rocks crop out at a number of places south of the Rio Magdalena. The largest mass is a dikelike body of augite andesite at least 1.5 km long and as much as 350 m wide, intruded into quartzite. Several sills 50 cm to 2 m thick of porphyritic dacite are intruded into limestone. The andesites are younger than the basal volcanic rocks; the age of the dacite relative to the volcanic rocks is not known, but the basal volcanic section contains tuffaceous rocks of similar composition.

A few faults of small displacement cut sedimentary and volcanic rocks south of the Rio Magdalena and offset veins in the Paredones area; north of the Rio Magdalena no faults of any consequence were recognized outside the mineralized area at Paredones. The sedimentary rocks are probably folded to a considerable extent, but within the studied area these rocks are largely covered by volcanics, so that few data were available. The volcanic rocks appear to be gently folded, but except in the basal part of the volcanic section their attitudes could not be determined with much assurance.

ORE DEPOSITS

All the ore deposits at Chilete are quartz-sulfide veins carrying zinc, lead, silver, and a little copper. The veins range in strike length from a few meters to 1,700 m and attain a maximum width of about 4 m. Greatest depth below the outcrop thus far reached during mining is about 245 m. Most of the veins strike either northwest or east-northeast and all dip steeply, generally 60° or more. Vein mineralogy is very simple. The only abundant sulfides are sphalerite, galena, and pyrite; chalcopyrite occurs megascopically in only four veins, although it is ubiquitous as microscopic inclusions in sphalerite; arsenopyrite was seen in one vein. The gangue is almost entirely quartz or silicified and pyritized andesite. Small amounts of pink and white calcite, dolomite, ankerite, and barite are also found, and gypsum is a common although not abundant constituent. Most of the veins are banded and several contain comb quartz. Parts of several veins consist of breccia cemented by vein minerals.

Veins consisting mainly of quartz have prominent outcrops and contain sulfides at the surface, whereas highgrade veins are thoroughly oxidized and have very inconspicuous outcrops. Vein outcrops are generally difficult and often impossible to recognize in natural exposures, and most of the unexplored veins can be seen clearly only in road cuts or along main trails.

History and Production

Historical data on Chilete are scarce; only two sources were available (1, 2). Veins of the Paredones area were discovered in the middle of the 17th century, and the oxidized ores were worked at that time for several years. After a serious cave-in on the West Pacasmayo vein, which trapped a considerable number of miners, the mines were abandoned. After a long period of inactivity the veins were reopened in 1856 and sulfide ores were mined more or less continuously until 1883, when transportation difficulties and lack of water for milling caused a shutdown. Most, if not all, of the production of the early years came from the Murcielago and West Pacasmayo veins. No data on total production are available.

The mine was leased by the Northern Peru Mining & Smelting Co. in 1924 and after 4 years of exploration was purchased outright for future development. In August 1951 construction of the present mill and camp began, and the mine came into production in May 1952. Monthly production has increased from about 7,000 tons in the beginning to about 9,000 tons at present (1953).

Inasmuch as vein walls are generally clean and strong, ore is mined by shrinkage stoping. All broken ore is drawn on the 5th (lowest) level, either from stopes or from ore passes from the higher levels, and is transported on that level to the 250-ton flotation mill. Lead and zinc concentrates are trucked in one-ton steel containers to the railhead at Chilete, where they are loaded on flatcars for transportation to the port at Pacasmayo. For the period January 1 to August 30, 1953, lead concentrates averaged 60.36% Pb, 7.90% Zn, 1.73% Cu, and 56.87 oz. Ag per ton; and zinc concentrates contained 52.73% Zn, 1.26% Pb, 0.51% Cu, and 6.52 oz. Ag per ton.

Mineralogy

Vein minerals are listed below in order of abundance, and their occurrence is briefly described. No attempt was made to study the minerals of the oxidized zone.

Sphalerite is the most abundant sulfide mineral at Paredones. It occurs in all veins and in some parts of certain veins, particularly the Pacasmayo vein, it is the only abundant mineral. Three distinct types of sphalerite can be recognized: a moderate brown (5YR4/4 or 5YR3/4) "rosin" sphalerite giving a nearly white powder; a deep reddish brown type yielding a pale yellowish brown (10YR6/2) powder, and a purplish black variety giving a pale brown (5YR5/2) powder.

TABLE 1

ANALYSES OF SPHALERITE FROM CHILETE

	Color	Vein	Zn	Fe	Mol. %ZnS	Mol. %FeS	Sum
1.	Dark	West Pacasmayo, 5th level	56.25	9.56	83.9	15.1	99.0
2.	Dark	Murcielago, 5th level	47.65	9.21	71.1	14.5	85.6
3.	Medium	Murcielago, 3d level	57.50	6.28	85.8	9.9	95.7
4.	Medium	Pacasmayo, 1st level	61.40	4.39	91.7	6.9	98.6
5.	Medium	Murcielago, 4th level	59.20	4.32	88.4	6.8	95.2
6.	Light	West Pacasmayo, 5th level	63.65	1.67	95.0	2.6	97.6
7.	Light	Pacasmayo, 1st level	62.55	1.26	93.3	2.0	95.3

Seven hand-picked samples of sphalerite were analyzed for zinc and iron and the results are given in Table 1. Pure zinc sulfide contains 67.10% Zn and 32.90% S. Samples 1 and 6 come from the same locality, as do samples 4 and 7. All of the iron reported probably cannot be attributed to sphalerite as all the sphalerite at Chilete contains a small amount of chalcopyrite, but the amount to be deducted is very small. The major impurity is silica except in sample 2, which contains in addition 2.83% of galena. None of the sphalerites analyzed is the variety marmatite—10% or more Fe, according to Palache, Berman, and Frondel (4, p. 212)—although the dark type is close to marmatite. Where two varieties are found together, the lighter mineral is invariably the later.

Spectrographic determinations of Cd, Ga, Ge, and In were made on the same seven samples by Harry Bastron, of the U. S. Geological Survey. The results are given in the following table; a lone zero in the unit column means that the element was looked for but not detected.

