Geology and Mineral Deposits of the San Cristóbal District Villa Martin Province Potosi, Bolivia

By HERBERT S. JACOBSON *and* CARLOS MURILLO, LORGIO RUIZ, OSCAR TAPIA, HUGO ZAPATA, HUGO ALARCON, EDGAR DELGADILLO, *and* CARLOS VELASCO

GEOLOGICAL SURVEY BULLETIN 1273

Prepared in cooperation with the Servicio Geologico de Bolivia as part of the cooperative training program under the auspices of the United States Agency for International Development

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1969

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

GEOLOGY AND MINERAL DEPOSITS OF THE SAN CRISTOBAL DISTRICT, VILLA MARTIN PROVINCE, POTOSI, BOLIVIA

By HERBERT S. JACOBSON [1] and CARLOS MURILLO, LORGIO RUIZ, OSCAR TAPIA, HUGO ZAPATA, HUGO ALARCON, EDGAR DELGADILLO, and CARLOS VELASCO [2]

ABSTRACT

The San Cristóbal silver district near Uyuni, Bolivia, was jointly studied in detail during the months of August to November 1966 by members of the Servicio Geologico de Bolivia and the U.S. Geological Survey, under the auspices of the Agency for International Development, U.S. Department of State.

The rocks of the district are Cenozoic. The oldest rocks are the red beds of the Potoco Formation, which are unconformably overlain by agglomerate, conglomerate, sandstone, and tuff of the flat-lying Quehua Formation. Both formations are intruded by dacite porphyry and andesite porphyry stocks, and both are overlain by recent dacite porphyry lava flows. The intrusive and sedimentary rocks near the intrusive contacts are hydrothermally altered.

Mineral deposits of the district are associated with the intrusive rocks and are of four distinct types:

1. Sulfide veins containing lead, zinc, and silver associated with dacite porphyry intrusives (Colon and Tesorera mines).
2. Oxide veins containing iron and silver associated with andesite porphyry intrusives (Toldos mine).
3. Partial sulfide replacement of intrusive breccia containing silver, lead, and zinc (Animas mine).
4. Disseminated lead-zinc-silver minerals in altered dacite porphyry intrusives and in adjacent altered sedimentary rocks (Hedionda mine).

Disseminated silver minerals may provide a basis for the development of open-pit silver mines. This possibility should be further investigated, beginning with geochemical surveys and hydrothermal alteration studies.

[1] U.S. Geol. Survey.
[2] Servicio Geologico de Bolivia.

INTRODUCTION

The San Cristóbal district is in southern Bolivia, approximately 500 kilometers (airline) south of La Paz and 65 kilometers southeast of Uyuni (fig. 1). The district is readily accessible by road from Uyuni, a trip of 3 hours by car, except during the rainy season (December to March). A detailed field investigation of the district was made from August 26, 1966, to November 4, 1966, by the U.S. Geological Survey and the Servicio Geologico de Bolivia (GeoBol) under the sponsorship of the Agency for International Development, Mission to Bolivia, U.S. Department of State.

