# Geology and Ore Deposits of the Atacocha District Departamento de Pasco Peru

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GEOLOGIC INVESTIGATIONS IN THE AMERICAN REPUBLICS

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# GEOLOGIC INVESTIGATIONS IN THE AMERICAN REPUBLICS

## GEOLOGY AND ORE DEPOSITS OF THE ATACOCHA DISTRICT, DEPARTAMENTO DE PASCO, PERU

By Robert F. Johnson, Richard W. Lewis, Jr., and Guillermo Abele C.

**ABSTRACT**

The Atacocha district is in central Peru between the Río Tingo and Río Huallaga north of Cerro de Pasco. Roads from Cerro de Pasco extend along both the Tingo and Huallaga, and all mines are accessible by road. The district lies on a ridge extending north from the high central plateau of Peru and is characterized by steep topography with more than 900 meters of relief. The district and the three producing lead-zinc mines in it were studied in 1952–53 by geologists of the Instituto Geológico del Perú and the U. S. Geological Survey.

Bedded rocks range in age from pre-Permian to Tertiary(?). The pre-Permian rocks are exposed only on the edges of the district. The total thickness of Permian and younger rocks is estimated at 2,420 to 3,930 meters, but no complete section is exposed owing to folding and faulting. The Mesozoic section ranges from 1,400 to 2,900 meters in thickness. The Pucará formation of Late Triassic to Early Jurassic age makes up the lower two thirds of the section, and is composed of limestone with some interbedded shale. Cretaceous rocks overlie the limestone and consist of quartz sandstone overlain by basalt flows. Cretaceous limestone is found at the top of the section in two horizons separated by basalt flows. The youngest consolidated rocks are conglomerates of probable Early Tertiary age. The sedimentary rocks are dated largely by lithologic correlation; fossils were found only in the Pucará formation.

Dacite of probable Tertiary age intrudes the bedded rocks. Dikes and sills are numerous and four small stocks were found. All but one stock and most of the dikes and sills are near the Atacocha fault, which may have formed a favorable zone for intrusion. The intrusives are most abundant between Milpo and Atacocha.

The Atacocha fault divides the district into two structural areas. East of the fault the principal structural features are simple folds. To the west of the fault, folding is more complex and the rocks are cut by a series of northwesterly-striking faults, and a fault parallel to the Atacocha fault. The Atacocha fault, a reverse fault, dips steeply eastward, the east side having moved up and to the north relative to the west side.

The history of the area between Permian and Late Cretaceous time was one of marine and continental deposition interrupted by three and perhaps four periods of uplift and erosion. No strong folding took place during this interval as the sedimentary contracts are either conformable or disconformable. Volcanic activity occurred during the Permian and again in the Cretaceous.

The Andean orogeny began in Late Cretaceous time and continued through much of the Tertiary. The rocks were folded, faulted, and intruded by dacite.

Subsequent to the intrusions, lead and zinc sulfides were deposited from hydrothermal solutions, possibly as a late phase of intrusive activity.

The ore deposits of the district are concentrated in three areas, Milpo, Machcán, and Atacocha. Lead and zinc are the principal metals obtained, and silver is an important byproduct. More than 90,000 tons of lead and 65,000 tons of zinc have been produced since 1940, nearly all from the Atacocha mine.

Galena and sphalerite are the principal ore minerals. They occur with small amounts of jamesonite and tetrahedrite-tennantite in a gangue of pyrite, calcite, clay minerals, quartz, rhodochrosite, and fluorite. Cerussite is an important lead mineral at Machcán where most of the workings are in the oxide zone.

Three stages of mineralization are recognized at Atacocha: a quartz-pyrite stage, a sulfide stage, and a realgar-orpiment stage. The deposits are classified as leptothermal to mesothermal.

Both replacement ore bodies and veins are found in the district. Replacement bodies are the principal source of ore at Machcán and Atacocha but are not important at Milpo. The veins at Machcán are formed by replacement, but those at Atacocha and Milpo seem to be formed by fissure filling.

The most important features in localizing the ore deposits appear to have been the porphyry intrusions, the Atacocha fault, and the contact of the Mitu and Pucará formations. Nearly all the ore is found in limestone of the Pucará formation or in the overlying sandstones of the Goyllarisquisga formation. Rocks of the Mitu group and rocks younger than the Goyllarisquisga formation seem to have been unfavorable for ore deposition.

## INTRODUCTION

Geologists of the Instituto Geológico del Perú and the U. S. Geological Survey have been making a study of the lead-zinc deposits of Peru since 1947. The general outlines of a lead-zinc province extending from northern Peru south into Bolivia have long been known and the large copper-lead-zinc properties of the Cerro de Pasco Corp. in central Peru are world famous, but no systematic study of the geologic setting and mineral potential of the province as a whole has been undertaken previously. Most of the work has been of a reconnaissance nature because of the large area to be covered, but some districts, notably Hualgayoc and Sayapullo in the Departamento de Cajamarca, and several mines, such as La Florida and Quiruvilca in the Departamento de La Libertad, and Chilete in Cajamarca, have been studied in detail.

This report describes the results of 9 man-months detailed work in the Atacocha district in the Departamento de Pasco. Most of the work was done at or near the three producing mines, Atacocha, Milpo, and Machcán, but sufficient regional mapping was carried out to fit the ore deposits into the geologic picture of the district. The work was done as part of the program of Technical Cooperation (Point Four) under the auspices of the U. S. State Department and the Instituto Nacional de Investigación y Fomento Mineros, of the Peruvian Ministerio de Fomento y Obras Públicas.

## LOCATION AND ACCESS

The Atacocha district is defined, for the purpose of this report, as that area extending from Cerro de Pasco north to the latitude of Huariaca and lying between the Río Tingo and Río Huallaga (fig. 45). Reconnaissance mapping was carried on to Salcachupán at the confluence of the two rivers 6 kilometers below Huariaca but the geology was not included on the district geologic map (pl. 23). The three producing mines are near the center of the district.

The great mining center of Cerro de Pasco is the principal town of the region. Cerro de Pasco is 317 kilometers by road from Lima and also has regular rail connections to Lima. All-weather roads, forming part of the central highway system, lead from Cerro de Pasco down both the Río Huallaga and Río Tingo to Salcachupán. Below Salcachupán the road follows the Río Huallaga for 60 kilometers to Huánuco which has regular air service to Lima. Roads connect Atacocha and Milpo with the main road along the Río Huallaga, and Machcán is reached by a road from the Río Tingo. Some of the problems of road construction in the area are indicated by the need of 20 switchbacks on the 14-kilometer road from Atacocha to the main road at San Miguel. A network of trails connects the mines and small villages, and makes the entire district accessible.

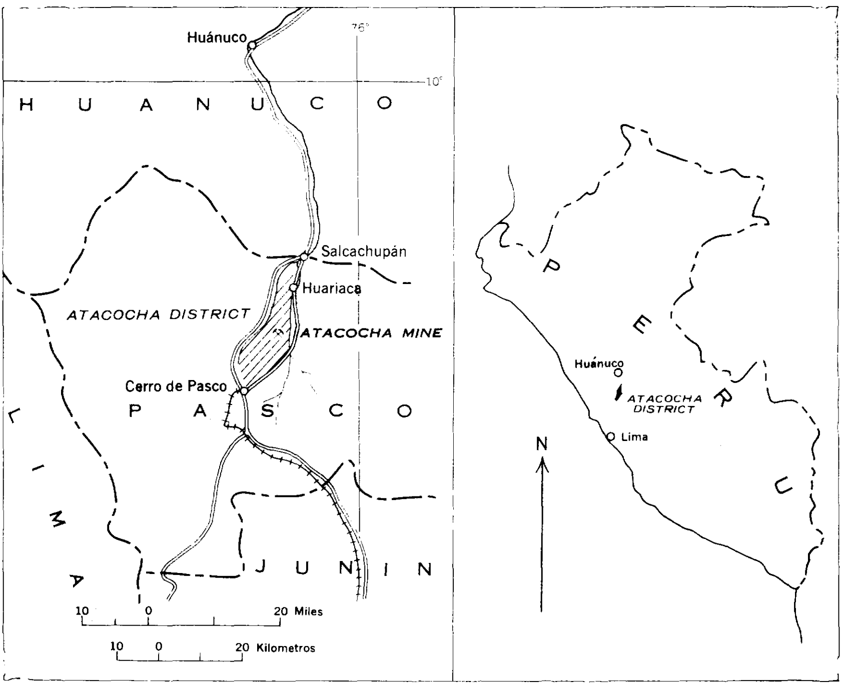


FIGURE 45.—Index map showing the location of the Atacocha district, Departamento de Pasco, Peru.

## PHYSICAL FEATURES

Cerro de Pasco is on the eastern edge of the high central plateau of Peru at an altitude of 4,350 meters above sea level. The Atacocha district is on a long ridge extending northward from the plateau between the Río Huallaga and Río Tingo. Peaks on the ridge have the same general altitude as the peaks on the plateau (4,400 to 4,500 meters) from the edge of the plateau to as far north as the village of Yarusyacán, where the ridge drops off abruptly to end at the junction of the two rivers at Salcachupán. Parallel ridges with peaks of about equal height extend from Milpo to Machcán; the western ridge is the watershed between the Río Huallaga and Río Tingo and the eastern is cut by the deep Quebrada Atacocha and Quebrada Chicrín which drain the area between the ridges. Pumaratanga, the highest peak in the district (4,560 meters) is near the north end of the western ridge and marks the point at which the watershed shifts to the eastern ridge. North of Pumaratanga the western ridge gradually dies out.

The Río Huallaga is the principal stream. It is the largest tributary of the Río Marañón, which together with the Río Ucayali form the Amazon. The headwaters of the Huallaga are in a high glacier-covered ridge east of the district, but one large tributary heads near Cerro de Pasco. This tributary has a steep gradient, dropping more than 600 meters in the 8 kilometers from its head to where it joins the main river at La Quinua. The gradient is moderate below La Quinua except for a steep stretch between Batanchaca and Chaprín. The Tingo also heads near Cerro de Pasco but has a relatively even gradient throughout its entire length. The result of this difference in stream profile is that the Huallaga canyon is deeper and more rugged than that of the Tingo. Relief in the district is considerable, more than 900 meters in places, and slopes are steep; part of the Huallaga canyon is bordered by dip slopes of 60°–70° on limestone and sandstone, and slopes of about 40° are common throughout the area.

## CLIMATE AND VEGETATION

Owing to its altitude, the Andean region of Peru has a cool temperate climate in spite of its proximity to the equator. The dry season from May to October is the coldest part of the year, with frosts common above an altitude of 3,000 meters. Rainfall amounts to more than 500 millimeters (about 20 inches); January, February, and March are particularly rainy months. Snow and hail are common above 4,000 meters, but the ground is never covered for more than a day or two, probably due as much to rapid evaporation as to melting.

There are no forests; even individual trees are scarce except along the river valleys below an altitude of 3,800 meters where eucalyptus has been introduced. The only native tree is the quinual, a small gnarled evergreen tree that grows singly or in small groves in sheltered places and is occasionally found at altitudes over 4,000 meters. The quinual is used for firewood and, to some extent, for fence-posts and farm implements; it is useless as timber. Weberbauer (1945) lists several varieties of recumbent shrubs and many species of mosses, grasses, and herbs as growing in the high Andes. A bunch grass known as ichu is very prominent and is used for thatching and to some extent for fuel. Ichu is too coarse to be used for feeding stock although llamas browse on it during the dry season for lack of better food. The principal mine timber is eucalyptus that is brought in by truck from groves along the Río Huallaga near Huánuco. Some timber is brought in from the jungle areas below Huánuco but the cost of transportation is very high.

## PREVIOUS WORK

Other than a brief report on the Atacocha mine area by Díaz (1909), most geologic work in the district has been done by consultants working for the mining companies and has not been published. Several papers on the Cerro de Pasco area have been published, and much of the geology is pertinent to the Atacocha district as well. McLaughlin (1924) describes the stratigraphy and physiography of a large area in central Peru. The formations proposed by him are found in the Atacocha district and the same nomenclature will be used in this report, except that, following the usage of Jenks (1951), the Pucará formation will include both Upper Triassic and Lower Jurassic limestones as field separation for purposes of this report was not practicable. The district geologic map (pl. 23) overlaps Jenks' map to some extent and the structures mapped by him have been followed to the north.

Private reports of geologic work in the Atacocha district consist of a surface reconnaissance by J. B. Stone of the Cerro de Pasco Corp. in 1928, and studies of the Atacocha mine by Otto Welter in 1929 and David Torres Vargas in 1948. Maps prepared by Stone and Torres Vargas were made available to the writers and the geology is in general similar to that shown on the maps of this report.

## ACKNOWLEDGMENTS

Mine operators in the district cooperated wholeheartedly during this study. Sr. E. Portaro, Sr. F. Bautista C., and Sr. C. Valdivieso, officials of the Compañía Minera Atacocha, furnished living accomodations and office space for the field party in 1952 and again in 1953. Sr. A. Venegas F. and Sr. L. Cáceres F., manager and superintendent of the Compañía Minera Milpo, furnished accomodations for the field party working there. At Machcán similar help was furnished by Sr. Cipriano Proaño and Sr. J. A. Proaño, owners of the property.

Help from the engineering staffs of the various properties is also gratefully acknowledged. Eleodoro Bellido and Alberto Manrique, geologists of the Instituto Geológico del Perú, and members of the joint commission, were our associates during the field work. Manrique worked at Atacocha most of the 1952 field season and also worked at Machcán for a short time. Bellido worked at Milpo and also at Atacocha. Dr. Jorge A. Broggi, Director of the Instituto Geológico del Perú, kindly placed the facilities of that organization at the service of the field parties and was helpful in many ways.

Frank S. Simons and George E. Ericksen of the Geological Survey made the necessary arrangements for the study and Simons kept in close contact with the field work.

## FIELD WORK

Field work began in May 1952 and continued with few interruptions until December of that year. Plane-table maps were made of the areas surrounding the three operating properties. Triangulation nets of the mining companies were used for control at Atacocha and Milpo, but a net had to be established for the Machcán map. Most accessible underground workings were mapped geologically, using base maps provided by the companies. Brunton-compass and tape surveys of underground workings were made when necessary.

Aerial photographs of the district were taken in 1952, so the district was revisited the following year in order to map the regional geology and thus tie together the mineralized areas. About 200 square kilometers was mapped geologically. A planimetric map (pl. 23) was prepared from the photographs using ground control furnished by the Cerro de Pasco Corp. and the Compañía Minera Atacocha. Control was limited to the central part of the area. This limited control together with the distortion due to the steep topography detract from the accuracy of the map.

The authors carried out individual studies of the three producing mines; Lewis at Machcán, Abele at Milpo, and Johnson at Atacocha. The district geology was mapped by Johnson.