In ores containing two types of sphalerite, cadmium is slightly more abundant in the lighter of the two types—1 (dark) and 6 (light), 4 (dark) and 7 (light)—but the differences are not large. The other spectrographic data are largely negative; the complete absence of germanium in all samples is notable.

	Cd	Ga	Ge	In
1.	0.36	0.0004	0	0.005
2.	0.23	0	0	0.002
3.	0.37	0.0005	0	0.009
4.	0.29	0	0	0.006
5.	0.42	0.0005	0	0.010
6.	0.39	0	0	0.005
7.	0.50	0	0	0.002

The sphalerite is ordinarily rather coarse grained; euhedral crystals up to 2 cm across and cleavage faces as much as 4 cm across are not uncommon. In general the sphalerite appears to contain only a little chalcopyrite as microscopic inclusions; however, chalcopyrite was found in all of the 19 polished sections studied.

Pyrite is ubiquitous at Chilete and occurs as thin layers in banded ore, as very fine grained veinlets cutting earlier sulfides, or impregnating wall rock fragments in breccia ore. Vein pyrite, where its habit could be recognized, is either pyritohedral or octahedral, whereas pyrite in walls or wall rock fragments is cubic.

Galena is found in all veins but may be present in only very small amounts locally. It is much finer-grained than the associated sphalerite, rarely showing cleavage faces as much as 1 cm across. Both coarse galena and the fine grained "steel" variety are found. In some veins, such as the Murcielago on the 3d level and the West Pacasmayo on the 1st level, galena appears to have been sheared during post-mineralization movement along the veins.

Megascopically visible chalcopyrite is scarce at Paredones and was seen only in the West Pacasmayo vein on the 1st level, the Esperanza vein on the 3d level, the Pacasmayo vein on the 4th level, and the "Valenciana" (Murcielago) vein on the 4th level. It is widespread, however, as microscopic inclusions in sphalerite from all veins. In general these inclusions are extremely small and become visible only at magnifications of 500 diameters or more.

Arsenopyrite was recognized in the field only in the West Pacasmayo vein on the 5th level, where it occurs as small rounded knots of minute acicular prisms or as tiny needles disseminated in quartz. It was recognized, however, as a minor constituent in polished sections of ores from all veins, although it seems to be rather rare in the Murcielago vein.

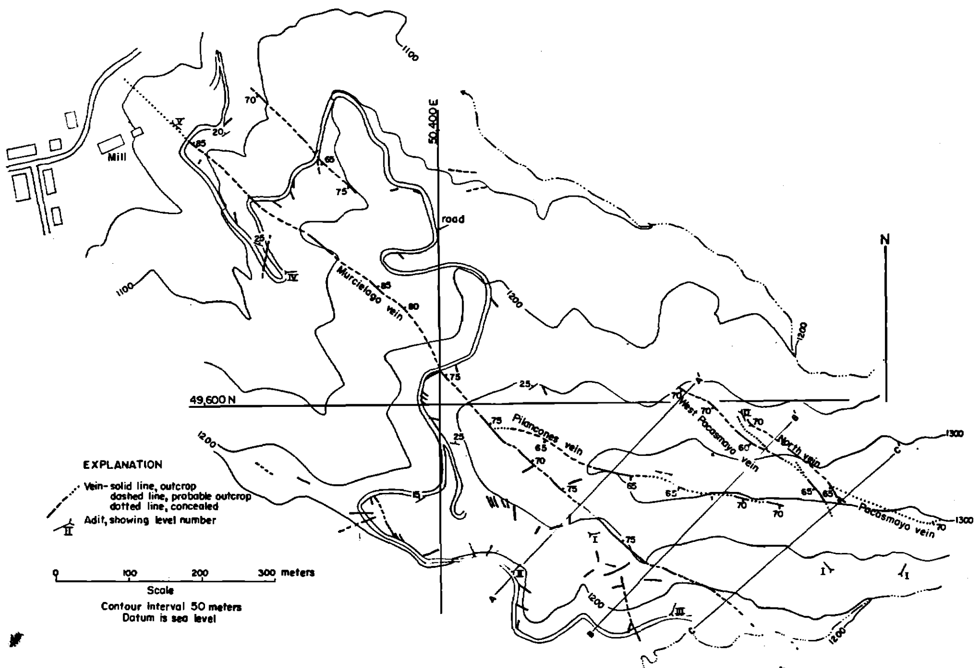
Marcasite (FeS_2) was identified in one polished section of ore from the West Pacasmayo vein on the 1st level. It forms ragged prisms replaced by sphalerite.

The only abundant gangue mineral is quartz; it is likely that more than 99 percent of the non-metallic vein minerals is quartz. It occurs as a fine-grained sugary groundmass, as comb quartz in the more prominently banded vein sections, and in vugs and late veinlets. It appears to have been deposited throughout the sequence of vein formation.

Small amounts of barite are found in vugs in the Pacasmayo vein and in a minor vein on the 5th level with pink calcite. Ankeritic dolomite occurs in veinlets cutting sphalerite and quartz in the Murcielago and Esperanza veins. Gypsum is widespread but not abundant. Most of it appears to be supergene, but gypsum in vugs in the Pacasmayo and Murcielago veins and in cores of quartz stringers in the Esperanza and "Valenciana" veins is probably hypogene. Sericite is a very minor constituent of several veins. It was identified only in thin section, in late veinlets with quartz, carbonate, and pyrite.