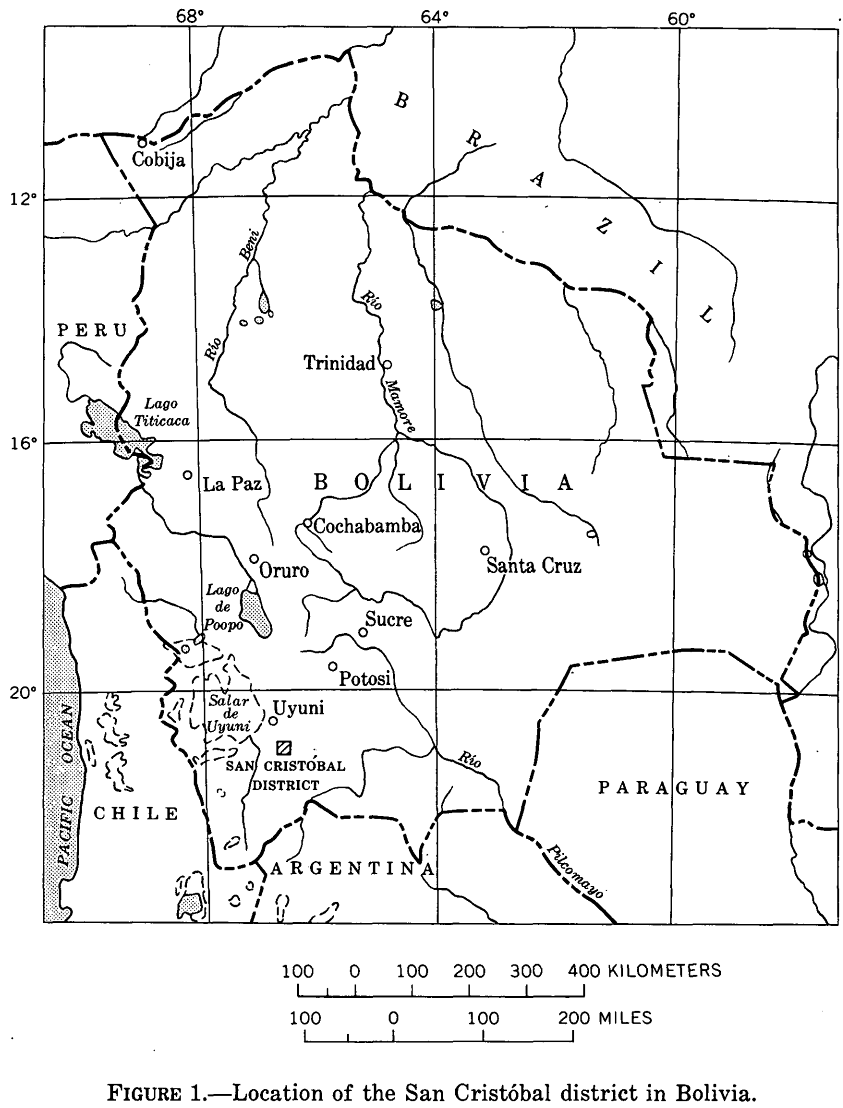


FIGURE 1.—Location of the San Cristóbal district in Bolivia.

This report presents the results of the field investigation but does not include the laboratory work which is in progress. A more detailed report will be published in Spanish by GeoBol.

HISTORY OF THE DISTRICT

Silver was discovered at the Hedionda mine (Santa Barbara de Jayula) by the Spanish priest A. A. Barba over three centuries ago (Barba, 1637, book 1, chap. 2). Repeated attempts to mine the silver ended in failure because of the presence of carbon dioxide gas which caused the death of many miners. The gas continues to issue from the wallrocks of the mine at the present time.

Other silver mines in the district were exploited by the Spaniards in the 17th and 18th centuries, but no details are available. However, considerable mining activity in this period is indicated by the numerous abandoned mine workings in the district.

In the past century the district has been the scene of intermittent mining activity. The Toldos mine was operated from 1870 to 1921 by the Compania Minera de San Cristóbal, and it produced ore containing 0.2–0.5 percent silver (Ahlfeld, 1944, p. 15). Production from 1918 to 1921 averaged about 200 kilos of silver per month. The Hedionda mine was rediscovered in 1896 by the Polish engineer J. Jackowski, who operated the mine from 1896 to 1901 and from 1927 to 1936, after having found a remedy for the carbon dioxide problem. This remedy was simply the excavation of a canal in the floor of the mine workings which allowed the gas to flow out of the mine like water. In addition, mining was confined to work above the adits.

Partial smelter returns are an indication of the mine production (J. Jackowski, unpub. data):

Date	*Kilos*	*Percent* Ag	Pb
October 21, 1900	905	1.51	—
November 13, 1900	6,195	.76	17.59
September 6, 1901	4,544	.38	38.50
September 6, 1901	279	.26	—
March 19, 1929	3,300	.70	43.0
April 4, 1929	600	.53	42.1
May 10, 1929	336	.53	38.2

After 1936, no mines in the district were active until the De Wett adit at the Hedionda mine was opened in 1963 by P. Zubrzycki, who in 1959 was given the right to operate the mine by the heirs of J. Jackowski. Recently, this right has been transferred to the Lipez Mining Co. which began operations in the district in 1966. This company now controls eight properties totaling 627 hectares and is reopening some of the old mines in the district. There has been no recent production (O. B. Stoughton, manager, Lipez Mining Co., oral commun.).

In addition to the Lipez Mining Co., the Cooperativa Minera Litoral is now active in the district. This organization started mining lead-silver ore at the Animas mine in December 1965. Current production is 2–3 tons of silver-bearing hand-sorted galena per month. The mine was started as a result of technical assistance to the Cooperativa Minera Litoral by one of the writers (Oscar Tapia), who examined five mineral prospects and selected the site of the Animas mine.