## DESCRIPTIVE GEOLOGY

Sedimentary rocks of the area range in age from middle Paleozoic to Cretaceous or early Tertiary. The bulk of the sedimentary rocks is shale and sandstone, but a thick limestone sequence forms part of the Upper Triassic and Lower Jurassic section, and thinner limestone sequences are found in the Cretaceous. Volcanic rocks, largely flows, are found in the Permian and also in the Cretaceous. Dacite stocks and dikes of Tertiary age intrude the older rocks and are the youngest rocks in the area. The stratigraphy of the district is summarized in the following chart.

*Stratigraphic chart of rocks exposed in the Atacocha district*

| Age | Formation and map unit | Thickness (meters) | Lithology and remarks |
|---|---|---|---|
| Recent. | Unconsolidated material. | | Talus, slope wash, landslide material. |
| Tertiary(?). | Conglomerate. | 450 | Chert and limestone pebbles and cobbles increasing in coarseness upward. Some interbedded sandstone, shale, and limestone. Disconformable (?) on upper limestone. |
| | —Disconformity(?)— | | |
| Lower(?) Cretaceous. | Upper limestone. | 150–200 | Light-brown limestone, clastic limestone, marl, and shale; few fossils. Conformable on upper basalt flows. |
| | Upper basalt flows. | 40–60 | Basalt flows with minor amounts of red shale and sandstone. Local conglomerate at base. Disconformable on Chicrín limestone. |
| | —Disconformity.— | | |
| Lower Cretaceous. | Chicrín limestone. | 80–120 | Massive and thin-bedded brown limestone; nonfossiliferous. Cliff forming. Conformable on basalt flows. |
| | Basalt flows. | 0–250 | Basalt flows with minor amounts of red shale and sandstone. Locally contains thin white quartz sandstone bed near middle of section. Conformable above and below. |
| | Quartz sandstone. | 100–150 | Crossbedded white quartz sandstone with discontinuous conglomerate at base. Red beds near top. Disconformable on Pucará formation. |
| | —Disconformity.— | | |
| Lower Jurassic to Upper Triassic. | Pucará formation. | 1,000–2,100+ | Limestone with minor amounts of interbedded shale. Shale increases near top. Siliceous nodules and veinlets common in some beds. Disconformable on Mitu group. |
| | —Disconformity.— | | |
| Permian. | Mitu group. | 600+ | Red sandstone and shale with minor amounts of conglomerate. Basic flows locally abundant. Lower contact not exposed but reported unconformable. |
| | —Angular unconformity.— | | |
| Devonian(?). | Excelsior formation. | | Gray phyllite and quartzite. Limited exposure in district. |
| Unknown. | | | Contorted green schists. Limited exposure in district. Relations to other rocks unknown. |

## PRE-PERMIAN ROCKS

The oldest rocks of the district crop out in the northeast and southwest corners of the mapped area. Highly contorted green schists are found in fault contact with Permian and younger rocks in the northeast corner, and gray phyllites of the Excelsior formation (Devonian?) age are found near Cerro de Pasco. No attempt was made to date the green schists as they were outside the area studied and seemed to have no relation to the lead-zinc ore deposits. Their area of outcrop is north of the Río Chinchán and east of the Huallaga, except for a small area west of the river between Chaprín and Huariaca. The bedding of the schists is highly contorted and often two or three folds can be observed in an ordinary hand specimen. A strong schistosity is superimposed on the bedding. Quartz veins cut the schists but no sulfide mineralization was noted.

Gray phyllite of the Excelsior formation is found west of a fault near the Rumiallana adit of the Cerro de Pasco mine at the headwaters of the Río Tingo. Conglomerate and interbedded volcanic rocks of unknown age unconformably overlie the phyllite and the entire sequence is intruded by a porphyry stock. Shales and sandstone of the Permian Mitu group or the overlying Triassic limestone are found east of the fault. The age of the Excelsior formation is not known other than that it is pre-Permian. McLaughlin (1924) interpreted the formation as probable Silurian, but later workers have assigned it a probable Devonian age.

## MITU GROUP

The name Mitu formation was first used by McLaughlin (1924) in describing the red beds and volcanic rocks of late Paleozoic age in central Peru. Various formational names have been given to these rocks in different parts of Peru but Newell, Chronic, and Roberts (1949, p. 16) conclude from their work on the upper Paleozoic rocks of Peru that only one major group of rocks is involved, and proposed the name Mitu group for all.

Rocks of the Mitu group underlie nearly half the area shown on plate 23. The contact between Mitu rocks and the overlying Pucará formation closely follows a line drawn from the Rumiallana adit northeastward to Huariaca, except for two long tongues of limestone that extend northwestward into the Mitu outcrop area, in the troughs of two synclines. Some isolated limestone masses are found west of the main contact as erosional remnants.

The thickness of the Mitu section in the Atacocha district is not known as the base is nowhere exposed. Sections described by Newell, Chronic, and Roberts (1949) show a thickness of about 500 meters at Chacayán, 20 kilometers west of the district, and 750 meters at Salipayoc, 50 kilometers to the southeast. The Río Tingo cuts Mitu beds for nearly its entire length although its course is often close to the strike of the beds and in its upper part it flows across several folds. A sequence of sandstone and shale beds, between 500 and 600 meters thick, is cut by the river below the contact with the Pucará formation, near the Machcán road junction, and may represent the most complete section in the district.

Red and maroon shale and siltstone interbedded with sandstone and conglomerate make up the bulk of the section along the Río Tingo; sandstone and conglomerate are more abundant near the top of the section. The sandstone is usually poorly sorted and contains abundant clay and iron oxides, but at Batanchaca there is an exposure of clean crossbedded quartz sandstone. The conglomerate contains chert and porphyry pebbles and is easily distinguished from the younger conglomerate by the lack of limestone pebbles. Volcanic rocks of basic composition are abundant between Huariaca and Salcachupán on the Río Huallaga and are also found near the top of the section at Batanchaca and Yarusyacán. They must be local in extent as they were not noted along the Río Tingo or near the contact south of Yarusyacán. Reddish phyllites crop out along the river north of the Rumiallana adit. Inasmuch as they are not as strongly metamorphosed as the Excelsior phyllites and are conformable with the overlying beds, they are mapped as Mitu.

Fossil-bearing beds are rare in the Mitu group as it is composed largely of continental clastic sediments; no fossils were found in the Atacocha area. Dunbar and Newell (1946) found a late Paleozoic marine fauna in beds near the top of the Mitu in the vicinity of Tarma, south of Cerro de Pasco. Newell, Chronic, and Roberts (1949, p. 19) report finding rocks of the Mitu group lying on Permian rocks, and believe the Mitu to be Permian. McLaughlin (1924) and Harrison (1943) both recognized the late Paleozoic age of the beds but called them Carboniferous.

The lower contact of the Mitu group is nowhere exposed in the Atacocha district, but a strong unconformity is reported to exist between the Mitu and the Excelsior formation northwest of Cerro de Pasco (McLaughlin, 1924). Near Cerro de Pasco, gently dipping volcanic rocks and conglomerates that bear no resemblance to the Mitu beds rest on vertically dipping beds of the Excelsior formation. The gently dipping rocks may be part of the Rumiallana agglomerates described by McLaughlin.

The upper contact with limestones of the Pucará formation is clearly exposed. The actual contact can be seen in many places, and the greater part of the contact is marked by limestone cliffs (fig. 46) so that it can be located with precision except where the Río Huallaga flows over it or where it is obscured by landslides and talus. The contact is depositional for the most part and the two formations are nearly conformable with only a 10°–15° difference in strike or dip. Local faulting is found along the contact, particularly near Machcán.

No metallic mineral deposits have been discovered in rocks of the Mitu group in the Atacocha district. The contact of the Mitu group and the Pucará formation is mineralized at a few places. Several prospects were seen in the course of the mapping and ore has been found at Machcán where the contact is faulted. Gypsum is mined for local use from bedded deposits in the Mitu near Huariaca.

## PUCARÁ FORMATION

The name Pucará formation was proposed by McLaughlin (1924) as a general name for the widespread Jurassic limestone units that are known by various names in central Peru (Paria limestone at Cerro de Pasco, Potosí limestone at Morococha, and Pucará limestone at Goyllarisquisga). Jenks was unable to map separately the Jurassic and Triassic limestones at Cerro de Pasco, as they are conformable and similar in appearance, and so included both the Triassic Uliachín limestone and the Jurassic Paria limestone in the Pucará formation. Distinguishing the Jurassic and Triassic limestones in the field was not found practicable in the Atacocha district either, so Jenks' definition of the Pucará formation will be used in this report.

Limestone underlies most of the area east of the Mitu red beds and west of the Río Huallaga from Chaprín south to beyond the edge of the mapped area and is also found east of the river north of Batanchaca The Río Chinchán marks the northern limit of the Pucará formation east of the Huallaga in the mapped area. South from the Chichán the limestones form the core of a southward-plunging anticline and disappear before reaching Ticlacayán.

The contact between the Pucará formation and Mitu group has a general north-northeast strike, but two long tongues of limestone extend north-northwestward from the main contact along the troughs of two synclines. The western tongue lies close to the Río Tingo and is cut by the river at one point. This tongue narrows northward and finally disappears. The eastern tongue is larger and extends beyond the Tingo to a large area of limestone west of the river, comparable in size to the area underlain by limestone in the Atacocha district. In a regional sense the bulk of the limestone units in the Atacocha

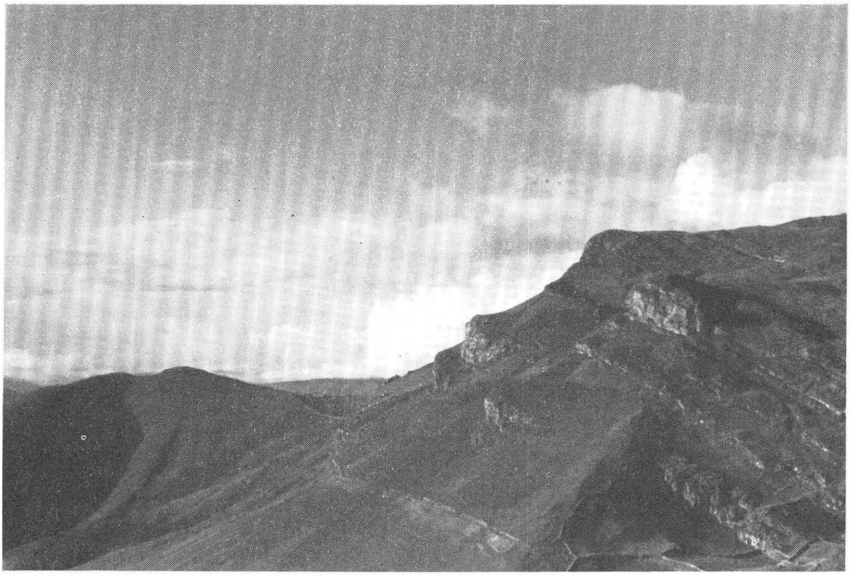

FIGURE 46.—The contact of the Mitu group and the Pucará formation as seen from Machcán, looking north toward Yarusyacán. The contact is located above the trail near the base of the lowermost cliffs, which are Pucará limestone.

district seem to lie on the east flank of a broad southward-plunging complex anticline.

Jenks (1951) found the Pucará formation east of Cerro de Pasco to be about 2,900 meters thick. No sections were measured in the Atacocha district but the same order of thickness is indicated. An adit driven west from Chicrín passed through over 2,100 meters of conformable limestone and shale beds and did not reach the base of the formation. Some repetition by faulting may be possible as two large fault zones were crossed, but no evidence of repetition could be found either underground or on the surface above the adit. Another thick section is found on the west side of the syncline south of Hacienda Carmen Chico where more than 1,800 meters of Pucará is found, but neither the upper or lower contact is exposed. The Pucará thins to the north and is only 1,000 meters thick in the Batanchaca area.

The formation is made up of a rather monotonous succession of thin- to thick-bedded, gray to dark-gray limestone beds with a minor amount of black shale. Siliceous material, both nodules and anastomosing veinlets, is abundant in at least two horizons, but no characteristic beds were found that could be used with confidence to determine the stratigraphic position of any local outcrops. The thick section east of the Atacocha fault at Chicrín can be divided into four types of limestone on the basis of chert content and the thickness of individual beds. At the base, forming more than half of the section, are thin-bedded (10–30 centimeters) limestones with some shale. Siliceous concretions are abundant, and some beds are fossiliferous. Thick-bedded (50–120 centimeters) dark-gray limestones containing little siliceous material overlie the thin beds. Above are thinner beds (40–80 centimeters) of light-colored limestone overlain by sandy limestone and shale at the top of the section. Farther north above Cajamarquilla the lower thin-bedded and the overlying thick-bedded limestone are present, but the thick beds are overlain by thin beds again containing siliceous nodules and veinlets, and the top of the section consists of siliceous limestones. The sandy limestone with interbedded red and green shale is an easily mappable unit and is shown separately on plate 23. It has a thickness of nearly 300 meters at San Miguel but thins rapidly to the north and disappears near Chicrín.

The sequence described above cannot be identified west of the Atacocha fault, where the limestone beds are cut by a series of northwestward-striking faults. Rocks of the overlying Goyllarisquisga formation fill the trough of a syncline west of the fault, and the lithology of the limestone beds at the contact differs from that at Chicrin. A chert breccia is a local feature of the contact of the Pucará and Goyllarisquisga west of Atacocha. The rock consists of angular black chert fragments in white siliceous groundmass (fig. 47). Bedded chert is found at the base of the breccia in the Curiajasha area west of Atacocha. This rock was mapped as part of the Goyllarisquisga formation in the detailed mine examination in 1952 as it seemed more closely related to the sandstones of that formation, but with the extension of the work the following year a limestone conglomerate was found to lie between the chert breccia and the sandstone suggesting that the chert breccia may represent altered beds near the top of the Pucará. The chert breccia dies out to the south near the latitude of Milpo. Another limestone conglomerate is found lower in the section in the same area; possibly the beds west of the Atacocha fault were laid down closer to the margin of the depositional basin and under more varied conditions than the beds to the east of the fault.

A brecciated red chert interbedded with clastic limestone is found in the Atacocha mine area east of the syncline in fault contact with sandstone of the Goyllarisquisga formation. It is found only in the mine area and does not seem to be related to the black chert breccia.

In a few places highly fossiliferous zones occur in the limestone beds, but fossils are rare or absent over much of the area. Ralph W. Imlay of the Geological Survey identified the following fossils in a group collected by Lewis in the lower part of the formation near Machcán:

*Spondylospira acrotamboensis* Steinmann
*Pseudomonotis ochotica* Keyserling
*Nuculana oxyrhynchia* (Jaworski)
*Nucula* cf. *Nucula carantana* Bittner
*Myophoria multicostata* Korner
*Astarte incae* Jaworski
*Promathildia bittneri* Kittl
*Promathildia* cf. *P. subornata* Mstr.
Crinoid columnals
Echinoid spines

Imlay reports that the collection is of Late Triassic age.