Structure of the Paredones Vein System

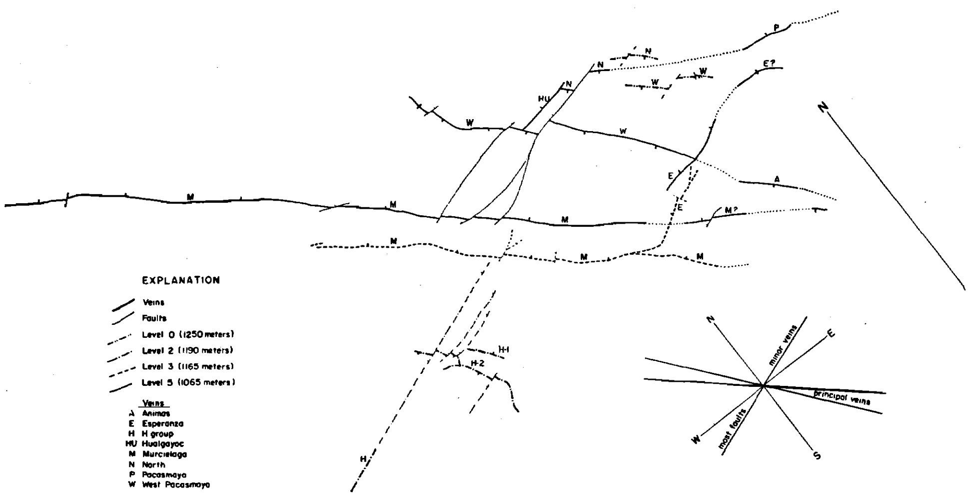
Vein outcrops in the Paredones area are shown on Figure 3, a generalized pattern of veins and faults is shown on Figure 4, and structure sections across the southeast corner of the area appear in Figure 5. Among the major veins, the Murcielago, West Pacasmayo, North, and Animas veins strike northwest and the Pacasmayo, Esperanza, Pilancones, and Hualgayoc veins strike within about 20° of east.



GEOLOGIC MAP OF PART OF THE PAREDONES AREA, CHILETE DISTRICT

FIG. 3.

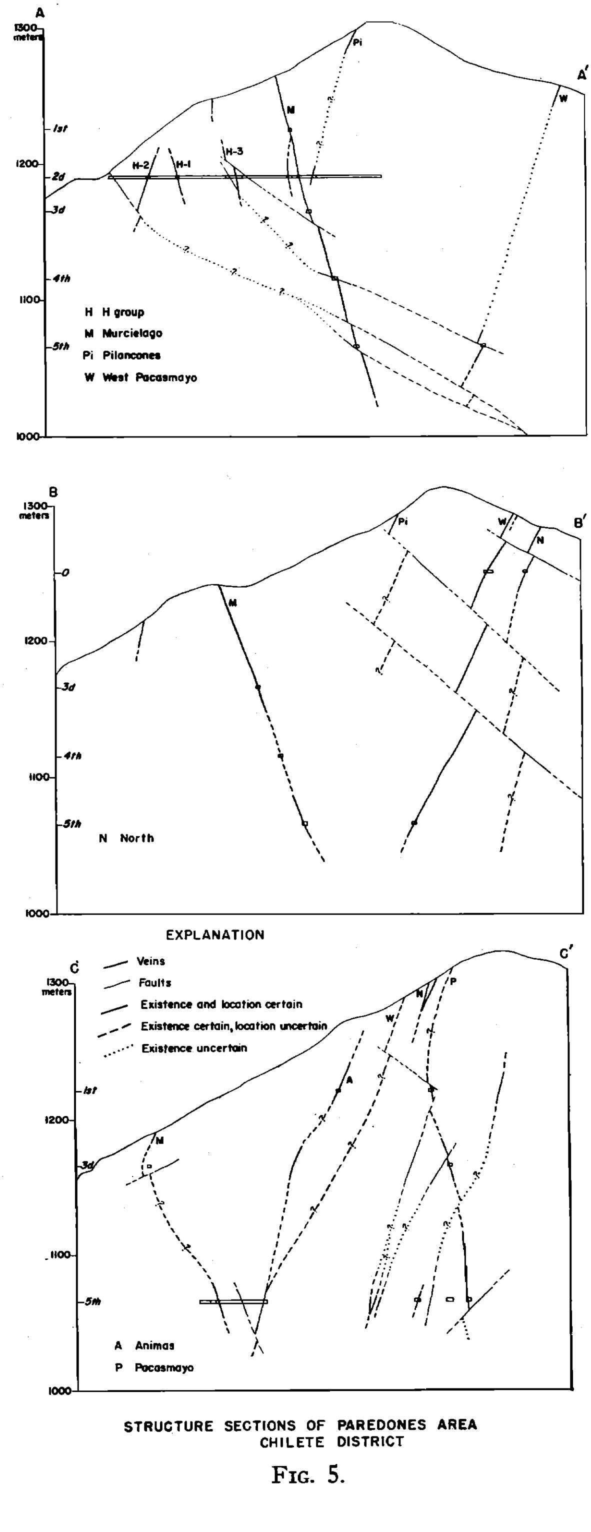
Major Veins.—The principal producing vein is the Murcielago, which has a known or inferred strike length of 1,700 m and has been explored over a length of about 1,000 m and to a maximum depth of 210 m below the outcrop along 6 levels. This vein strikes northwest and dips 65°–85° northeast. Near its southeast end the Murcielago vein splits into the Esperanza vein, which strikes east-northeast, and the "Valenciana" vein, which is the southeast continuation of the Murcielago vein. The only other vein to intersect the Murcielago vein is the Pilancones, described below. The Murcielago vein ranges in width from 1 to 4 m and averages perhaps 2 m. The Esperanza vein is known only underground on the 3d, 4th, and 5th (lowest) levels; its area of possible outcrop is covered with slide rock and talus. It dips steeply north



GENERALIZED STRUCTURAL PATTERN OF PRINCIPAL VEINS AND FAULTS ON FOUR LEVELS, PAREDONES AREA, CHILETE DISTRICT

Fig. 4.

in most places, but steep south dips are also recorded. The maximum known strike length of the vein is about 150 m, on the 3d level. On this level the vein splits to the east into two semi-parallel veins 40–55 m long; the north split ends against a fault and the south split seems to terminate against the Animas vein. The Esperanza vein intersects the West Pacasmayo vein on the 5th level, but the intersection is not well defined and it is uncertain whether the West Pacasmayo vein terminates against the Esperanza or whether the two veins cross without notable offset; it seems likely that the West Pacasmayo vein either ends or continues southeast as a barren fracture which may become the Animas vein. The corresponding intersection is not found on the 3d level; on this level the West Pacasmayo vein is a weakly mineralized strong fracture where is crosses the level, and the Esperanza vein appears to be cut off before it reaches the fracture. The Esperanza structure is rather weak compared with other vein structures at Paredones. The vein



STRUCTURE SECTIONS OF PAREDONES AREA
CHILETE DISTRICT

FIG. 5.

ranges in width from a thin stringer to 2.5 m and probably averages a meter or so.