PREVIOUS INVESTIGATIONS

During its long history many engineers and geologists have studied the district, but little information has been published. The principal known studies were made by: J. Jackowski, 1896–1901 and 1927–1936; Ahlfeld (1944); Ahlfeld and Schneider-Sherbina (1964); P. Zubrzycki, 1956–66; Oscar Tapia, 1965–66; Torrico (1966); H. R. Cooke, 1966; and Lorgio Ruiz, 1966. The work of Jackowski, Ahlfeld, Zubrzycki, and Cooke emphasized the mineral deposits; Tapia, Torrico, and Ruiz were mainly concerned with the regional geology. Tapia prepared the San Cristóbal quadrangle for the geologic map of Bolivia, which will be published by GeoBol at a scale of 1:100,000.

PRESENT INVESTIGATION

The aim of the present investigation was twofold:

1. To make a detailed study of the San Cristóbal district to assist in the development of its mineral deposits.
2. To provide training for GeoBol geologists in modern geological, geochemical, and geophysical field methods as a guide to similar future studies of other districts in Bolivia.

The methods employed in the investigation were:

1. Surface geological planetable mapping.
2. Underground geological mapping of the accessible mine workings.
3. Reconnaissance geochemical sampling and analysis to determine the limits of the mineral district.
4. Detailed geochemical sampling and analysis.
5. Geophysical magnetic and electromagnetic surveys.

ACKNOWLEDGMENTS

We are grateful for the support provided by Mr. Gaston Pereira, Director of GeoBol, and the GeoBol staff in La Paz. Many thanks are also due to the following GeoBol personnel who assisted us in the field: Salmon Rivas, Eduardo Mendoza, and Jose Torres. In addition, we are indebted to O. B. Stoughton (manager), R. Gamarra, and other staff members of the Lipez Mining Co. for their helpful assistance in San Cristóbal. We also are thankful for the assistance received from members of the Cooperativa Mineral Litoral.

REGIONAL GEOLOGIC SETTING

The San Cristóbal district lies within a north-trending range of mountains surrounded by the high plateau (altiplano) of western Bolivia. The mountain range has a mature topography and maximum relief of about 800 meters. Altitudes within the area studied range from 4,080 to 4,640 meters. The climate is dry, cold, and windy. Vegetation is sparse. The bedrock is relatively well exposed but in many places is covered by talus on the mountain slopes.

All the rocks in the mountain range are Cenozoic—Tertiary and possibly Quaternary. The oldest rocks are Paleocene to lower Miocene sandstones and shales of the 4,500-meter-thick Potoco Formation. These rocks are unconformably overlain by generally horizontal beds of agglomerate, sandstone, and tuff of the Quehua Formation (Pliocene) which has a thickness of more than 600 meters. This formation is covered by horizontal dacite porphyry lava flows (Pliocene?), 5–30 meters thick, which cap the mountains. The age of the flows was considered Quaternary by Torrico (1966).

The rocks of the Quehua Formation are cut by dacite porphyry and andesite porphyry intrusive stocks (Pliocene or Pleistocene). The composition of dacite porphyry stocks and dacite porphyry lavas is similar, and the stocks, therefore, probably were the feeders for the flows. The relative age of the dacite and andesite porphyry intrusive rocks is unclear. The valleys in the area are filled with unconsolidated Quaternary alluvium.

GEOLOGY

The geology of the San Cristóbal district is complex because a variety of rock types are present, many of which result from hydrothermal alteration. In the field, several different rock types were mapped as the same lithological unit, owing to difficulties in indentification. Laboratory studies of rock samples by the Servicio Geologico de Bolivia are now in progress. Rock names used in this report must therefore be regarded as provisional and subject to change.

SEDIMENTARY ROCKS

Potoco Formation

The Potoco Formation is exposed over a large area (pl. 1 and fig. 2) in the southern half of the San Cristóbal district. A section estimated to be about 2,000 meters thick is partly exposed, but exposures were not adequate for compilation of a detailed stratigraphic section.