Another collection made by Johnson near Atacocha and possibly from higher in the section was reported by Imlay to contain the following forms:

*Spondylospira acrotamboensis* (Korner)
*Macrodon*? sp.
*Myophoria pascoensis* Steinmann
*Astarte incae* Jaworski
cf. *Inoceramus*? *priscus* Goldfuss
Gastropods undetermined

These fossils are also Late Triassic. *Myophoria* is an easily identified Triassic genus and was recognized in most of the fossiliferous limestone beds.

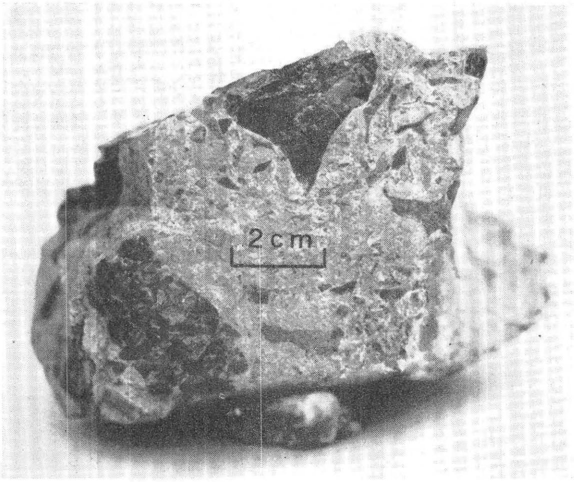


FIGURE 47.—Chert breccia found along the contact of the Pucará and Goyllarisquisga formations west of Atacocha.

Fossils found by Abele in the Milpo area are also Late Triassic; the fossils are from beds east of the Atacocha fault but probably low in the Pucará formation. Forms identified by Srta. Dora Gutiérrez, paleontologist of the Javier Prado Museum of Natural History in Lima, include:

*Spondylospira acrotamboensis* (Korner)
*Pascoella peruviana* Cox
*Palaeocardita peruviana* Cox
*Myophoria* sp.

Ammonites found near Chicrín in the upper part of the section close to the Goyllarisquisga contact were identified by Dr. Rosalvina Rivera of the Instituto Geológico as *Arietites*, an Early Jurassic form. Pentagonal crinoid stems found lower in the section near Chicrín are also probably Early Jurassic. The limestone in which the crinoid stems were found is identical in appearance with the Triassic limestone beds, and the contact could not be located.

The limestone of the Pucará formation rests with slight angular discordance on the rocks of the Mitu group. The upper contact with the Goyllarisquisga formation is conformable, but probably the limestone was subjected to erosion before the sandstone was deposited, and in places conglomerate with abundant limestone pebbles and cobbles is present along the contact.

### GOYLLARISQUISGA FORMATION

The name Goyllarisquisga formation was given by McLaughlin (1924) to a series of clastic sediments overlying the Pucará formation at Goyllarisquisga, 30 kilometers northwest of Cerro de Pasco. The

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formation is widespread in the Andean belt of Peru; Steinmann (1930, p. 99) states that it is found from the Departamento de Moquegua, in southern Peru, north into Ecuador.

Rocks of the Goyllarisquisga crop out along the west side of the Río Huallaga from south of the mapped area at La Quinua north to Toma Huanchal, where the river cuts through the sandstone near the trough of a syncline. The beds east of the river curve back to the south and then extend around the nose of the southward-plunging anticline north of Ticlacayán. The formation is also found in a syncline west of the Atacocha fault, from Atacocha to 2 kilometers south of Milpo. These rocks crop out as parallel bands on either side of the structure at Milpo and join in the trough of the fold at Atacocha.

McLaughlin divided the section at Goyllarisquisga into the following units:

| | *Meters* |
|---|---|
| Calcareous sandstone | 180 |
| Chontas sandstone | 270 |
| Bolognesi red beds, containing 3 lava flows | 150–180 |
| Upper coal series | 3–75 |
| Morocata sandstone | 30–120 |
| Lower coal series | 15–45 |
| Basal conglomerate | 2–10 |

In contrast the section at Chicrín is as follows:

| | *Meters* |
|---|---|
| Basalt flows with minor red beds | 250 |
| Crossbedded quartz sandstone | 140 |
| Basal conglomerate | 8 |

There is no coal at Chicrín, but the lower coal series is represented in the district in local basins. Dark sandstone with abundant charred wood fragments is present below the quartz sandstone at Atacocha, and coal is reported from the same horizon near Cajamarquilla. The upper coal series seem to be absent. The thick volcanic section at Chicrín can probably be correlated with the Bolognesi red beds at Goyllarisquisga, as both sections are undoubtedly continental and seem to contain the same rocks, although in widely different proportions. The upper two divisions at Goyllarisquisga are absent in the Atacocha district, where the basalt flows are conformably overlain by limestone, 80 to 110 meters thick.

The basal conglomerate at Chicrín is discontinuous and pinches out both to the north and south. Conglomerate is locally present at the base of the section west of Milpo but is absent at Atacocha, where bedded chert and chert breccia mark the contact with the Pucará limestones.

The white crossbedded quartz sandstone beds are a very distinctive part of the section, as they are resistant to erosion and form prominent outcrops. The beds are composed of subangular to subrounded quartz grains in a siliceous matrix. The grain size ranges from fine to very coarse; some beds could be termed pebble conglomerates. In thin section the sandstone is seen to contain more than 95 percent of quartz and a little interstitial sericite. Authigenic outgrowths are common on the quartz grains.

The basalts are greenish black on fresh surfaces. They weather red and break down to form a red soil. Olivine and plagioclase phenocrysts can be seen in hand specimens. Some flows are amygdular with carbonate or chlorite filling the cavities. A thin section from a typical flow showed a diabasic texture and that it contains 45 percent basic plagioclase ($An_{80\pm5}$); 25 percent of olivine, partly to completely altered to antigorite and chlorite; 20 percent of titanaugite interstitial to the plagioclase; and 10 percent of ilmenite and magnetite. A few beds of red sandstone and shale are interbedded with the flows. The thickness of this series of flows is variable. The flows extend to the north from Chicrín with only slight thinning but disappear to the south; limestone rests directly on the quartz sandstone near San Miguel. The series is much thinner but is continuous in the area west of the Atacocha fault.

No fossils were found in the Goyllarisquisga rocks of the Atacocha district, but work in other areas has established their age as Early Cretaceous.

The formation rests conformably on limestone or shale of the Pucará formation, but the presence of limestone pebbles in the basal conglomerate of the Goyllarisquisga indicates that the limestone was uplifted and eroded before the deposition of the conglomerate and sandstone. The upper contact is also conformable and shows an abrupt change from basalt flows through a few meters of limy shale to limestone. The flows seem to be land laid; no pillow structures were seen and the tops of individual flows are oxidized.

## POST-GOYLLARISQUISGA BEDDED ROCKS

No attempt will be made here to correlate the sediments and volcanics above the Goyllarisquisga formation with rocks elsewhere in Peru. Two limestone horizons separated by about 50 meters of basalt flows and red beds overlie the basalt flows of the Goyllarisquisga, and have the same distribution as the Goyllarisquisga in the Atacocha district.

The lower limestone will be given the name Chicrín limestone, for descriptive purposes in this report. It is well exposed at Chicrín where the Río Huallaga cuts through the entire sequence. The limestone at Chicrín crops out as a large wedge-shaped mass reminiscent of the flat-iron structures along the Front Range in Colorado; the east side of the outcrop is a 65° dip slope that extends up about 150 meters from the river. A similar but smaller structure is found in the same limestone at Cajamarquilla. Near Ticlacayán the limestone is well exposed where it folds around the nose of an anticline and the overlying rocks have been stripped away.

The limestone at Chicrín is 110 meters thick. The lower 25 meters consists of thin-bedded sandy limestone and shale; the remainder is dense, brown, thick-bedded limestone. Near Milpo the unit has about the same thickness although in places there is an apparent thickening due to repetition of beds as a result of small thrust faults.

Fifty meters of basalt flows and red beds lie on the Chicrín limestone with small angular unconformity. They will be called the upper basalt flows in this report, to distinguish them from the Goyllarisquisga basalts. A basal conglomerate was found east of Chicrín but but was not seen elsewhere. The basalts are identical in appearance with those of the Goyllarisquisga formation below the Chicrín limestone. A thin section of a specimen from a flow west of Milpo shows a diabasic texture and the same minerals as the Goyllarisquisga basalts—basic plagioclase, olivine, titanaugite, ilmenite and magnetite. The titanaugite, however, forms large violet phenocrysts, as large as 4 mm in diameter, and grains interstitial to feldspar.

The upper limestones overlie the basalt flows with apparent conformity; the contact is not exposed, but dips near the contact are similar. About 200 meters of these rocks are exposed along the Río Huallaga. West of the Atacocha fault the upper limestone is confined to isolated outcrops in the trough of the syncline near Milpo. Lithologically the beds consist of clastic crossbedded limestone, marl, and limestone. The rocks are light brown on fresh surfaces but weather nearly white. Thin bedding predominates but beds as much as 1 meter in thickness are found.

These limestones are unfossiliferous and so cannot be correlated with confidence with other limestones above the Pucará. They could be Machay limestone (Lower Cretaceous) but are not very similar lithologically to the Machay limestone described by McLaughlin, who does not mention red beds or volcanic rocks beneath the limestone but states that it is overlain discordantly by conglomerates of the Pocobamba formation. Conglomerate that Jenks correlates with the Pocobamba formation is found above the limestone east of the Río Huallaga.

## TERTIARY(?) CONGLOMERATE

A thick series of red-weathering conglomerate beds with some interbedded shale, sandstone, and limestone overlies the upper limestone with apparent conformity. The ridge east of the Río Huallaga from La Quinua north to Hacienda Aurora is capped by these conglomerate beds. The lower beds are composed of pebbles and cobbles of chert and limestone, with chert predominating. The pebbles are well rounded and lie in a red sandy matrix. Higher in the section the conglomerate becomes coarser, and limestone cobbles are more abundant; large subangular boulders of limestone are found in many beds, indicating that the source area was not far distant. Over 500 meters of conglomerate is exposed east of Chicrín.

No fossils were found except in the limestone cobbles, so that the age of the conglomerate is not known. They may have formed during an early phase of the Andean orogeny that began in Late Cretaceous time. If so they must have been deposited in the first stages of the orogeny as they are folded with the underlying rocks. Jenks (1951) correlated the conglomerate beds with the Pocobamba formation of McLaughlin which is thought to be Tertiary in age.

Another series of red conglomerate beds of unknown age crops out about 1 kilometer east of Laguna Nahuelpún. The conglomerate is much finer grained than that east of Chicrín, and pebble conglomerate predominates. Chert and limestone pebbles are the most abundant constituents. About 150 meters of beds is exposed in a lenticular outcrop faulted on the west and covered on the east. The conglomerate beds definitely do not belong to the Mitu group as they contain abundant limestone pebbles, but neither do they seem to be Tertiary as they do not overlie Goyllarisquisga rocks but seem to be isolated in the Pucará limestone. They may have been deposited in a local basin during the erosion interval between the deposition of the Pucará and Goyllarisquisga formations, but they bear little resemblance to other rocks found along the same contact.

## UNCONSOLIDATED MATERIAL

Moraines, alluvium, and landslides cover the consolidated rocks over considerable areas, but only part of these materials are shown on the geologic map.

Moraines are well developed north of Pumaratanga and can be seen along the trail from Atacocha to Machcán. Unsorted gravels, of probable glacial origin, were found during excavations in Quebrada Chicrín above Atacocha.

Alluvium in the form of slope wash, talus, and valley fill accumulates in favorable localities. The talus on slopes underlain by limestone is often cemented by carbonates deposited by meteoric water. On one such slope crossed by the Atacocha road the talus had to be blasted before it could be removed. A soil-covered talus slope near Chicrín includes an area of about 400 by 600 meters and is unusual in that it has a remarkably plane surface sloping at an angle of over 35° (fig. 48).

Many landslides occur on steep slopes underlain by rocks of the Mitu formation or the rocks above the Goyllarisquisga quartz sandstone. The large slides shown on plate 23 have flat tops and hummocky surfaces typical of such features. A stabilized slide at Chicrín was cut into to make room for construction, and subsequent movements have raised serious engineering problems.

Terraces are well developed near La Quinua and remnants are found near Batanchaca but owing to the steep topography and consequent rapid erosion they are easily destroyed.

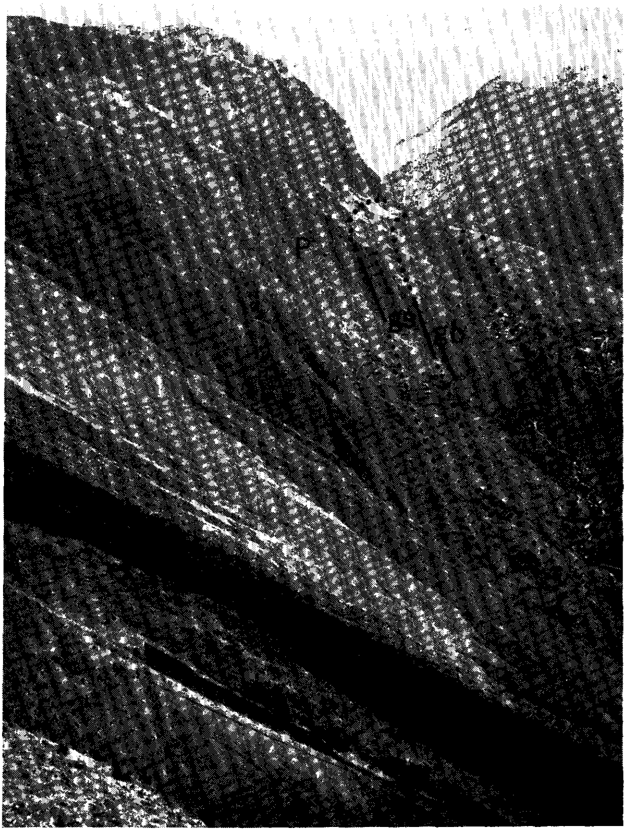

FIGURE 48.—Physiographic and geologic features of the west side of the Huallaga canyon north of Chicrín. Cajamarquilla, the town in the background is built on the relatively flat top of a landslide. The smooth slope in the foreground is a soil-covered talus slope inclined at about 35°, the beds behind dip 75°–80° E. *P*, Pucará formation; *gs*, Goyllarisquisga sandstone; *gb*. Goyllarisquisga basalt flows; *C*, Chicrín limestone.