The Pilancones vein splits off the Murcielago vein near coordinates 49,600N–50,400E on the surface, and can be traced along the outcrop for about 400 m east-southeast of the intersection. The intersection is not exposed either on the surface or on the Murcielago Zero (highest) level. The vein dips 65°–80° south. It has been recognized with certainty only on the surface and on the Zero level; apparently the rake of its intersection with the Murcielago vein is such that the vein does not appear in any working below the Zero level, unless the narrow vein cut 10 m northeast of the Murcielago vein on the 2d level is the Pilancones. The Pilancones vein in outcrop is about 3 m wide; at its only exposure underground it is 1.5 m across.

The West Pacasmayo vein strikes roughly parallel to the Murcielago and crops out about 200 m northeast of the southeast extremity of the latter vein. The vein can be traced for some 250 m along the outcrop and for 260 m on the 5th level. Inasmuch as the West Pacasmayo vein dips 60°–70° southwest, toward the Murcielago, the traces of the two veins are only about 90 m apart on the 5th level, which here is 200 m below the West Pacasmayo outcrop. The vein has been recognized on the Zero, 1st, 3d, 4th, and 5th levels. It ranges from 1 to 3 m in width and averages slightly more than one meter.

The North vein lies parallel to the West Pacasmayo vein and crops out about 20 m to the northeast. It can be traced clearly along the outcrop for 150 m and may extend for another 150 m to the east-southeast as the Pacasmayo vein. The North vein is known with certainty underground only on the Zero level; it probably appears also on the 5th level, where, because of its slightly steeper dip, it lies some 20 m farther northeast of the West Pacasmayo vein than at the outcrop. The vein is as much as 1.5 m wide but its average width is only about one meter.

The outcrop of the Pacasmayo vein lies along the southeast extension of the North vein, but the exact relationship of the two veins cannot be determined because of lack of exposures. An open cut 100 m long marks the former outcrop of the vein. The Pacasmayo vein strikes east-southeast to east and dips 70° south at the outcrop, 70°–85° north on the 1st and 3d levels, and more or less vertically on the 5th level. Maximum known strike length is 200 m, on the 1st level. Clarification of the relation between the Pacasmayo and North veins on the 5th level awaits further development, but it seems likely that the two veins will prove to be one and the same. The Pacasmayo vein attains a maximum width of 3.5 m and has an average width of perhaps 1.5 m or slightly more.

The Animas vein strikes northwest and dips 65°–80° southwest. It lies about 30 m southwest of the West Pacasmayo vein at the surface. Its maximum known strike length, on the 1st and 5th levels, is about 80 m, and the limits of the vein probably have been reached. The vein appears to cross the north branch of the Esperanza vein on the 3d level without offset and to cut off the south branch. No other veins are known to intersect the Animas vein unless the Animas and West Pacasmayo veins join on the 5th level.

Although the Animas structure is fairly strong in places, the vein is generally rather thin; it averages less than one meter in width.

The Hualgayoc vein is found only on the 5th level, where it forms a crossing between the West Pacasmayo vein and the presumed North vein. The vein strikes slightly north of east and dips 50°–75° north. It has a strike length of about 45 m. To the west it appears to terminate against the West Pacasmayo vein, and eastward it passes into a single fracture on approaching the North(?) vein. The Hualgayoc vein cannot be correlated with any other vein at Paredones either on the surface or underground. It has a maximum width of 1.5 m and an average width of about one meter.

Faults.—Veins at Paredones are cut by a large number of post-mineral faults. The principal faults strike east-northeast and dip northwest (Fig. 4), although in the eastern section of the mine a few faults strike north to northwest and dip steeply west. Some if not all of the faults have a marked strike-slip component of movement, as along several faults, veins which dip toward each other are offset in the same sense (Fig. 5, sec. AA'). In general the southeast side moved northeast relative to the northwest side; this regularity of displacement is well shown in Figure 5, where the vein offsets simulate those ascribable to reverse faulting. Maximum strike-slip displacement is about 18 m, but most veins are displaced less than 5 m.

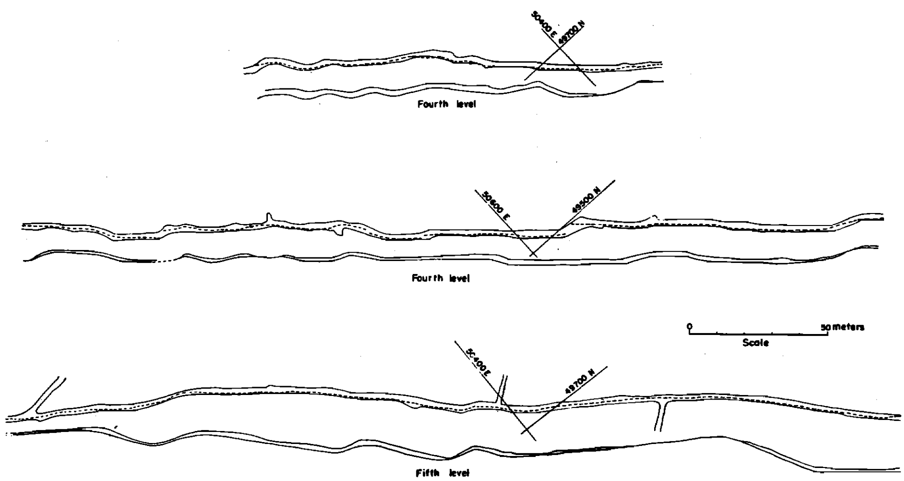
Post-mineral Movement Along Veins.—Very little evidence of post-mineral movement along veins was found. Striations in the hanging wall of the Murcielago vein on the 3d level near coordinate 10,650E plunge 10°–15° northwest and on the 5th level near coordinate 10,400E plunge 25° northwest.