The Potoco Formation consists mainly of steeply dipping red shale and siltstone. The shales are thin bedded and poorly indurated. Locally, beds of sandstone, quartzite, and conglomerate are present. The sandstone is medium grained and red, and the quartzite is a yellow medium-coarse-grained rock, which was observed

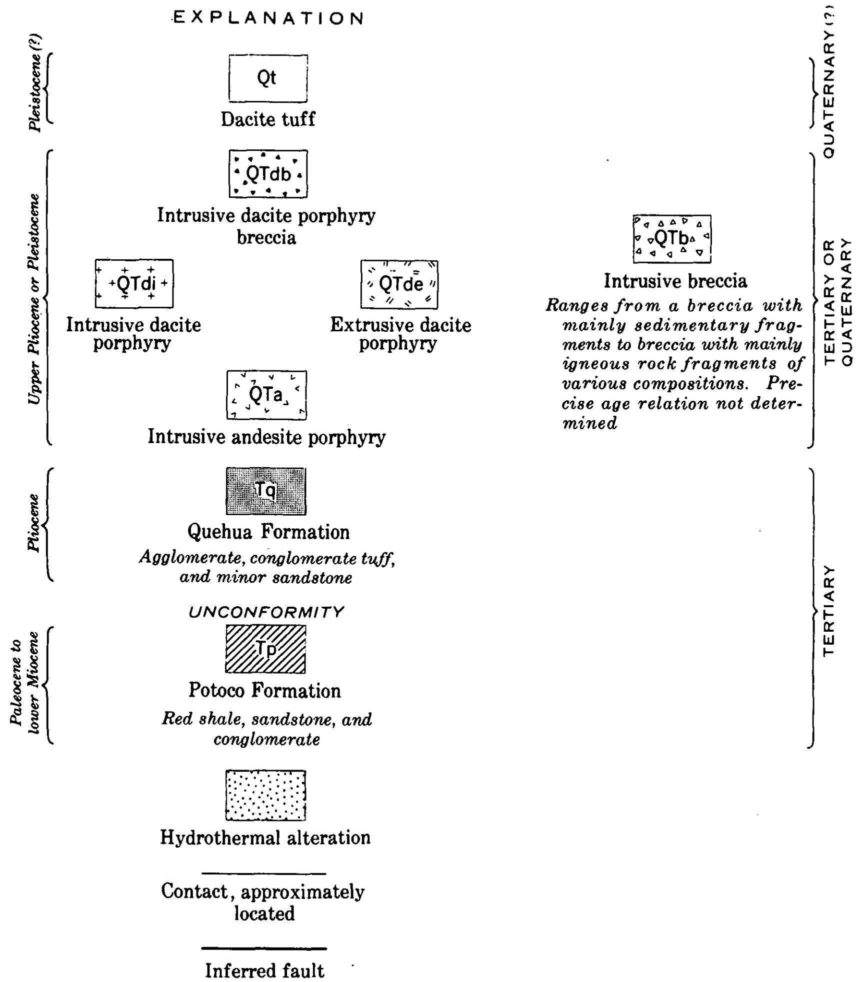


FIGURE 2.—Generalized bedrock geologic map and section of the San Cristóbal district, Bolivia. See plate 1 for distribution of surficial deposits.

only in hydrothermally altered exposures. The quartzite beds are 0.5–6 meters thick. The conglomerate consists of angular thin-bedded shale fragments and boulders from 2 to more than 50 centimeters in diameter, commonly 5–10 centimeters, in a red shale matrix. The conglomerate is probably the result of deformation during deposition of the shale. The age of the Potoco Formation, on the basis of regional studies (Torrico, 1966), is Paleocene to early Miocene.