## INTRUSIVE ROCKS

Dikes, sills, and small stocks of dacitic intrusive rocks are common in the central part of the district, particularly near Milpo and Atacocha. The two largest intrusive bodies lie near Atachocha on either side of the Atacocha fault. The stock east of the fault is lenticular with maximum dimensions of 1 kilometer in length by 150 meters in width. It is elongate along the strike of the limestone in the enclosing Pucará formation. The western intrusive is more irregular with a curved outcrop 1.5 kilometers long and 100 to 200 meters wide. Near Milpo two small outcrops of dacite are probably parts of a single stock. Another small stock crops out near San Miguel. Dikes and sills are most common adjacent to the larger intrusives but occur sporadically over an area of several square kilometers.

With the exception of the San Miguel stock the intrusive activity seems to have been concentrated along the Atacocha fault and some of the adjoining northwestward-striking faults. Emplacement of the intrusives may be related to faulting as there is no evidence that the intrusions are of earlier origin than the faults.

The irregular intrusive west of the Atacocha fault is a dacite. The rock is greenish gray to dark gray on fresh surfaces and weathers to a reddish brown. Phenocrysts of plagioclase and quartz as large as 5 millimeters in diameter, together with smaller crystals of hornblende and biotite, are enclosed in a fine-grained groundmass of quartz and plagioclase, possibly with some orthoclase. The composition of the plagioclase is on the andesine-labradorite boundary, An $_{50\pm5}$. Phenocrysts make up 50 percent of the rock, with plagioclase forming about half of the phenocrysts. The percentages of quartz, hornblende, and biotite are about equal. The biotite is often altered to an aggregate of carbonate, chlorite, and epidote. Crystals of quartz and plagioclase are embayed. Minor accesories are apatite and zircon. Pyrite is common, particularly near the margins of the intrusive.

The intrusive east of the Atacocha fault is so highly weathered that no fresh rock could be obtained. It contains more quartz than the intrusive west of the fault but otherwise seems to be of similar composition.

Two types of intrusive rock crop out at Milpo; a dacite that forms a stock as well as numerous dikes and sills, and a diorite porphyry that makes up a sill adjacent to the Atacocha fault. The dacite is light colored with phenocrysts of andesine (An $_{34-49}$), hornblende, biotite, and pyrite, in a groundmass of quartz, feldspar, and carbonate. The hornblende is partly altered to chlorite and epidote. The diorite porphyry is dark green and contains the same minerals as the dacite with the exception of quartz, which is rare or absent. Biotite is more abundant in the diorite porphyry.

No direct evidence was found for closely dating the time of intrusion. The dacite stock at Atacocha intrudes the basalt flows of the Goyllarisquisga formation, and one dike west of Milpo cuts the upper basalt flows, so the intrusions are probably post-Early Cretaceous. Similar intrusions elsewhere in central Peru are Tertiary in age. The absence of dacite pebbles in the Tertiary(?) conglomerates suggests that the intrusions occurred after deposition of the conglomerate, but of course the intrusives may not have cropped out in the source area of the conglomerates. The close association of many of the intrusives with the Atacocha fault suggests that emplacement took place during the Andean orogeny after the major faulting. Dikes are offset a few meters by late faults, but there is no evidence to indicate large displacements of the porphyry.

## CONTACT METAMORPHISM

The sedimentary rocks and lavas have been metamorphosed for various distances from their contacts with the intrusive rocks, and have been altered in different ways depending on their lithology and the size of the intrusive. The composition of the metamorphosed rocks has been changed by the addition of silica, iron, and sulfur from the intrusives.

The most intense metamorphism appears to be in the limestone beds of the Pucará formation west of the lenticular porphyry intrusion southeast of Atacocha. There the limestone beds are completely silicified and impregnated with pyrite for a maximum distance of 180 meters from the west border of the porphyry. The silicified zone is thickest adjacent to the widest part of the porphyry outcrop and tapers out toward both ends of the intrusive. The outcrop of the highly altered rock is a structureless siliceous mass with streaks of gossan and many limonite-stained cavities. Inasmuch as this stock contained more quartz phenocrysts than any other in the area, the solutions emanating from it may also have been richer in silica, for intense silicification on such a scale is not found elsewhere in the district. Outside the zone of intense alteration is a discontinuous zone of lime silicates containing garnet, wollastonite, calcite, and pyrite. This zone is as much as 100 meters wide and has a fairly sharp contact with unaltered limestone. Alteration on the east side of the intrusive is limited to a few meters of lime silicates. Garnet and wollastonite are also abundant on one level of the Atacocha mine adjacent to porphyry dikes. Elsewhere along intrusive contacts, contact metamorphic minerals are rare or absent. At Milpo for example, the stock is surrounded by pyrite and recrystallized marble in a zone of variable width.

Quartz sandstone shows little or no alteration adjacent to porphyry, as might be expected; locally, the rock is converted to quartzite.

Basalt, on the other hand, was easily recrystallized and is found as a fine-grained dark-green rock indistinguishable in the field from the chilled margins of the porphyry. Distinction between the two rocks can sometimes be made by studying thin sections if relict calcic feldspar from the lava is present. Little or no alteration is found adjacent to the dikes or sills.

## STRUCTURE

The rocks in the Atacocha district have been strongly folded, and are cut by both normal and reverse faults. In a regional sense much of the district seems to be on the east side of a southward-plunging anticline whose axis lies near the valley of the Río Tingo. Superimposed on this structure however, are a series of smaller folds, some of considerable magnitude. A reverse fault, herein called the Atacocha fault, traced from Hacienda Carmen Chico north to near Batanchaca, has also influenced the district's structural picture. Rocks east of the fault are thrown into long slightly asymmetrical folds with minor faulting, but west of the fault the folds are smaller and more irregular and the rocks are broken by a series of northwesterly-striking faults. A curious feature is that these faults, which seem to be important structures with large displacements in the Pucará formation, die out toward the Mitu contact and only offset the contact a few meters if at all.

### FOLDS

The pre-Mitu rocks are strongly folded but were not mapped in sufficient detail to locate any structures. Work done elsewhere in the Excelsior formation (McLaughlin, 1924) shows that the rocks were folded before the deposition of the sediments of the Mitu group, and that a pronounced angular conformity is present between the two formations. Mitu rocks, on the other hand, are nearly conformable with the overlying limestone beds and seem to have been folded with them. Some gently folded reddish phyllites north of the Rumiallana adit have been mapped therefore as belonging to the Mitu group rather than the Excelsior formation as shown by Jenks (1951). The tongue of limestone east of the Río Tingo marks the axis of a syncline, with red shales and sandstone of the Mitu formation bordering the limestone throughout its entire length. Individual beds could not be recognized with certainty on both sides of the limestone, but there is no evidence that the syncline crosses the contact of the Excelsior and Mitu formations as shown by Jenks.

The Mitu group and younger rocks have been compressed into a series of folds, most striking a few degrees west of north and plunging to the south. In addition, the limestone west of the Atacocha fault is folded into many small folds that are irregular in strike and plunge.

An anticline and syncline were mapped east of the Atacocha fault. The anticline is well exposed west of Ticlacayán and is shown on section *C–C* (pl. 23). This fold probably extends north to the fault along the Río Chinchán; the southern extension lies outside the mapped area. The syncline is shown on all three sections and is well defined from Batanchaca south nearly to La Quinua; it may also extend north to the fault on the Chinchán. The axis of the syncline lies close to the Río Huallaga from Batanchaca to the Hacienda Aurora but farther south the fold is found on the crest of the ridge east of the Huallaga and the axis lies just west of the ridge crest. Both folds plunge south at Ticlacayán, but the syncline has a north plunge at its southern end and so is canoe shaped. Both folds are slightly asymmetrical, with the axial planes dipping east. The asymmetry is probably due to compression in an east-west or southeast-northwest direction that may also have caused the reverse movement on the Atacocha fault. Asymmetry could also be due to drag on the flank of a larger fold to the west, and some evidence for this view was found along the Río Tingo.

Between the axis of the syncline and the Atacocha fault, the strata generally have a consistent eastward dip, or are vertical. The presence of Triassic fossils near the fault and Jurassic forms higher in the section to the east shows that the beds are in the normal sequence—"right side up." Small wrinkles with local reversals in dip are found in the rocks above the limestone on the west flank of the syncline; one small fold was found in the upper limestone beds above Cajamarquilla. No complete structure was seen but this local crumpling may represent drag folding during the development of the larger folds. A syncline is found immediately west of the Atacocha fault and may have been accentuated by movements along the fault. The syncline is well exposed from 2 kilometers north of Atacocha to about 2 kilometers south of Milpo. A similar syncline is found farther north along the fault but is not as clearly defined. The syncline at Atacocha is asymmetric, locally overturned to the west, and plunges south. West of Milpo the fold is more symmetrical, but overturned dips are found along the Atacocha fault south of the mine (fig. 49). The two masses of Cretaceous "upper" limestone exposed in the trough of the fold near Milpo plunge toward each other so this syncline is also canoe shaped in part. The reversal in plunge near the south end of the fold may be due to drag along the large cross fault that offsets the structure near Hacienda Carmen Chico. The syncline in the Pucará limestone south of the fault is probably the same structure.

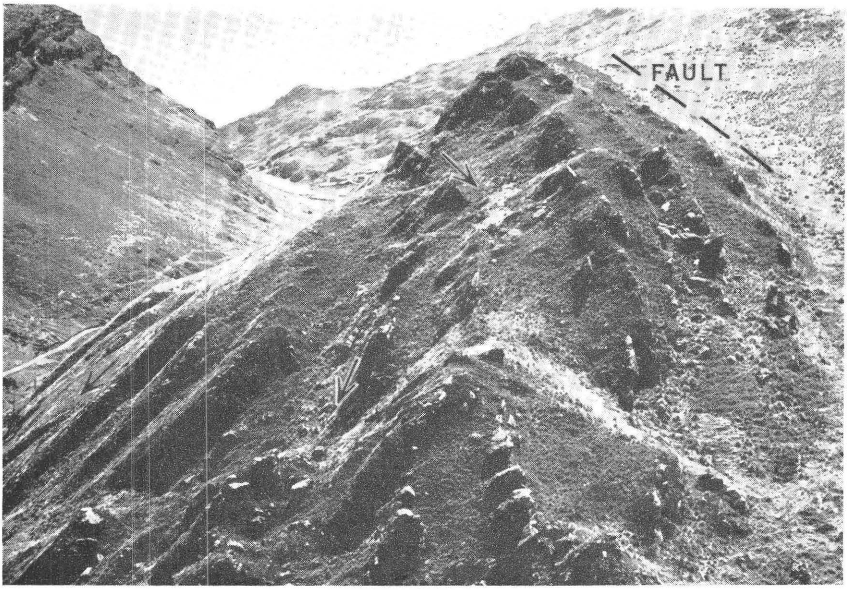


FIGURE 49.—Overturned beds in the Goyllarisquisga sandstone adjacent to the Atacocha fault near Milpo. Arrows point in the direction of dip. Beds along the fault are overturned, those in the lower left corner are in normal sequence. The cliffs in the upper left corner are Chicrín limestone.

The syncline just described was thought by Welter (1929) to be an inverted anticline. The fact that the stratigraphic section east of the Atacocha fault is in normal sequence, as shown by study of the fossils, and the presence of the identical stratigraphic sequence in the syncline, show that the section is right side up and the structure is a syncline.

Folds between the Atacocha fault and the contact with rocks of the Mitu group are complicated by faulting in the Pucará limestone beds, as is shown on the sections (pl. 23). The anticline that brings up the Mitu rocks in the middle of the Pucará outcrops in section *A-A′* is probably the same as the large anticline in the Mitu rocks shown on section *B-B′*. Other folds were mapped in the limestone south of section *A-A′*. Synclines are easily seen in the field but the anticlines are not well marked.

The folds in the Mitu group sediments marked by the two tongues of Pucará limestone have been mentioned earlier in the report. The anticline east of the larger limestone tongue (section *B-B′*) is thought to be the major anticline in the district. Asymmetry in the folds west of this anticline, although not well defined, seems to be toward the east, opposite to the asymmetry of the folds east of the Atacocha fault.

## FAULTS

Many faults, both reverse and normal, are found in the rocks of the Atacocha district, and the displacements along them range from a few centimeters to over 2,000 meters. Among the largest faults are those separating the green schists from the Pucará formation along the Río Chinchán, and the Excelsior formation from the Pucará formation near Cerro de Pasco. The age of the green schists is not known, but unless they are metamorphosed rocks of the Mitu group, the displacement along the fault must be very large. The fault between the Excelsior and Pucará formations may be the northern extension of the Cerro de Pasco fault described by Jenks (1951). In any event the entire Mitu group is cut out together with parts of the Pucará and Excelsior formations.

The Atacocha fault was traced from the edge of the mapped area at Hacienda Carmen Chico north to near Batanchaca where it crossed the contact of the Mitu and Pucará formations; the fault could not be followed northward in the Mitu rocks. The fault is well marked topographically over most of its length; drainage follows the fault zone and narrow gaps mark its location between drainage systems.

The Atacocha fault is the largest fault on which an estimate of the stratigraphic throw can be made. At Milpo this fault brings limestone beds about 2,000 meters below the top of the Pucará formation in contact with quartz sandstone of the overlying Goyllarisquisga formation, indicating a displacement of more than 2,000 meters. Displacement is at a maximum near Milpo and seems to decrease rapidly to the north. The Mitu contact near the north edge of the mapped area is displaced only 300 meters by the fault, but the net slip or total movement on the fault probably is much more. The Atacocha fault is interpreted as being a steep reverse fault with a considerable horizontal component; the east side moved up and to the north relative to the west side. Additional evidence for the reverse movement is the presence of a reverse fault in the Atacocha mine that has thrust Pucará limestone over quartz sandstone, and seems to be related to movement on the larger fault.

The ore deposits of Atacocha and Milpo may be related to movements along the Atacocha fault, although the fault itself is not known to be mineralized. Relations at Milpo are not clear, but the ore bodies at Atacocha are near the trough of a small cross fold formed by drag along the fault.

Another large fault cuts the limestone beds about 2 kilometers west of the Atacocha fault and roughly parallel to it. This fault is entirely in Pucará limestone except for a short distance where it forms the contact between the Pucará and a small outcrop of Mitu rocks (section *A–A′*). The displacement cannot be determined until the stratigraphy of the limestone beds is better known. The fault seems to terminate to the north against a northwesterly striking fault and is probably offset by another fault about 3 kilometers west of Milpo. The fault zone is well marked topographically by longitudinal valleys. It has an east dip and is flatter than the Atacocha fault as the trace of the fault on the surface is considerably influenced by the topography. A slip surface in the fault zone, about 2 kilometers north of where it crosses the Río Huallaga, has a dip of 40° E., but this may be a local feature as the trace of the fault is straighter than would be expected for so low a dip.