Most of the minor splits in the hanging wall of the Murcielago vein strike 10°–30° W and dip steeply east (the acute angle of their intersections with the vein opens to the northwest); they are mineralized gash fractures opened during the movement postulated in the following section. Minor splits in the footwall of the vein are less regular, and some whose acute angle of intersection opens to the northwest may have been opened by a reversal of movement during mineralization.

Minor splits off the West Pacasmayo vein are mostly in the hanging wall, and they have a more westerly strike than the vein, suggesting that at least some of the movement along the parent fracture during mineralization was in a sense opposite to that along the Murcielago vein.

Localization of Ore

Veins.—The only vein that has been developed and mined sufficiently to offer much evidence on ore localization is the Murcielago. On the 5th level the vein consists of two large ore shoots 55 and 90 m long respectively and a small shoot 25 m long, separated longitudinally by barren vein sections 10 to 15 m long. Only the two large shoots are found on the 4th level, which begins southeast of the small shoot. Within the shoots the vein varies somewhat in width, depending on the strike; the thicker parts of the vein tend to occur where the strike swings slightly to the north. Barren sections generally begin where the vein swings to a more easterly strike and end at or near a slight bend to the north. These relations of vein width to strike are shown schematically on Figure 6. In this figure the changes in strike are greatly exaggerated for clarification and emphasis, as actually they are extremely subtle, mostly less than 5°, and although they can be recognized readily enough in the field, they could not be illustrated clearly without some exaggeration. These variations in width indicate that the southwest side of the original fracture moved northwest relative to the northeast side before or during deposition of vein minerals. At the present stage of development of the vein, data are inadequate to show whether this movement had any vertical component.



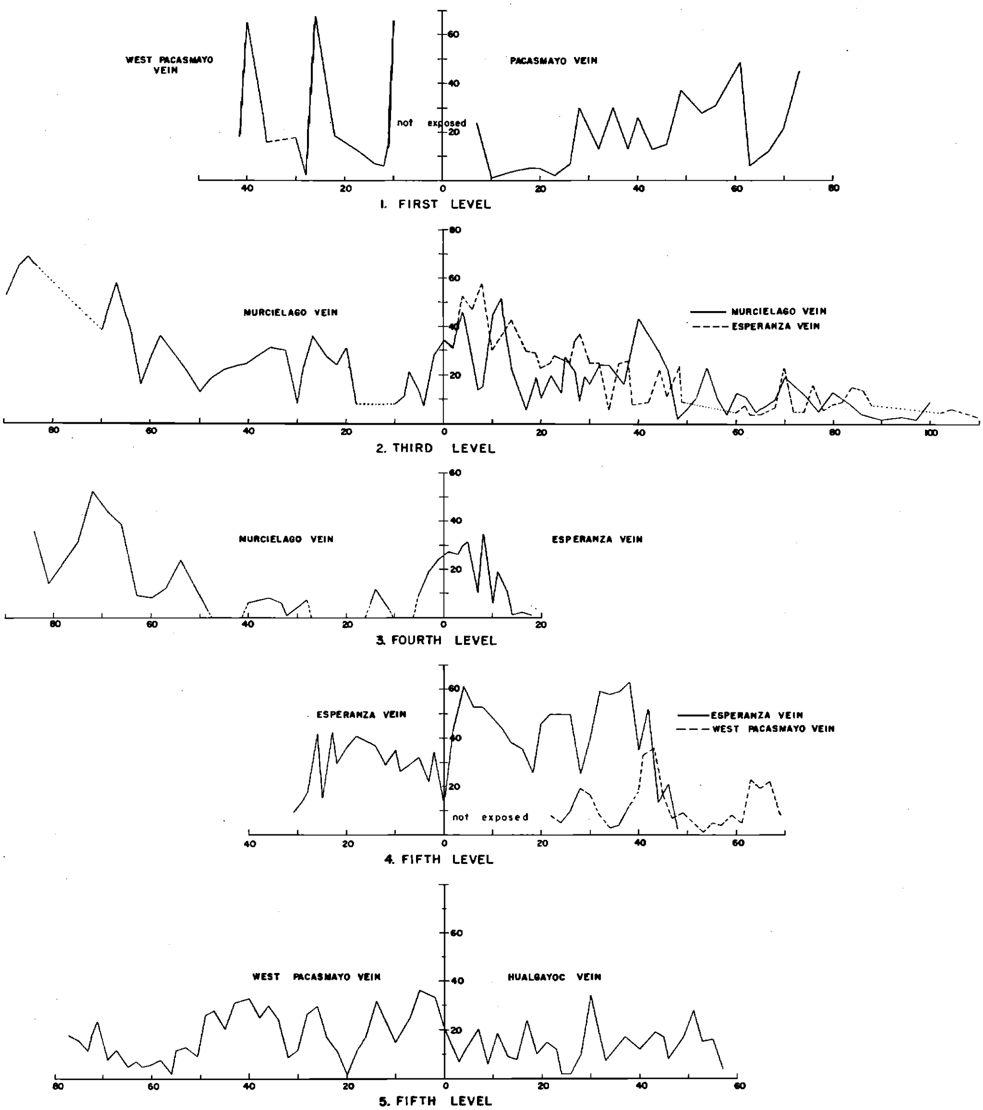
VARIATION IN WIDTH OF MURCIELAGO VEIN WITH CHANGES IN STRIKE

FIG. 6. In each group of drawings, the upper plan is of the level with the footwall of the vein shown as a dashed line; the lower plan shows vein widths according to sample maps with bends exaggerated for clarification.

Vein intersections.—Vein intersections at Paredones are exceptions to the well-established generalization that such intersections should be favorable loci for ore deposition. Although several intersections have been found, no ore shoots or even increases in vein width are associated with them; indeed, at several intersections the veins are leaner or thinner or both than at some distance away. Figure 7 presents quantitative data on the lead and zinc content of several veins at and near intersections. The combined lead and zinc content taken from company assay maps and recomputed to one-meter width is shown as ordinates; distances from intersections are shown in meters as abscissae. The curves therefore show the relative total lead and zinc content at any given distance from the intersection.

The various vein intersections and their characteristics are listed below:

Zero level—Murcielago and Pilancones veins: intersection inaccessible but apparently no significant change in either vein; Pilancones vein may pinch out near intersection.