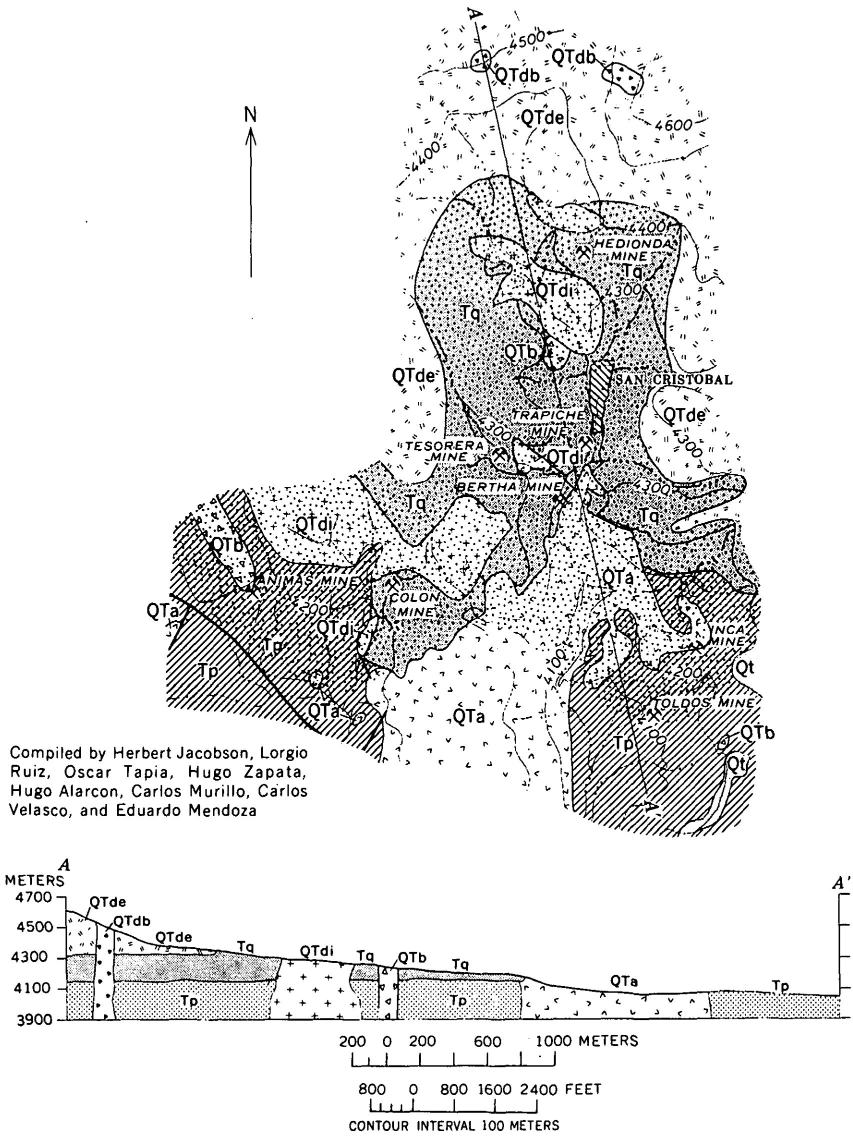


FIGURE 2.—Continued.

Quehua Formation

The Quehua Formation unconformably overlies the Potoco Formation and is horizontal, except where it has been disturbed by intrusion. It is exposed in the center of the mapped area (pl. 1 and fig. 2), and the best exposures are just south of the village of San Cristóbal on the west bank of the creek.

The Quehua Formation is composed of a series of agglomerates, conglomerates, and tuff, as well as minor amounts of sandstone. The uppermost bed of the formation is an agglomerate rich in andesite porphyry fragments. These fragments are apparently derived from a source older than the andesite porphyry which intrudes the Quehua Formation.

Below the andesite agglomerate is a section of poorly sorted conglomerate and sandstone which contains tuff. The conglomerates contain mostly sedimentary rock fragments, but some igneous fragments are also present. In the district, the basal unit of the Quehua Formation is a white tuff bed.

The age of the Quehua Formation is considered to be Pliocene because it overlies the Paleocene to lower Miocene Potoco Formation, and because in adjacent areas it interfingers with a welded tuff (ignimbrite) which is 7.5 million years old, about middle Pliocene, according to a radiometric age determination.

Quaternary(?) rocks

In the southeastern margin of the mapped area (pl. 1 and fig. 2), a horizontal bed of dacite tuff overlies the Potoco Formation and is probably the youngest rock in the district. It is probably Pleistocene in age. The tuff consists of rock fragments (dacite?), as much as 1 centimenter in diameter, in a very fine grained white tuff matrix. Near the base of the tuff, red shale fragments from the underlying Potoco Formation are locally present.

Quaternary deposits

The Quaternary unconsolidated sediments (pl. 1) in the area include alluvium in the creek valleys, talus on some mountain slopes, and soil.

IGNEOUS ROCKS

Andesite porphyry

Andesite porphyry intrusive stocks crop out in the south-central and southeastern parts of the area mapped (pl. 1 and fig. 2). The rock consists of euhedral to subhedral plagioclase phenocrysts in a green fine-grained matrix. Andesite porphyry breccia is present locally at the intrusive contacts.