A series of faults striking N. 40°–60° W. are found west of the Atacocha fault from Hacienda Carmen Chico to Atacocha. The largest of these extends northwest from the Hacienda. The Goyllarisquisga rocks in the syncline west of Milpo terminate on the south against this fault, and the syncline seems to be offset. The north side moved down and to the west with respect to the south side, with an horizontal offset of about 600 meters. The stratigraphic displacement is not known, but at least 600 meters of beds above the Pucará formation are cut out together with an unknown thickness of Pucará. The fault also offsets the north-striking fault west of the Atacocha fault and may offset the Atacocha fault itself, but the relations were not studied. As shown on the geologic map, the fault is discontinuous and may be en échelon. The west end could not be traced far into the Mitu formation and the fault may die out as the tongue of limestone in line with the strike of the fault is not offset.

The many other faults shown on the geologic map are smaller features of only minor importance. Small-scale faulting is important in the mineralized areas and will be discussed in the description of the individual mines.

## GEOMORPHOLOGY

Land forms in the district strongly reflect the lithology of the underlying rocks. Rounded subdued ridges and smooth slopes of areas underlain by rocks of the Mitu group contrast sharply with the rugged, nearly vertical cliffs so common in the limestone areas. The less resistant rocks above the Goyllarisquisga formation weather to subdued surfaces similar to those on Mitu rocks. A particularly striking contrast in resistance to erosion is shown by the steep-dipping Chicrín limestone where it rises sharply above the overlying and underlying basalt flows. The contact of the Mitu and Pucará formations is marked along much of its length by limestone cliffs 20 meters high, broken only by the larger gullies that cut steep canyons in the limestone and open out on entering the softer Mitu rocks.

Most landscape features developed in the Atacocha district are the result of the dissection of an old elevated peneplain that forms a large part of the high central plateau of Peru. High points on the ridges in the district reach the same general level as the peneplain as far north as the village of Yarusyacán; Pumaratanga is probably 200 meters above the general level. Rivers are actively cutting into this peneplain on its northern and eastern margins and are superimposed on the old structures. Both the Tingo and Huallaga are of this type, as are their major tributaries. The Huallaga particularly, although it follows the general trend of the bedding for the most part, cuts indiscriminately across beds varying in resistance to erosion. At Batanchaca, for example, the river cuts through the last of the limestone beds and enters an area underlain by rocks of the Mitu group. The river follows the contact for a short distance then cuts back into the more resistant limestones and flows through a spectacular gorge before finally leaving the limestone at Chaprín.

Subsequent streams have developed on a small scale along both less resistant beds and fault zones. Their best development is along the Atacocha fault and the parallel fault zone 2 kilometers to the west.

## GEOLOGIC HISTORY

The Permian rocks of the Mitu group are reported to rest with strong unconformity on the Devonian(?) Excelsior formation but the depositional contact is not seen in the Atacocha district. The geologic record begins with the deposition of red shales and sandstone of the Mitu group, locally interbedded with basic lava flows. The red beds are probably continental but were laid down near the sea. Bedded gypsum near Huariaca may represent local basins that became separated from the sea with the subsequent deposition of evaporites.

The area was uplifted at the close of Mitu deposition but was not strongly folded as only a small angular discordance was found between the Mitu and the overlying limestone beds. The area was subject to erosion throughout most of the Triassic unless some of the red beds are of that age. In the absence of fossils the age of the red beds must remain in doubt, although Newell, Chronic, and Roberts (1949, p. 19) report finding middle or late Permian fossils high in the section near Tarma.

Limestones of Late Triassic age were deposited directly on the clastic rocks apparently without any basal sandstone or shale. The few exposed contacts show a lensing out of the limestone beds against the red beds and a slight angular disconformity right at the contact. The sea seems to have advanced rather rapidly over the area.

The limestone beds seem to be autochthonous in origin for the most part, according to the classification proposed by Pettijohn (1949, p. 293). The limestone is nearly all recrystallized but the association with calcareous shales and the occasional presence of fossil-rich beds with articulated shells shows that much of the section formed by accretion. The presence of dark limestone beds, which give off a fetid odor when struck with a hammer, interbedded with black shale indicates deposition in a semistagnant basin. In general conditions seem to have been stable with gentle but continuous downwarping until over 2,000 meters of limestone and shale were laid down. Deposition seems to have been continuous across the Triassic-Jurassic time boundary. Upper Triassic fossils are found in the greater part of the section but Lower Jurassic forms occur in the upper limestone and shale beds. Lithology is similar throughout the section except that shales become abundant near the top, at least along that part of the basin extending southward from Chicrín. The Pucará formation thins northward from Chicrín, possibly because of a high in the Mitu surface, although no overlapping of the upper beds to the north was noted.

The area was uplifted in the Early Jurassic and thereafter a marine environment was present only during short periods. Deposition was resumed in the Early Cretaceous, when chert beds accumulated in a basin west of Atacocha. These beds were followed by fine-grained sandstone with abundant carbonaceous material, locally containing thin coal seams. Following the filling of the low areas, a widespread series of white crossbedded quartz sandstone beds was deposited. Pure quartz sand is evidence that stable shelf conditions predominated during the time of accumulation. The sand was probably transported a long distance with opportunity for reworking and removal of less stable constituents.

The eruption of basalt flows brought this period of deposition to a close. Continental red beds are interbedded with the early flows and a few meters of white quartz sandstone were deposited after basalt flows had accumulated to a thickness of over 100 meters. The quartz sandstone is identical in appearance with that found below the lavas. Flows continued to accumulate near Chicrín until they reached a total thickness of 250 meters. Chicrín may have been near the center of lava accumulation. Only 50 meters of flows is found west of Milpo and they seem to pinch out entirely to the south; a slight decrease in thickness is found to the north. The flows near Chicrín may have been deposited in a downwarping basin as the limestones that cap the flows show only a small variation in thickness throughout the district.

The Chicrín limestone overlies the lava flows and represents a short invasion by the sea. A few meters of shale at the base of the limestone marks the transition from continental to marine deposition.

After the accumulation of about 100 meters of limestone the area was again uplifted and tilted; a slight angular discordance is found between the limestone and the overlying red beds and basalt.

A thin but widespread deposit of red beds and interbedded basalt flows overlies the Chicrín limestone. After deposition of these beds, the region was again downwarped and clastic limestone, shale, marl, and limestone (the "upper limestone" of this report) were deposited. No diagnostic fossils were found in either the Chicrín limestone or the upper limestone so no dating of beds younger than the Goyllarisquisga formation has been possible. The upper limestone may be the equivalent of the Machay limestone of late Early Cretaceous age but the correlation can not be made with confidence.

An erosion interval of unknown length separates the upper limestone from the overlying conglomerate. The contact is covered but may well be disconformable. The lower conglomerate beds contain abundant well-rounded chert pebbles, indicating considerable transport, but the overlying beds contain coarser chert cobbles and small subangular boulders of limestone, which probably were derived from a rising land mass nearby. The age of the conglomerate beds is Late Cretaceous or early Tertiary. They may have been deposited during an early phase of the Andean orogeny and folded with the underlying rocks during later compression. The conglomerate beds mark the close of the depositional history of the area, except for Quaternary alluvial deposition.

During the Andean orogeny the rocks were folded, faulted, and intruded by dacitic rocks. Folding was probably the earliest manifestation of the orogeny and was followed by the development of the north-striking faults due to compression in an east-west or southeast-northwest direction. The northwestward-striking faults were formed later, at least in part, as some of them offset the northward-striking set. Emplacement of the porphyry bodies may have followed the faulting; the elongation of the dacite stock west of the Atacocha fault, south of Atacocha, is suggestive of intrusion along one of the faults that strike northwestward. Some time after the intrusion the rocks were altered by hydrothermal solutions and the metallic sulfides were deposited.

A large region in central Peru was reduced to an area of low relief by Pliocene time, according to McLaughlin (1924) and Harrison (1943), and subsequently was elevated to its present height in three stages. Evidence for or against the three-stage uplift was not found in the Atacocha district. The streams are eroding so rapidly that terraces cannot be preserved for long. Some terraces are found about 100 meters above the present river level but they are too widely spaced to correlate with confidence.

Glaciers were present in the district during Quaternary time but their extent is not known. Closed basins and U-shaped valleys above 4,000 meters altitude show that glaciers extended down to that altitude, at least in sheltered locations.

## ORE DEPOSITS

The presence of mineral deposits in the Atacocha district has probably been known since colonial times because of its nearness to the great Cerro de Pasco deposit, whose rich silver-bearing oxide ores were exploited by the Spaniards. Oxidized ores, however, were relatively scarce in the Atacocha district, and the sulfides were not amenable to treatment by the primitive recovery methods then in use, so production prior to the present century was probably insignificant. Figures are available only from 1940 and show a production of nearly one million tons of ore, almost all from the Atacocha mine. This mine has produced more than 90,000 metric tons of lead and 65,000 tons of zinc from 1940 to 1953. Over 225,000 kilograms of silver has also been produced. More than 12,000 tons of ore was shipped from Milpo in the period 1949–51 and a mill of 75 tons capacity was placed in operation in 1952. No figures are available for production at Machcán, but at the time of the examination about 30 tons of hand-sorted ore was being shipped per month.

The three producing mines mark the centers of mineralization in the district. Numerous small workings are scattered about the part of the district underlain by Pucará limestone, but production seems to have been negligible in most places.

A close spatial, and probable genetic, relation exists between ore and intrusive rocks at Milpo and Atacocha. The porphyry dikes at Machcán are not in the immediate vicinity of the ore bodies.

## MINERALOGY

The mineralogy of the ores and gangue of the three mines is probably similar. The sulfide mineralogy of the Machcán is not known in detail as most of the workings are in the oxide zone, but the sulfides found are those common to the other mines. The following minerals are closely associated with the ore deposits.

### SULFIDES AND SULFOSALTS

*Alabandite, MnS*—A considerable amount of the black manganese sulfide alabandite was seen on a dump on the Tres Mosqueteros level of the Atacocha mine. The mineral was not seen in place.

*Arsenopyrite, FeAsS*—Small amounts of arsenopyrite are found intergrown with and replacing pyrite in the Atacocha ores. Arsenopyrite is replaced by sphalerite and galena. The arsenopyrite is massive and no crystal faces were noted.

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*Chalcopyrite, $Cu_2Fe_2S_4$*—Copper is a minor constituent of the ores and is not of economic interest. Chalcopyrite, the most abundant copper mineral, is found throughout the Atacocha mine in scattered small grains, and as blebs in sphalerite. The age relations with other sulfides were not determined.

*Galena, PbS*—Galena is one of the principal ore minerals. It usually occurs in granular masses with typical cubic cleavage, but crystals are found; the largest perfect crystals are found at Machcán and measures 2.5 cm on an edge. At Machcán the galena commonly forms large masses of intergrown cubes 1.3 cm on an edge. Some galena has a banded appearance due to the orientation of the cubes. Galena was deposited after most of the pyrite and contemporaneously with the sphalerite. A vein in the Atacocha mine has a galena-rich center bordered by sphalerite and pyrite, so at least some of the galena seems to have been deposited later than sphalerite.

The galena is probably argentiferous as the silver content of the ores varies directly with the galena content.

*Jamesonite, $Pb_4FeSb_6S_{14}$*—Jamesonite was identified both at Milpo and Atacocha. The mineral is massive with good cleavage in one direction. Age relations at Atacocha were indeterminate but at Milpo jamesonite is found in veinlets cutting sphalerite.

*Marcasite, $FeS_2$*—Marcasite from Atacocha is listed in the Catálogo Mineralógico Nacional, but none was noted during the present work.

*Orpiment, $As_2S_3$*—Bladed and micaceous yellow orpiment is found at Atacocha associated with realgar. Orpiment is more abundant than realgar, and most of it seems to be an alteration product of the realgar.

*Pyrite, $FeS_2$*—Pyrite is the most abundant sulfide in the district, and, with sphalerite and galena, forms the characteristic mineral assemblage in the ore. Pyrite, however is found over a much wider area than the other sulfides. Concentrations of pyrite are often present along intrusive contacts and barren pyrite veins are found in the mine. Both massive and crystalline pyrite are common. Pyrite in the ore bodies is massive or forms small striated cubic crystals, whereas in the hydrothermally altered zones the disseminated pyrite is usually found as small pyritohedrons. Crystals over 2 centimeters in diameter are rare. Pyrite was probably the first sulfide to form and continued to be deposited throughout most of the period of sulfide mineralization.

*Realgar, AsS*—Realgar and orpiment were found at the Atacocha mine only. They are abundant on the 4,240 level and were noted on other levels in the upper workings. They are also found in fractures in limestone between 1,200 and 1,300 meters from the portal of the Chicrín adit, or 3,600 level, several hundred meters from any known ore. The realgar occurs as orange-colored platy masses enclosed in orpiment and as small red isolated crystals that resemble cinnabar.

The larger realgar-orpiment veins are not associated with lead-zinc minerals, but realgar in one place is found as fill in fractures in a small ore body.

*Sphalerite, ZnS*—Light-brown to nearly black sphalerite occurs in varying proportions with galena. It is found as a massive mineral with good cleavage, as rounded grains, and as crystals, many showing multiple twinning. The mineral is found intergrown with galena and replacing pyrite.

*Tennantite* $(CuFe)_{12}As_4S_{13}$—Tennantite was observed in one polished surface of Atacocha ore. It was found replacing pyrite, but its age relations to adjoining sphalerite and galena could not be determined. The mineral gave a microchemical test for arsenic but not for antimony.

*Tetrahedrite,* $(CuFe)_{12}Sb_4S_{13}$—Tetrahedrite is reported from Milpo in veinlets, 3 to 4 cm wide associated with rhodochrosite. The mineral is gray massive and has a red streak.

NONSULFIDES

*Anglesite,* $PbSO_4$—Anglesite was noted at Machcán as a coating on galena.

*Aurichalcite,* $2(Zn,Cu)CO_3{\cdot}3(Zn,Cu)(OH)_2$—Light-turquoise-blue aurichalcite was noted at Machcan as drusy coatings in small cavites and as fibrous bands associated with hydrozincite and cupriferous opal.

*Calamine,* $H_2ZnSiO_5$—Calamine was the most abundant secondary mineral found in the suite collected at Machcán. It is fibrous in habit and was found in a series of minute laminae.

*Calcite,* $CaCO_3$—Veins of calcite are abundant in limestone, and some are found in quartz sandstone where calcite is the common gangue mineral. The calcite is white or cream colored and medium grained with rhombohedral cleavage. It is intergrown with rhodochrosite in the ore-bearing veins and coats walls of cavities. The carbonates are among the last minerals to form; they fill the centers of veins and enclose angular fragments of sulfides. Veins of fibrous calcite are found in the upper levels of the Atacocha mine. They are definitely postmineralization and may be supergene.

*Cerussite,* $PbCO_3$—Cerussite, is the principal lead mineral in the oxide ores of Machcán and was also found at Atacocha, although in very small amount.

*Clay minerals*—White clay minerals are common constituents of the hydrothermally altered rocks in the Atacocha mine. Positive identification was not possible but the low birefringence of some of the material in thin section indicates that minerals of the kaolin group are represented.