VARIATIONS IN LEAD-ZINC CONTENT NEAR VEIN INTERSECTIONS

FIG. 7. Ordinates—Percent of combined lead and zinc, recomputed to 1 m width. Abscissae—distance from intersection (0) in meters.

First level—Pacasmayo and North veins: intersection not recognized, may be a minor barren fracture. Pacasmayo and West Pacasmayo veins: intersection not exposed but both veins are reduced to a series of thin veinlets as the intersection is approached (Fig. 7–1).

Third level—Murcielago and Esperanza veins: intersection poorly defined, but no noticeable change in Murcielago vein after Esperanza splits off to east-northeast. Both veins die out to southeast and northeast respectively beyond intersection (see Fig. 7–2). Esperanza and Animas veins: no assay data available, intersection poorly defined and metal content appears to diminish near intersection.

Fourth level—Murcielago and Esperanza veins: intersection very poorly defined, both veins weak where Esperanza vein splits off to east-northeast (see Fig. 7–3).

Fifth level—Murcielago and Esperanza veins: no intersection on this level, as Esperanza vein appears to terminate 25–35 meters before Murcielago vein is reached. Esperanza and West Pacasmayo veins: no noticeable change in Esperanza vein at either side of intersection; workings along the West Pacasmayo vein end about 18 meters before the intersection is reached but no change is evident as the intersection is approached (see Fig. 7–4). West Pacasmayo and Hualgayoc veins: intersection well exposed, no noticeable change in either vein (see Fig. 7–5).

Wall Rock Alteration

The country rock of the mineralized area at Paredones is a monotonous body of greenish gray to dark greenish gray porphyritic rocks. Only the occasional occurrence of flow breccias gives any clue in the field to the origin of the rocks; in general any flow layering, variation in composition from flow to flow, interbedded tuffs or other characteristics of volcanic assemblages have been effectively obliterated during alteration. Under the microscope, however, all the rocks studied show fairly well preserved flow structures and the typical hyalopilitic or trachytic groundmasses of andesitic volcanic rocks. Wall rocks from four localities along three veins were examined in thin section. At each locality two or three specimens were collected at various distances from the vein walls. A total of 11 sections was studied. All the rocks present certain alteration features in common.

Feldspar phenocrysts invariably are sericitized, the intensity of sericitization increasing somewhat as the vein is approached. Most feldspars are also altered to calcite, but this alteration decreases in intensity with nearness to veins at three of the four localities. The sequence of feldspar alteration is not clear, but the reciprocal variation in intensity suggests that sericitization may be later than and superimposed on calcitization. Epidote, chlorite, and iron oxide replace feldspar in very minor amounts. In all but one thin section the feldspar remnants are albite and the original composition is unknown; unaltered feldspar phenocrysts in the very few fresh rocks found at Chilete are andesine or andesine-labradorite.

Dark silicates are completely altered to a very fine grained aggregate of pale green chlorite (antigorite), commonly accompanied by varying amounts of calcite, iron ore, quartz, sericite, leucoxene, and reddish iron oxides. A common alteration is to pseudomorphs composed of a mesh of chlorite with interstitial quartz or sericite, which simulate the common mesh serpentine alteration of olivine. Another widespread alteration is to pseudomorphs of chlorite cut by a triangular or irregular reticulated network of leucoxene or iron ore. The original minerals are unknown; shapes of some pseudomorphs suggest hypersthene and of others suggest biotite (although biotite is extremely rare in the fresher rocks), but in many examples alteration has extended beyond the original crystal boundaries and even the shape of the replaced grain gives no clue to its identity.

The groundmass of all the rocks consists of dusty plagioclase microlites and iron oxide granules in a nearly isotropic matrix that is in part chlorite. Microphenocrysts of feldspar are sericitized but not as completely as the accompanying phenocrysts. Irregular scattered patches of quartz, chlorite, and calcite are common; quartz becomes more abundant near the vein in three localities. All the rocks are pyritized, but only at one locality did the amount of pyrite increase near a vein; elsewhere pyritization seems to have affected the country rock more or less uniformly. The pyrite is largely if not entirely cubic in habit.

In wall rocks of the Pacasmayo vein (1st level) and the West Pacasmayo vein (5th level) small amounts of a mineral believed to be adularia are associated with quartz. The adularia occurs as tiny euhedral crystals, commonly rhomb-shaped, around the edges of quartz patches. In one section the adularia was found with irregular amygdule-like bodies as a thin layer between a rim of chlorite and a core of quartz; in another it forms a crust between quartz and wall rock. The crystals are so minute as to preclude any precise optical measurements, even with the use of an oil-immersion objective, but the negative optical sign, birefringence of about 0.006, marked negative relief, and particularly the rhombic cross-sections, suggest adularia.

Internal Vein Structures

Veins at Paredones were formed by a variety of processes, including fissure filling, breccia filling, and replacement. The most abundant ore type is a banded rock consisting of subparallel veinlets of sulfide minerals ribbing and replacing country rock or of a series of crustified quartz-sulfide veins; these

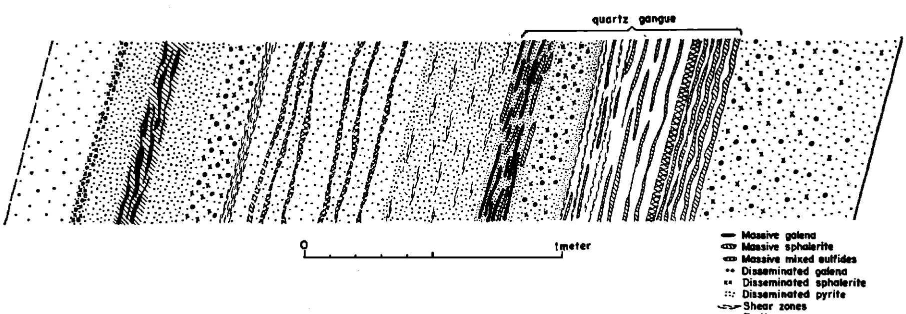


FIG. 8. Section of Murcielago vein, I-4 stope, looking SE. The footwall is marked by gouge and slickensides; the hanging wall is only slightly faulted. Quartz gangue is abundant only in the place indicated; elsewhere the sulfide minerals are either vein or are disseminated in silicified country rock.

two subtypes commonly occur together. Breccia ore is found locally, particularly in the Pacasmayo vein near the east end of the 3d level and in the Murcielago vein near the northwest end of the same level. A few examples of ore types are illustrated in Figures 8 to 10.

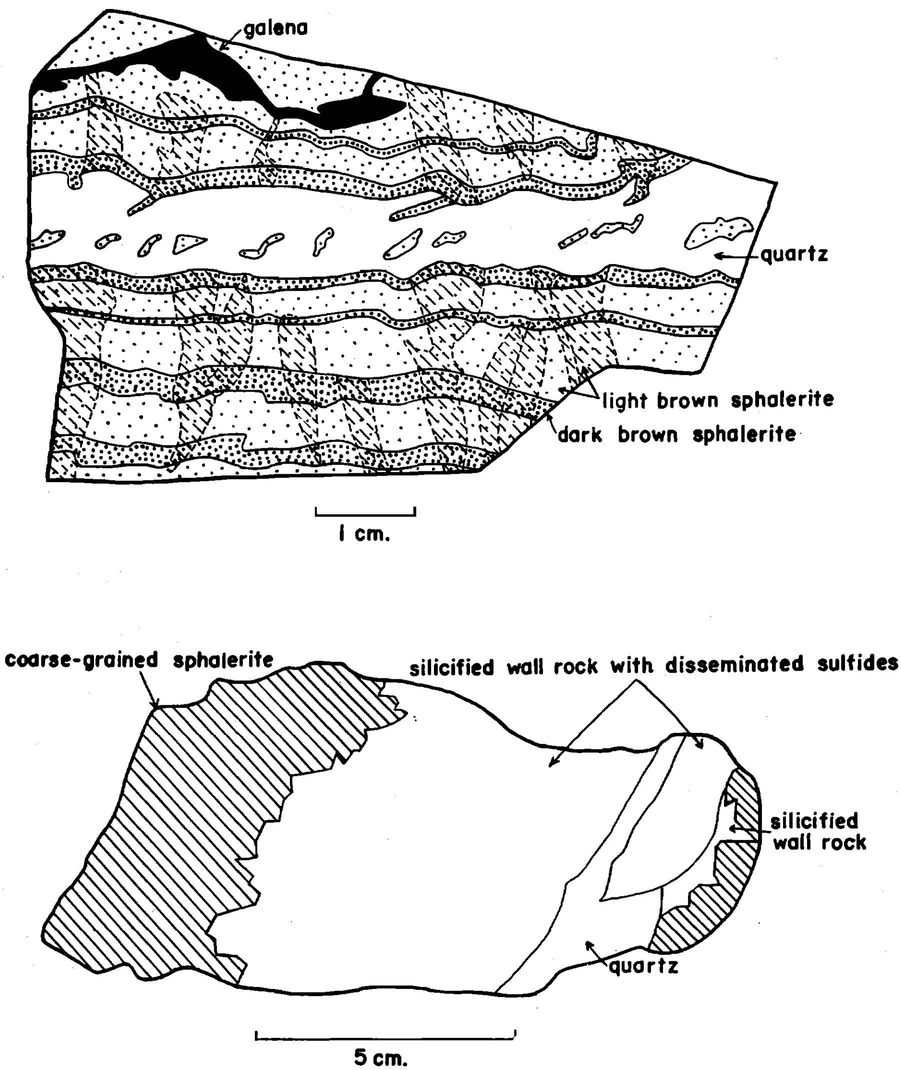


FIG. 9. Upper: Banded sphalerite from Murcielago vein, 3rd level. Cross-hatched areas are individual crystals of sphalerite that cross compositional layers, suggesting that they crystallized from an original colloidal state. Lower: Coarse-grained sphalerite from West Pacasmayo vein, 5th level. Silicified country rock is replaced by sphalerite in large euhedral crystals.

Figure 8 is a section of the Murcielago vein in the I–4 stope above the 4th level. The vein at this place was about 3.2 m wide. The banding, although irregular in detail, is very regular if the entire vein is considered. Such banding is typical, particularly of the Murcielago vein. Quartz is a prominent gangue mineral in a section 30 cm thick near the right (southwest) side of the vein; elsewhere the gangue is silicified and pyritized andesite country rock.

Figure 9 (upper) is a sketch of a sawed but unpolished face of a specimen of banded sphalerite from the Murcielago vein on the 3d level, showing rhythmic symmetrical deposition of the light brown and medium brown types of sphalerite. Galena is clearly later than sphalerite. Each of the cross-

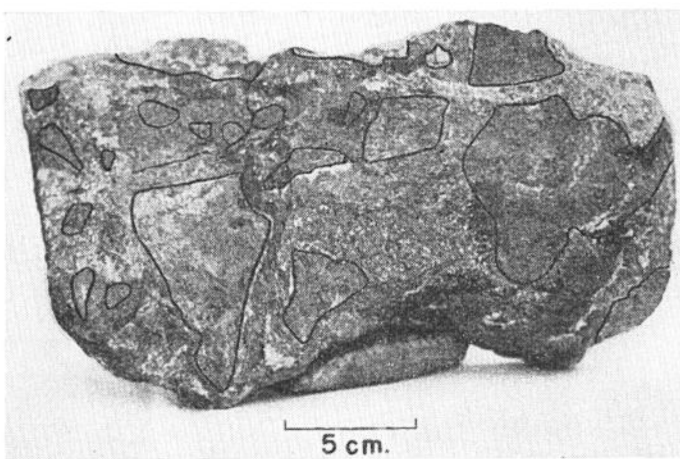


FIG. 10. Breccia ore from Pacasmayo vein. Breccia fragments are outlined in black. Interstitial material is mostly galena with scattered quartz-lined vugs (white patches).

hatched areas within the sphalerite shows a uniform orientation of cleavage surfaces and represents a single crystal unit; inasmuch as the units are rather irregular and cross more than one compositional layer, it seems likely that the sphalerite was deposited originally in open space as colloidal layers of different composition, and subsequently crystallized.