*Fluorite,* $CaF_2$—Violet and green fluorite is found in carbonate veinlets in the upper mine levels at Atacocha, both in ore bodies and in country rock. Violet fluorite is found at Milpo associated with ore minerals. Abundant fluorite was reported from the 3,840 level at Atacocha beneath one of the large ore bodies but the area was inaccessible at the time of this examination. Fluorite also is found in tiny fractures in porphyry and quartz sandstone. Cubes and irregular masses of fluorite with crystals as large as 2 cm on an edge are found associated with late-forming calcite and rhodochrosite.

*Gypsum,* $CaSO_4 \cdot 2H_2O$—Gypsum occurs as thin scaly crystals in fractures and on exposed surfaces, and as small massive granular aggregates in the alteration zones at Atacocha.

*Hydrozincite,* $2ZnCO_3 \cdot 3Zn(OH)_2$—White hydrozincite with a chalky appearance was found in a suite of secondary minerals collected at Machcán.

*Limonite,* $2Fe_2O_3 \cdot 3H_2O$—Limonite is found pseudomorphous after pyrite and as stalactitic and botryoidal forms in old workings and is a common oxidation product. Limonite and other iron oxides are very abundant at Machcán.

*Malachite,* $CuCO_3 \cdot Cu(OH)_2$—Malachite is found both in old workings and in surface exposures. It is commonly associated with the copper sulphate, chalcanthite. Rare nodules of malachite were noted in the oxidized ores at Machcán.

*Manganese oxides*—Black manganese oxides are common on the walls of some workings, and in vein outcrops in limestone. Psilomelane-type oxide is the most abundant manganese mineral in vein outcrops, and pyrolusite is present in small amounts. The manganese-bearing outcrops are not sure indicators of ore below; some of the larger outcrops have been explored with discouraging results. At Machcán psilomelane-type oxide and pyrolusite are associated with barren veinlets and lean clay streaks in the ore.

*Melanterite,* $FeSO_4 \cdot 7H_2O$—Fibrous green melanterite is found in old workings.

*Muscovite,* $H_2KAl_3(SiO_4)_3$—The variety of muscovite known as sericite is present in sheared zones in hydrothermally altered rocks but is not a common alteration product in the Atacocha mine.

*Opal,* $SiO_2 \cdot nH_2O$—Green to blue-green zinc- and copper-bearing opal were found at Machcán intergrown with calamine.

*Plumbojarosite,* $PbFe_6(OH)_{12}(SO_4)_4$—Plumbojarosite was observed at several places in the oxidized ores of Machcán where it forms thick crusts around galena.

*Quartz,* $SiO_2$—Small acicular crystals of quartz are found in vugs in the veins and ore bodies, but quartz veins are not known. Silicification of the limestone is a common feature near Atacocha.

*Rhodochrosite,* $MnCO_3$—Rhodochrosite is a common gangue mineral at Atacocha and Milpo. Massive rhodochrosite predominates, but a scaly form was noted lining cavities in veins. The fresh mineral is pink but becomes nearly white on exposure to air.

## PARAGENESIS

Figure 50 summarizes the information on mineral succession obtained in the field and checked by the study of polished surfaces in the laboratory. The information is incomplete, as many of the minerals are not found in juxtaposition, and is purely qualitative in character. Minerals whose position is uncertain are shown by question marks.

Certain mineral associations represent stages in mineral deposition and three stages were recognized in the Atacocha mine, as follows:

The first stage is the quartz-pyrite stage, which includes most of the quartz and a lesser portion of the pyrite; arsenopyrite may also belong to this stage. Silicification is a common feature at Atacocha, particularly along the No. 1 fault. Both Pucará limestone and intrusive rocks on the hanging-wall side of the fault are converted into a dense silica rock containing disseminated pyrite crystals. Silicification of vein walls is not pronounced. Intrusive contacts commonly have silicified and pyritized rock along their margins. The early age of this

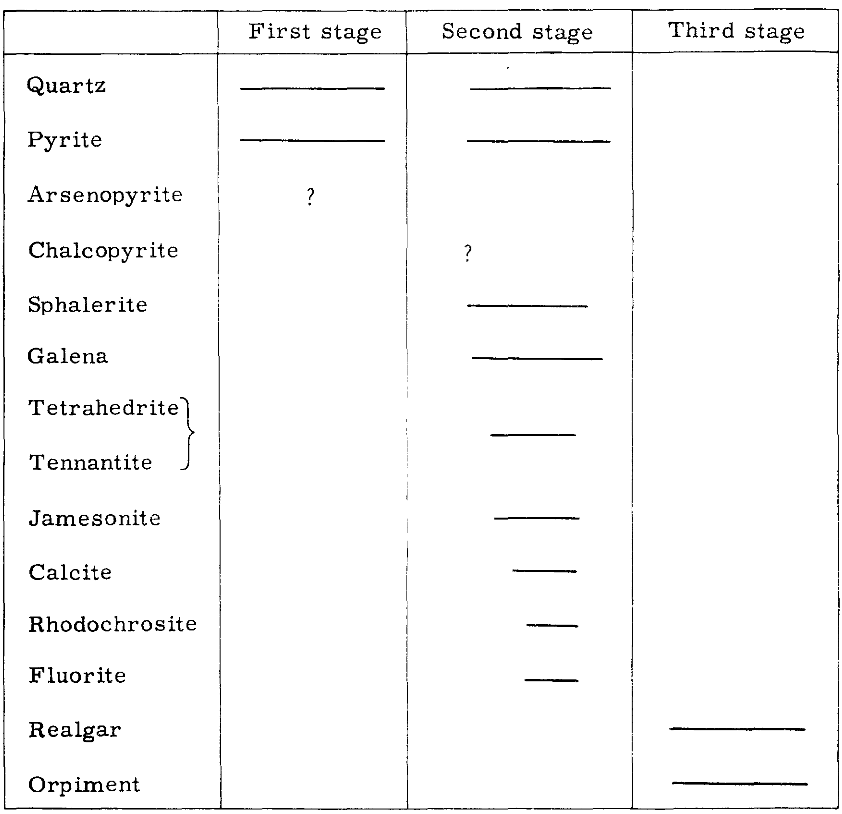


FIGURE 50.—Paragenesis of the vein minerals.

stage is shown by the presence of other sulfide minerals in veins or replacement bodies cutting the silicified and pyritized rock.

The second stage is the sulfide stage, during which all the ore minerals, the carbonates, and fluorite were deposited. Pyrite continued to be deposited in this stage. The relative age of chalcopyrite is not clear; it is one of the minor sulfides found with the pyrite-galena-sphalerite association typical of the stage. The sulfosalts jamesonite and tennantite were also deposited with the other sulfides and were probably overlapped in time by galena and sphalerite. The carbonate gangue minerals and fluorite are deposited late, as they fill the centers of veins and may enclose angular fragments of sulfides broken from the adjoining walls. Calcite may have a longer range of deposition than either rhodochrosite or fluorite.

The third stage is the realgar-orpiment stage. Veinlets of realgar and orpiment are found cutting the earlier sulfides, but the principal occurrence of the arsenic minerals is in a separate vein. This deposition in separate structures is interpreted to represent two widely separated stages of deposition with the realgar and orpiment later as shown by the crosscutting relationships in the one area where they come in contact with the other sulfides. Their deposition could also, of course, be one of the final events of the second stage.

At Milpo early-formed pyrite is found in the veins and a light pyritization of vein walls is unaccompanied by silicification. Galena and sphalerite were deposited contemporaneously after the pyrite. Jamesonite and tetrahedrite, while younger than pyrite, could not be definitely related in time to the galena and sphalerite. The fluorite is thought to be of the same age as the sulfides. Calcite and rhodochrosite fill late-formed fractures and form drusy coatings in cavities.

The sulfide minerals are not exposed well enough at Machcán to allow any determination of the sequence of deposition.

## CLASSIFICATION

The ore deposits of the Atacocha district are believed to be of hydrothermal origin, that is, they were deposited from hot aqueous solutions derived from a magmatic source. A possible magmatic source would be that from which the adjacent porphyry intrusions originated; the intrusives themselves are premineralization as veinlets of ore minerals cut the intrusive rocks. The association of ore deposits with intrusive rocks of intermediate composition is found throughout the lead-zinc province of Peru and is in itself suggestive of a genetic relationship between them.

Contact metamorphism of Pucará limestone with the development of lime-silicate minerals is found at Milpo and Atacocha. Inasmuch as no ore bodies are found in the contact metamorphic zones, none of the deposits can be classified as pyrometasomatic.

Further subdivision of the hydrothermal classification is possible. The mineralogy of the Atacocha ores indicates deposition under moderate conditions of temperature and pressure. Realgar and orpiment are typical epithermal minerals but were probably deposited in a late stage of mineralization. The galena-sphalerite-pyrite association is found in all classes of hydrothermal deposits, but the association with jamesonite and tennantite, and particularly with the gangue minerals rhodochrosite and fluorite indicate moderate to low temperature and pressure. The deposit should probably be classified as leptothermal.

At Milpo, on the other hand, the scarcity of jamesonite and tetrahedrite, and the absence of realgar and orpiment, suggest mesothermal conditions.

## STRUCTURAL CONTROL OF ORE BODIES

The ore bodies can be classified as replacement bodies and veins. Both types are found at Machcán and Atacocha, but replacement has not been an important process at Milpo.

Bedding replacements or "mantos" in Pucará limestone are common at Machcán, where nearly half of the prospect pits and small adits explore manto-type deposits. The majority of the deposits are small, ranging from 50 centimeters to 1 meter in thickness and from 1 to 20 meters in lateral extent; only two ore bodies more than 50 meters long were observed. The bedding replacements are always associated with veins and extend out from them. The veins probably served as feeders for the ore bodies. The walls of the mantos are often sharp and delineated by small bedding-plane faults. Laterally the sulfide content diminishes along the strike, changing from solid ore to disseminated ore, to stringers along fractures within the bed, and finally to unaltered limestone.

Another type of replacement at Machcán consists of irregular replacement along the contact of the Mitu and Pucará formations. Ore emplacement was controlled by the contact and by several faults that extend across it. Most ore is in limestone, but masses of sandstone within a gossan area indicate that some sandstone was also replaced.

Large irregular replacement bodies in Pucará limestone have provided most of the ore at the Atacocha mine. Most of the developed ore bodies of this type are found in a limestone sequence 50 to 60 meters thick above the No. 1 fault (pl. 26) but they are also known to occur near the chert breccia contact to the west of the syncline west of the Atacocha fault. The ore bodies were formed by incomplete replacement of limestone by sulfides and clay minerals. They vary widely in size; one of the largest, now nearly worked out, had a pitch length of about 250 meters, a breadth of 40 to 70 meters, and a thickness of 4 to 10 meters. The ore bodies seem to be related to some of the larger veins, which may have served as feeders.

Veins at Machcán follow two sets of fractures. The majority of the veins follow a set of fractures that strike N. 35°–70° W. and dip 55° to 70° SW. The other set of fractures strikes N. 10° E. to N. 20° W. and dip steeply both east and west. Individual veins vary in width from 30 centimeters to 2 meters; pinching and swelling along the vein is a common feature. Gouge and stringers of clay are common both along vein walls and within the veins. The veins were formed by replacement along faults or breccia zones; fissure filling seems to be of minor importance.

Veins at Atacocha are found in all rock types but those in limestone and quartz sandstone are most important; only one vein in porphyry is being mined. Most veins strike from N. 50° W. to west and dip steeply. Veins in limestone are concentrated near the axis of a small cross fold near the Atacocha fault and have been found only in the upper mine workings. They may have filled tension fractures opened during the formation of the cross fold. Veins in quartz sandstone and chert breccia are found on all levels and are the principal source of ore in the deeper workings. Vein width is usually less than 1 meter but occasionally it increases to 3 or 4 meters The most persistent vein has been mined for a strike length of 150 meters and over a vertical extent of 300 meters. The ratio of lead to zinc in veins in sandstone or chert breccia is 5:1 or even greater, in contrast to a ratio of about 1:1 in veins in limestone. The reason for this difference was not determined. Open-space filling seems to be the most important process in vein formation at Atacocha, particularly in the veins in quartz sandstone or breccia.

Veins are the only important source of ore at Milpo, where two fracture systems are found. In the northern area, a series of steeply dipping veins strike N. 40°–60° E., whereas farther south another group of more irregular veins strike both northeast and northwest. Some veins are irregular in strike and curve from northeast to northwest. The veins are all in Pucará limestone east of the Atacocha fault; one vein crosses a small porphyry mass in limestone. The veins have formed by filling open spaces. Their width is usually less than 1 meter and they show little variation along the strike, except for the vein that crosses the porphyry; this vein narrows in the porphyry, probably because of the difference in behavior of the porphyry during fracturing. Not enough exploration has been done at Milpo to determine the lateral extent of the veins, but their vertical extent is at least 300 meters.

## RELATION OF ORE DEPOSITS TO DISTRICT GEOLOGIC FEATURES

The geologic features on a district-wide scale that may have been important in the localization of the Atacocha ore deposits are: the porphyry intrusives; the Atacocha fault; the contact of the Mitu and Pucará formations; and the series of northwesterly-striking faults.

Intrusive rocks are found in or adjacent to mine workings at Milpo and Atacocha and not far from mine workings at Machcán. All the larger intrusives have mineralized areas within them or along their margins, but this mineralization has not proved to be of economic importance. Both the Atacocha and Milpo mines are adjacent to porphyry stocks, so the search for favorable structures around the stocks may be more important than exploring the stocks themselves.

An indirect relation certainly exists between the ore deposits of Atacocha and the Atacocha fault, and there may be a direct relation even though the fault itself is not mineralized. The fault seems to have controlled the emplacement of some of the intrusives, as all stocks but one are located close to the fault. A close control is indicated at Atacocha, where the ore bodies are found in a cross fold apparently formed by drag along the fault and are further localized by a moderately dipping reverse fault that probably branches from the Atacocha fault. A direct relation between ore deposits and the Atacocha fault could not be found at Milpo and the significance of the vein-filled northeastward-trending fractures, not found elsewhere in the district, was not determined.

Conditions elsewhere along the Atacocha fault do not seem as favorable for ore deposits. No other intrusive bodies were found along it. A small structure, similar in some respects to the cross fold at Atacocha, was found west of Cajamarquilla in the "V" between the Atacocha fault and the adjacent fault to the west, but no ore minerals were found.

Sulfide mineralization occurs along the contact of the Mitu and Pucará formation at Machcán where a gossan outcrop 200 meters long and 30 meters wide was found. A few prospect pits have been dug along the contact south of Machcán, but no ore has been discovered. The intersection of faults with the contact is probably more important than the contact itself. The faults may form channels for ascending solutions that spread out along the contact. Limestone beds above the contact are the favorable host rocks.