Figure 9 (lower) is a sketch of sphalerite ore from the West Pacasmayo vein on the 5th level. Silicified country rock is replaced by coarse-grained light brown sphalerite that shows sharp crystal faces against the replaced rock. The light brown sphalerite contains no pyrite and grades outward into purplish black sphalerite veined by pyrite; the light variety seems therefore to have been deposited later than the dark. Galena occurs only in the silicified wall rock, and its age relationship to sphalerite is unknown.

Figure 10 is a photograph of breccia ore from the Pacasmayo vein near the east end of the 3d level. Wall rock fragments are outlined in black. The interstitial material is largely galena with a few small quartz-lined vugs (white patches). Several breccia fragments are rimmed by a thin layer of comb quartz and locally the galena is interlayered with quartz. All the fragments are strongly pyritized. The fragments appear to have been rounded somewhat by replacement, but the high proportion of fragments to sulfide minerals (the proportion is much greater in general than in the specimen shown, which was selected as an example of high-grade breccia ore) indicates that little replacement has taken place.

Sequence of Deposition of Vein Minerals

No single well-defined sequence of deposition can be established for the vein minerals at Chilete, as in general several separate sequences are evident at almost any place in the veins. However, for any given single sequence, the following observations are applicable. Quartz was probably the earliest vein mineral to be deposited, as it is veined and replaced by early sulfide minerals. It was deposited throughout the period of mineralization and occurs finally in veinlets cutting sulfides, and in vugs. Pyrite was also deposited throughout the sequence but seems to have been formed for the most part at

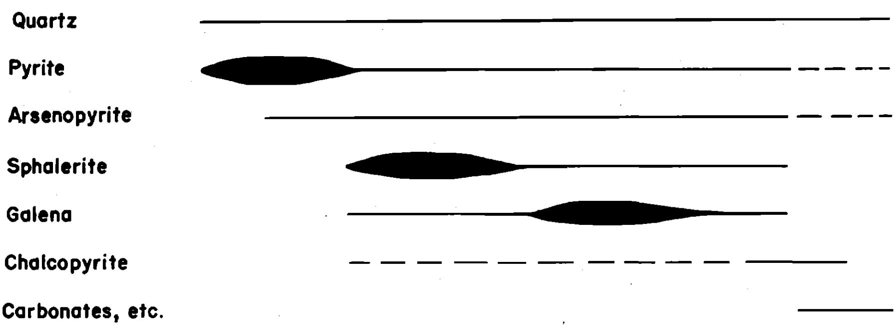


FIG. 11. Diagram showing generalized age relationships of vein minerals.

an early stage, as it is most abundant as euhedral or slightly corroded crystals embedded in sphalerite and galena. Arsenopyrite occurs both as early euhedral grains in sphalerite and galena and in late veinlets and vugs. Sphalerite and galena were deposited during the same general period, but sphalerite is generally earlier and is veined by galena. Chalcopyrite occurs in veins cutting both sphalerite and galena, but the very fine grained chalcopyrite disseminated in sphalerite may have been formed by exsolution from the sphalerite. The minor gangue minerals are all late and are found mainly in vugs. Age relationships of the various minerals are summarized in Figure 11.

Variation in Mineralization with Depth

The total combined lead-zinc content of four major veins (Murcielago, Pacasmayo, West Pacasmayo, and Esperanza) does not seem to vary systematically with depth; indeed each of these veins has roughly the same combined metal content throughout its known vertical extent, and furthermore all of them have nearly the same combined percentage of lead and zinc.

TABLE 2

ZN/PB RATIO IN INDIVIDUAL VEINS AT VARIOUS LEVELS

Vein	Level	No. of assays	Zn/Pb ratio
Murcielago	2	29	2.60
Murcielago	3	137	2.31
Murcielago	4 (NW oreshoot)	85	2.64 } 2.54
Murcielago	4 (SE oreshoot)	177	2.50 }
Murcielago	5 (NW oreshoot)	72	3.91 } 4.38
Murcielago	5 (SE oreshoot)	137	4.62 }
Pacasmayo	1	75	1.83
Pacasmayo	3	203	2.25
Pacasmayo	4	151	8.25
Pacasmayo	5	40	9.44
West Pacasmayo	1	23	1.85
West Pacasmayo	3	160	1.59
West Pacasmayo	4	180	3.09
West Pacasmayo	5	104	4.32
Esperanza	3	43	1.65
Experanza	4	93	5.03
Esperanza	5	91	4.16
Hualgayoc	5	38	3.26

All the veins show, however, a notable variation with depth in the proportion of zinc and lead; zinc is considerably more abundant relative to lead on the 4th and 5th levels than on any of the higher levels. Table 2 shows the Zn/Pb ratio in each vein at various levels, and Table 3 shows this ratio for the various veins at each level. In general, each vein shows an abrupt in-

TABLE 3

ZN/PB RATIO AT EACH LEVEL FOR VARIOUS VEINS

Level	Vein	Zn/Pb ratio
1	Pacasmayo	1.83
	West Pacasmayo	1.85
2	Murcielago	2.60
3	Murcielago	2.31
	Pacasmayo	1.45
	West Pacasmayo	1.59
	Esperanza	1.65
4	Murcielago	2.54
	Pacasmayo	8.25
	West Pacasmayo	3.09
	Esperanza	5.03
5	Murcielago	4.38
	Pacasmayo	9.44
	West Pacasmayo	4.32
	Esperanza	4.16
	Hualgayoc	3.26

crease in the Zn/Pb ratio between the 4th level and the next higher level (Table 2); this increase takes place in the Murcielago vein between the 5th and 4th levels. At a given level all veins, except the Pacasmayo vein on the 4th and 5th levels and the Esperanza vein on the 4th level, have roughly similar Zn/Pb ratios (Table 3). No vertical variation in types of sphalerite or in minor mineral content was detected, except that arsenopyrite appears to be more abundant on the 5th level than elsewhere. The uniformity of variation in the several veins and their very similar total lead-zinc content suggest that all the veins were formed during a single period of mineralization.

U. S. Geological Survey,
Washington, D. C.,
Nov. 1, 1954

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