The importance of the series of northwesterly-striking faults, found principally between Milpo and Atacocha west of the Atacocha fault, is not known. The faults themselves are not mineralized, but the intrusive south of Atacocha and west of the Atacocha fault is elongate in a northwesterly direction parallel to this system of faults. A set of mineralized fractures at Machcán has the same general strike and may be part of the northwesterly-trending fault system.

Other structural features seem to have little significance. No relation was found between the larger folds and ore deposits, although small folds may be important in individual mines.

The most favorable area for further prospecting, other than extension of present mine workings, is between Milpo and Atacocha close to the Atacocha fault. Small porphyry bodies are present in this area, and evidence of mineralization is abundant. No favorable structure was found that would indicate the possibility of finding large ore bodies of the Atacocha type, but veins of minable width and grade may be found. The present investigation shows that the ore deposits at Machcán are distinct from those along the Atacocha fault and no evidence exists for a favorable structure extending from Atacocha to Machcán, so the area between the two mines is not one of promise for prospecting. The relation of the Atacocha fault to the large northwest-striking fault near Hacienda Carmen Chico should be studied further in order to determine whether the Atacocha fault continues to the south. If so, additional work southward along the Atacocha fault would be warranted.

## MINE DESCRIPTIONS

### MACHCÁN MINE

The Machcán mine is the most northerly of the three producing mines in the Atacocha district. The mine is about 3 kilometers northwest of Atacocha and is reached by 35 kilometers of road from Cerro de Pasco along the Río Tingo.

The mine is owned and operated by Cipriano Proaño and Juan Antonio Proaño of Cerro de Pasco. Production in 1952 was about 30 tons of hand-sorted ore per month; both oxidized and sulfide ores are produced. A 50-ton mill was under construction at the time of this examination and was scheduled to begin operation early in 1954. The bulk of the ore produced comes from no. 1 vein in adit no. 1 (pl. 24). Some sulfide ore is mined in the Lizandro Sur workings.

The country rock at Machcán includes the upper beds of the Mitu group and the lower limestone beds of the Pucará formation. The contact between the two formations is faulted in part, and Pucará rocks seem to have moved over the Mitu along the contact. Dikes and sills of dacite were found in the southeastern part of the area shown on plate 24, and two dikes of aphanitic andesite were noted in the southwestern part of the area. The limestone adjacent to the dacite dikes has been serpentinized.

The mine area may be divided into three structural units. The first is composed of the red beds of the Mitu group in which no structure is visible. The second is in the central part of the area, where the limestones are folded into a shallow anticline and syncline which plunge to the southeast. In the southeastern part of the area the limestones are block faulted along two sets of faults that strike N. 5° E. and N. 70° E. The controlling factors in ore deposition are the contact and the faults.

The Mitu and Pucará contact trends north in the western part of the mapped area. It swings northeast north of adit no. 1 and trends N. 70° E. above the Carlos Chino Viejo workings. In the north and northwest the contact dips 30° to 50° SE. A fault trending N. 60° E. cuts the contact near adit no. 1 and the contact south of the fault is offset 200 meters to the west; the direction of movement on the fault is unknown.

The limestones in the area strike north to northeastward and dip 30°–70° E. They are folded into a shallow, symmetrical syncline near adit no. 1 and into a small symmetrical anticline further east; the folds plunge 30°–40° SE. Minor folds, most plunging to the north, are noted throughout the area. Folding, even on a small scale, is not a control in ore deposition.

The faults may be divided into three major groups which strike N. 35°–70° W., N 20° W. to N. 10° E., and N. 50°–70° E., respectively. The northwesterly-striking set is the most strongly mineralized, and the fractures show little displacement. The dacite dikes appear to have been intruded along this set of faults. The faults trending N. 20° W. to N. 10° E. are in part mineralized and are the most numerous faults of the area. They are younger than the first set. The no. 1 vein in the adit no. 1 (pl. 25) was emplaced along one of these faults and the many northward-trending cliffs in the southern part of the area are due to movement along these faults. The faults trending N. 50°–70° E. are postmineralization. The offset of the contact of the red bed and limestone west of adit no. 1 and the northern termination of the no. 1 vein are both caused by faults of this set, possibly the same fault.

The ore deposits of the area are replacement-type lead-zinc deposits found as veins, bedding replacements or mantos, and irregular replacements along the contact of the Mitu and Pucará formations. Only the Lizandro Sur workings are in sulfide ore; the other workings are all in the oxidized zone. Oxidation is known to extend to over 150 meters below the outcrop on the no. 1 vein and the other deposits are probably oxidized to comparable depths. The bottom of the oxidized zone was not observed, and so it was not possible to compare the metal content of the oxidized and sulfide ores to determine the extent of any possible leaching or enrichment.

The ore in general contains about 50 to 60 percent of iron oxides, 10 to 20 percent of calcite and calamine, and 20 to 30 percent of lead minerals. The lead is most commonly found as cerussite and small knots of galena. Anglesite forms coatings on galena. Plumbojarosite was observed in several areas, notably in the lower stopes of adit no. 3. Several other secondary minerals were observed and are described in the section on mineralogy.

The mine workings in the area may be divided into nine more or less distinct groups, the most important of which is the adit no. 1 (pl. 25). All the ore from these workings was being extracted from the no. 1 vein which strikes N. 20° W. and dips 65° to 70° E. The vein has an average width of 1.5 meters. It dies out to the south in a breccia zone, which extends on to the south for an additional 200 meters. Ore was deposited in the breccia zone but not in minable quantities. The northern end of the vein is not reached in the mine, but on the surface it terminates against a fault trending N. 70° E., 100 meters northwest of the no. 1 shaft. The offset segment of the vein north of the fault has not been definitely located but probably lies in the Palmira area. Although the vein follows a strong fault trending N. 20° W. it is locally very irregular. Replacement has taken place along bedding planes and minor faults, and in such areas the vein attains widths of several meters. A vein branches off to the southeast from the no. 1 vein north of the no. 1 shaft. This vein was not found in the mine but the junction of the two veins might be an especially favorable target for prospecting. The no. 1 vein has been stoped for 50 meters vertically and 75 meters laterally and a shaft has been sunk from the surface to the level of the stopes. Several small veins and two mantos (see p. 371) have been found in the mine but they have not been explored to date.

Adits nos. 2 and 3 are both on the same vein, which trends N. 45° W. and dips 65° to 70° SW. The vein is variable in width, ranging from 0.5 to 2 meters. Little work has been done on this vein except for some small stopes above and below adit no. 3.

The Lizandro Sur workings consist of a 15-meter shaft that follows an ore shoot and a short drift that connects with the shaft. The shoot is formed at the intersection of two veins; one strikes east and the other N. 50° W. The shoot is about 2.5 meters in diameter. Small amounts of pyrite, sphalerite, and gossan are found with the galena in this ore shoot.

Farther south is the Carmen area which contains one large and 10 small adits driven on a system of veins trending N. 60° W. and N. 10° W. The principal vein trends N. 60° W. and can be seen on a cliff east of Laguna Lulicocha. The vein dips 75° S. and has an average width of 1 meter. Several small ore shoots have been formed at vein intersections, and mantos were noted extending outward from the main vein. A manto on the eastern edge of the area follows the bedding for 25 meters and is 1.5 meters wide. The manto strikes N. 20° E. and dips 25° SE.

The Precaución claim lies on the far western edge of the mapped area near the Mitu and Pucará contact. Several veins trending N. 70° E. and a manto 20 by 30 meters in extent form the ore deposits. An adit driven beneath the mineralized area from the west revealed only one of the veins and failed to locate the manto, indicating that the deposits are very shallow.

The Lizandro Norte workings, located southeast of adit no. 3, explore a manto that has a strike length of 40 meters and is 1 to 2 meters thick. The manto strikes N. 30° E. and dips 30° SE. Its extent down the dip is not known.

The Carlos Chino Nuevo area includes a gossan outcrop of some 1,000 square meters along the contact of the Mitu and Pucará formations. The compactness and lack of porosity of the gossan indicate that it was derived largely if not entirely from pyrite. Exploration at depth would be advisable in order to determine the possible presence of other sulfides.

Above the Carlos Chino Viejo adit a series of veins and faults that trend N. 10° W. and N. 60° W. are associated with several mantos. An ore shoot formed at the junction between two of the veins warrants further exploration.

The Palmira area, south of the Carlos Chino Viejo adit, consists of a series of small veins trending N. 60° W. and N. 10° W, and several small mantos. The area is not heavily mineralized

## ATACOCHA MINE

The Atacocha mine is about 13 kilometers northeast of Cerro de Pasco, midway between Milpo and Machcán near the head of Quebrada Chicrín. The camp is at an altitude of about 4,000 meters but mine workings extend from 4,300 meters down to about 3,600 meters, the altitude of the Chicrín adit.

Little is known of the early history of the property. Modern exploration began about 1910, but successful exploitation did not begin until 1936 when the Compañía Minera Atacocha was formed. The accompanying table shows the production since 1940 and gives an idea of the growth of the operation

Rocks of the Pucará and Goyllarisquisga formations are found in the mine area. They are intruded by an irregular dacite body and several dikes and sills of dacite. Plate 26 shows the surface geology of the mine area.

A rock type at Atacocha not found elsewhere in the district is a brecciated red chert, interbedded with clastic limestone, that crops out in a 10- to 30-meter band over the mine workings. Clastic limestone is found between the angular fragments of red chert. The stratigraphic position of this limestone is unknown. It conformably overlies limestone containing red fossils of Triassic age and is in fault contact with sandstone of the Goyllarisquisga formation. The rock bears little resemblance to the chert breccia found along the contact of the Pucará and Goyllarisquisga farther west and in the mine workings.

### STRUCTURE

Both folding and faulting are important in ore control at Atacocha. The major structures, described in previous sections of this report, are an asymmetrical southward-plunging syncline in the sandstones west of the mine and a cross fold in the limestone directly over the mine workings. This latter fold seems to have formed by drag along the Atacocha fault. Ore in the mine is found in veins and replacement bodies near the axis of the fold.

*Metal production from the Atacocha mine, 1940–52*

[Data from "Anuario de la Industria Minera en el Perú"]

| Year | Ore milled (metric tons) | Lead concentrate (metric tons) | Lead (metric tons) | Zinc concentrate (metric tons) | Zinc (metric tons) | Silver (kilos) |
|---|---|---|---|---|---|---|
| 1940 | 49,019 | 4,930 | 3,337 | | | 9,335 |
| 1941 | 47,470 | 5,940 | 4,054 | 4,619 | 2,734 | 10,208 |
| 1942 | 50,868 | 8,613 | 5,615 | 10,159 | 6,215 | 12,628 |
| 1943 | 51,146 | 8,663 | 5,769 | 8,707 | 5,267 | 14,718 |
| 1944 | 57,329 | 11,095 | 7,710 | [1] 15,336 | 9,195 | 16,636 |
| 1945 | 58,519 | 10,229 | 7,240 | [1] 16,162 | 9,657 | 17,894 |
| 1946 | 52,257 | 8,289 | 5,768 | [1] 12,281 | 7,373 | 16,967 |
| 1947 | 54,902 | 8,023 | 5,628 | 7,477 | 4,529 | 13,640 |
| 1948 | 56,613 | 7,155 | 4,409 | 3,736 | 2,242 | 10,980 |
| 1949 | 59,263 | 8,989 | 6,105 | 3,090 | 1,852 | 14,583 |
| 1950 | 111,162 | 13,682 | 9,306 | 7,375 | 4,419 | 26,100 |
| 1951 | 155,106 | 16,887 | 11,357 | 8,583 | 5,135 | 28,931 |
| 1952 | 192,692 | 22,634 | 14,950 | 11,273 | 6,698 | 35,216 |

[1] Including reworked tailings.

The no. 1 fault is the most important fault in the area explored by the mine workings. The fault, as shown on the section (pl. 26), dips 45°–60° E. below the 4,103 level. It is a reverse fault on which Pucará limestone has been thrust over quartz sandstone of the Goyllarisquisga formation. On and above the 4,103 level the no. 1 fault steepens and joins a steep westward-dipping fault. The faults seem to have formed at the same time and may be the same fault. The strike of the no. 1 fault closely follows that of the bedding, even to the turn made in the cross fold.

The fault may be premineralization, although no direct evidence was seen to date the movement. Veins terminate against the fault but no correlation could be made between veins on opposite sides of the fault and no offsetting of any given vein could be demonstrated. Abundant gouge along the fault may have inhibited the formation of continuous structures. Mineralization was reported to have been continuous across the fault at one point between the no. 1 ore body and the Veta Prima (main vein) which also suggests a premineralization age for the fault.

## MINE WORKINGS

The mine is developed by about 30 kilometers of workings on 16 levels. Vertical spacing between levels is 25 to 55 meters and a total vertical distance of 700 meters has been explored. Ore is found below the bottom level so the vertical range of ore is not yet known. Three maps of mine levels included in this report show the method of exploration and typical geologic relationships found in the upper and lower sections of the mine.

The 4,103 level (pl. 27) explores the limestone east of the no. 1 fault and passes through the sandstone west of the fault in a few places. The close spacing of the veins near the axis of the cross fold (which is shown by the curve of the no. 1 fault) is apparent. A radial pattern is suggested by the strikes of the larger veins; this pattern may reflect tension cracks that developed during the cross folding and were filled later by vein material. Only the approximate positions of ore bodies no. 3 and no. 4 are shown; these bodies are being mined on the level below, but their boundaries are not known on the 4,103 level. Ore bodies no. 4 and no. 5 are close to the no. 1 fault and are elongate along the bedding in the limestone. Ore body no. 3 is farther from the fault and may have been controlled by highly fractured and easily replaceable limestone along the axis of the cross fold. Mineralization diminishes south of the no. 5 ore body. The large intrusive cut by the crosscut south of the no. 5 ore body is part of the irregular porphyry body mapped on the surface. The southern end of the level lies under the San Gerardo area, which was productive closer to the surface. The principal working in sandstone follows the "D" vein which is about 110 meters long on this level.

Conditions on the 4,000 level (pl. 28) differ considerably from those found above. The veins in limestone are weaker and more irregular. The no. 1 ore body has the same relation to the no. 1 fault as the ore bodies no. 4 and 5 above, but is the only ore body found along the fault. The limestone along the fault is highly altered, particularly south of coordinate 3840 N, but it is only slightly mineralized.

All igneous rock found on the 4,103 level seems to die out before reaching the 4,000 level, with the exception of the Tres Mosqueteros dike, which is barren on this level. The sandstone has been more thoroughly explored on the 4,000 level and numerous veinlets were cut, but little ore was found except in the "*C*" and "*D*" veins. The "*D*" vein is much longer than it was on the 4,103 level, because of the east dip of the no. 1 fault, which is the eastern limit of the vein.

The *"C"* vein, which is limited by the *"D"* vein and the no. 1 fault and thus also lengthens downward, has its apex not far above this level.

The map of the 3,900 level (pl. 29) shows conditions typical of the lower levels, which extended down an additional 125 meters at the time of this examination. Exploration in the limestone east of the no. 1 fault is confined to the vicinity of the no. 1 ore body, which continues downward another 60 meters. Workings in sandstone and chert breccia are extensive on these lower levels. The two bottom levels, 3,805 and 3,775, are entirely in sandstone and chert breccia, as the no. 1 fault lies east of the workings of those levels. The *"C"* and *"D"* veins on the 3,900 level are weaker than above and are broken by faults.

The Veta Prima is a strong vein that has been followed from above the 3,970 level to below the 3,775 level, or over 200 meters vertically. It may have been the feeder for the no. 1 ore body, as the north end of the ore body closely follows the intersection of the Veta Prima and the no. 1 fault.

No. 3 and no. 4 faults are splits from the no. 1 fault. The junction of the no. 3 and no. 1 faults nearly coincides with the intersection of Veta Prima and the no. 1 fault. This relationship is found on several levels and points to the possibility of a relation between fault splits and ore. The junction of the no. 4 and no. 1 faults is, therefore, worth investigation. The no. 2 fault is the western limit of the Veta Prima. The vein narrows and becomes pyritic on entering the fault zone, which lies parallel to a shale horizon in the sandstone, so the vein fissure may die out in the shale instead of being offset by the fault.

Workings in these lower levels have entered limestones on the western flank of the syncline, and small ore bodies have been found in the limestone near the contact with chert breccia; some of the veins in chert breccia widen out into replacement bodies on entering the limestone.

An adit driven under the mine area from Chicrín is 175 meters below the principal mine workings. An ore body was found on the adit (3,600) level in limestone that seems to be on the western flank of the syncline, but correlation is uncertain because the altitude of beds on the adit level is not the same as on the levels above.

At Atacocha, galena and sphalerite are the only important ore minerals, and pyrite, calcite, and clay minerals form the bulk of the gangue. Jamesonite and tennantite are minor ore minerals, and rhodochrosite and fluorite are found sparingly in the gangue. Realgar and orpiment are found but may belong to a later stage of mineralization.

## MILPO MINE

The Milpo mine is 10 kilometers northeast of Cerro de Pasco, and is accessible from there by a road 13 kilometers long. The mine workings are near the headwaters of Quebrada Atacocha at altitudes ranging from 3,900 to 4,200 meters.

The area was known to be mineralized for many years and the deposits have been worked sporadically. The Compañía Mineral Milpo, S. A., was formed in 1949 and has operated the property continuously since that time. Production to the end of 1951 amounted to over 12,000 tons of ore with an average grade of 8.2 percent of lead, 11.1 percent of zinc, and 376 grams of silver per ton. Production increased early in 1952 when a flotation concentrator of 60-ton capacity was placed in operation.

The sedimentary rocks in the area are limestone of the Pucará formation and quartz sandstone of the Goyllarisquisga formation (pl. 30). The sandstones crop out only in the southwest corner of the area where they are brought into contact with the limestone along the Atacocha fault. Both the sandstone and the limestone strike N. 15°–20° W. The limestone dips steeply or is vertical, whereas the sandstone dips 10°–20° W., except near the Atacocha fault where the dip steepens to 55°.

The limestone in the central and north central part of the area has been intruded by two irregular dacite bodies. Extensive alluvial cover prevented complete mapping of the two bodies and they may actually be parts of a single stock. Many satellite dikes and sills are associated with the larger intrusive. A dacite sill, 40 meters thick, lies along the east side of the Atacocha fault; this dacite is similar in appearance to the dacite of the stock, but contains less quartz and mafic minerals. The limestone has been recrystallized to marble along the intrusive contacts.

The limestones are cut by a series of transverse faults and by several bedding-plane faults. The transverse faults can be grouped into two sets, a northeastward-trending set found in the northern part of the area, and a northwestward-trending set found farther south. The northeastward-trending faults range in strike from N. 60° E. to N. 80° E. and dip north 75 degrees or more and most of them lie to the east of a bedding-plane fault that extends at least 500 meters north from near the mouth of the 170 level adit. The northwestward-trending faults strike from N. 45° W. to N. 80° W. and dip 65°–80° N.

All faults or veins are confined to the area east of the Atacocha fault. The faults of both sets cut the intrusives and offset contacts from 5 to 15 meters. These northeast- and northwest-striking faults are probably conjugate fractures. Ore was deposited mainly in open spaces and is restricted to the northeast-striking fractures, with the exception of the San Carlos vein.

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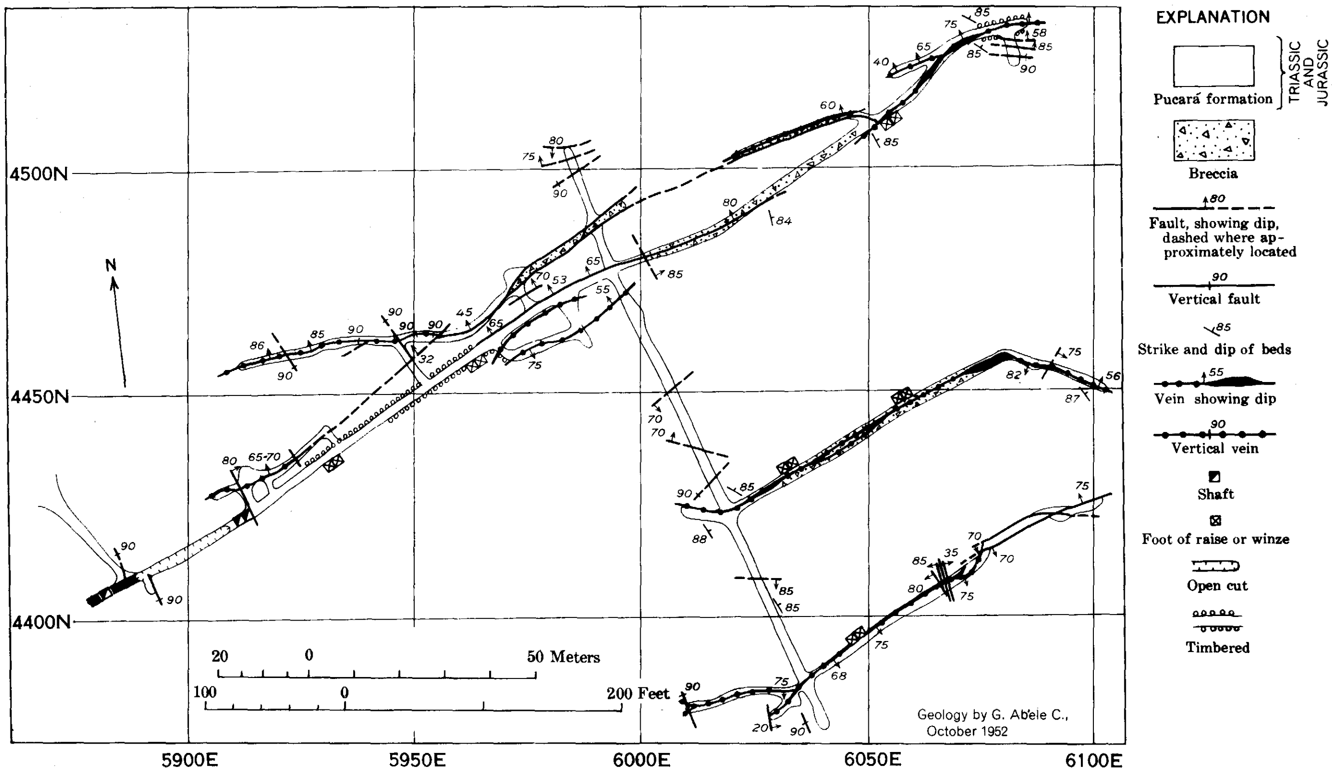


FIGURE 51.—Map of the 220 level, Milpo mine.

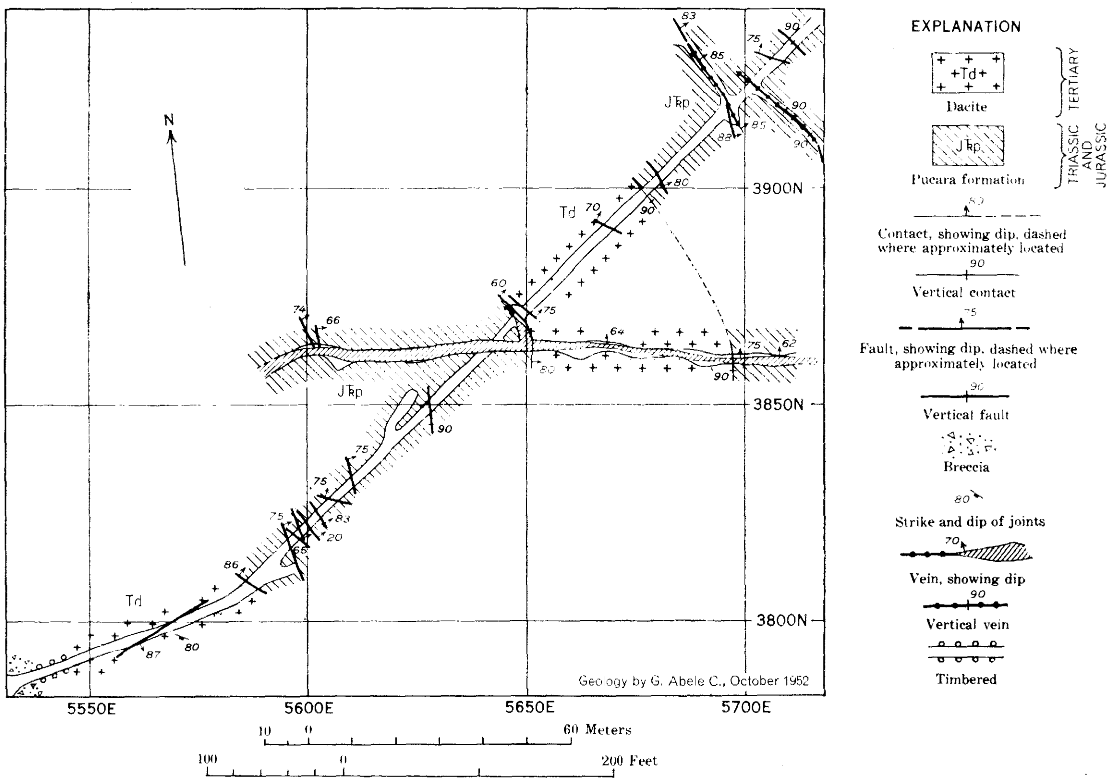


FIGURE 52.—Map of the Navarrico adit, Milpo mine.

Ore is being mined on the 120, 170, and 220 levels in the northern group of faults. The plan of the 220 level (fig. 51) shows the method of exploration. Crosscuts are driven normal to the general strike of the veins and drifts follow the veins found. The veins vary in width from 0.1 to 1 meter. In the southern group of veins the Navarrico adit (fig. 52) is the principal working. It cuts through the porphyry bodies and explores a portion of the San Carlos vein. This vein is the largest in the area, with a width of from 0.8 to 3 meters.

Mineralization consists of simple fissure filling with very minor replacement. The ore minerals galena and sphalerite, together with minor amounts of jamesonite and tetrahedrite, occur in a gangue of calcite and pyrite. Some quartz, fluorite, and rhodochrosite are also found with the gangue minerals. A pyritic body with disseminated galena and sphalerite is found on a faulted contact of porphyry and limestone extending northwest from the 170 level adit.

Angular fragments of sulfide ore in fault breccia and ground-up sulfides in gouge indicate postmineralization movement along the faults. The veins have been displaced as much as 2 meters. Faulting may have taken place near the end of the period of ore deposition, as faults that cut ore are themselves filled by ore minerals.

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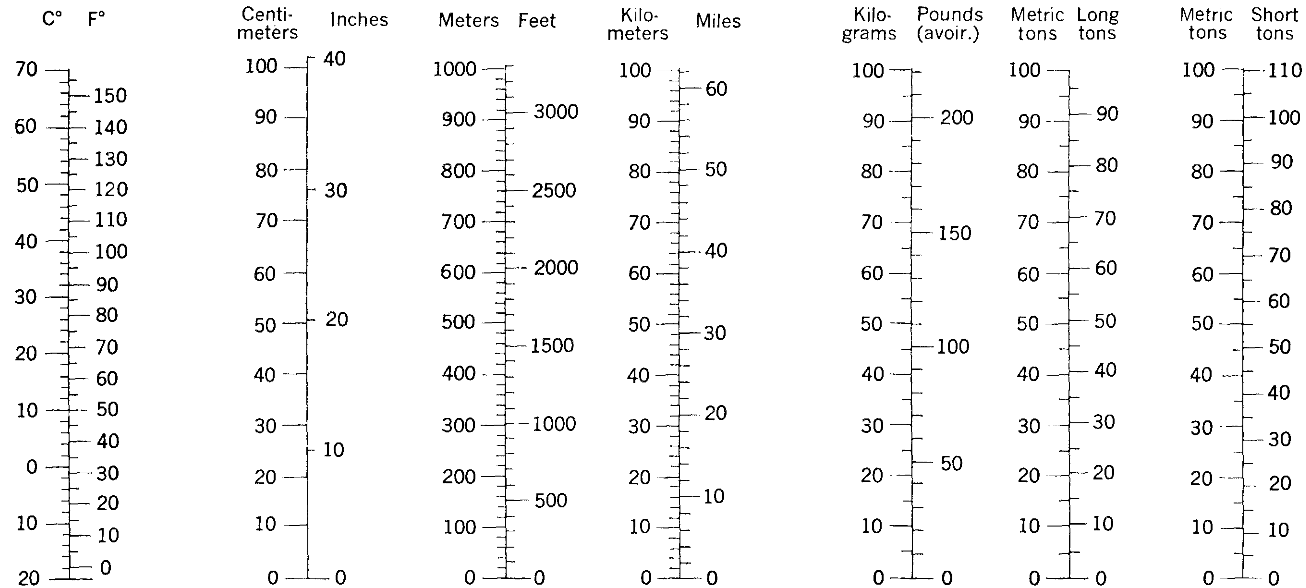
# METRIC EQUIVALENTS

TEMPERATURE — LINEAR MEASURE — WEIGHTS




1 cm. = 0.3937 inch
1 inch = 2.5400 cm.

1 meter = 3.2808 ft.
1 ft. = 0.3048 meter
1 sq. meter = 1.20 sq. yd.
1 hectare = 2.47 acres
1 cu. meter = 1.31 cu. yd.

1 km. = 0.6214 mile
1 mile = 1.6093 km.

1 kg. = 2.2046 lbs.
1 lb. = 0.4536 kg.

1 metric ton = 0.9842 long ton
1 metric ton = 1.1023 short tons
1 metric ton = 2205 lbs.
1 long ton = 1.0161 metric tons
1 short ton = 0.9072 metric ton

# INDEX