The andesite is probably Pliocene or Pleistocene in age because it intrudes the Quehua Formation.

Intrusive breccia

An intrusive breccia is present in one large outcrop and four small outcrops in the area studied. This rock ranges from a breccia of chiefly sedimentary rock fragments to a breccia of chiefly igneous rock fragments of various compositions. Its precise age relation to other rocks is not yet determined. The Animas mine workings are within this rock.

Dacite porphyry

Dacite porphyry is present in almost identical composition in three forms in the area studied: intrusive stocks, lava flows, and breccia pipes. All these rocks are probably derived from the same magma, the stocks being feeders for the flows. The stocks and the flows are thus contemporaneous, but the breccia pipes are younger because they cut the lava flows. Distribution of the dacite porphyry stocks is shown on plate 1 and in figure 2; the flows cap the ridges at the higher altitudes along the western, northern, and eastern borders of the district.

The dacite porphyry consists of quartz, plagioclase, and biotite phenocrysts in a fine-grained gray matrix. Quartz content is low, and plagioclase content is high. Phenocrysts of other unidentified mafic minerals were also observed.

The stocks are younger than the Quehua Formation, as indicated by observed intrusive contacts; however, contacts between the dacite porphyry and the andesite porphyry intrusive bodies were not found, and their relative ages are somewhat uncertain. The dacite porphyry flows overlie the andesite porphyry stocks, however, and if the dacite porphyry flows and stocks are presumed to be of the same age, all the dacite porphyry is presumably younger than the andesite porphyry. The age of the dacite porphyry, therefore, is probably late Pliocene or possibly Pleistocene.

STRUCTURE

A regional N. 10° W.-trending anticlinal axis passes through the center of the San Cristóbal district, but is not readily apparent within the area mapped because it is obscured by the intrusive stocks. Only the beds of the Potoco Formation are folded in the anticline. The younger Quehua Formation and the dacite porphyry lava are horizontal and unconformably overlie the Potoco Formation. The beds of both the Potoco Formation and the Quehua Formation have been uplifted by the igneous intrusions. This uplift is best illustrated at the Cuaresma adit of the Hedionda mine, where the beds of the Quehua Formation dip at 20° in the portal and increase to a maximum dip of 50° near the intrusive contact. The dacite lavas on Mount Jayula (northeast corner of pl. 1) may also have been deformed by an underlying intrusion, though large-scale slumping may also explain the erratic bedding attitudes.

One major fault is inferred in the southwest corner of the mapped area (fig. 2). The fault has changed the strike of the Potoco Formation from N. 35° E. south of the fault to N. 50° E. north of the fault, but the direction of the movement is unknown.

In general, there is little evidence for the existence of major faults in the district, but numerous faults with small displacement are present. The faults are best observed in the mine workings. Two fault systems were noted: one strikes N. 30°–40° E. and the other strikes N. 50°–70° W. The faulting was probably produced by regional east-west compressive forces. Some of the faults are mineralized.

GEOLOGIC HISTORY

The geologic history of the San Cristóbal district, based on the geologic data obtained, may be summarized as follows:

1. Deposition and subsequent folding of the sediments of the Potoco Formation.
2. Erosion of part of the Potoco Formation.
3. Deposition of the conglomerate, agglomerate, sandstone, and tuff of the Quehua Formation.
4. Intrusion of andesite porphyry stocks.
5. First period of hydrothermal activity resulting in rock alteration and deposition of iron oxide-siderite-barite veins containing silver minerals.
6. Intrusion of dacite porphyry stocks and associated uplift of Potoco and Quehua Formations, and deposition of dacite porphyry lava flows. The intrusive rocks probably were feeders for the lava flows.
7. Intrusion of breccia pipes and faulting.
8. Deposition of dacite tuff.
9. Second period of hydrothermal activity resulting in rock alteration and deposition of sulfide minerals (galena, sphalerite, and pyrite) with native silver and barite.
10. Erosion of the central valley in the district to create the present topography.

The exact dates of the above events are uncertain, but all took place in Tertiary and Quaternary time.

MINERAL DEPOSITS

Most of the Quehua Formation, part of the Potoco Formation, and parts of the andesite and dacite porphyry stocks are hydrothermally altered. Clay alteration, silicification, and chloritization were observed megascopically, and sericitization was noted microscopically.

Clay alteration is common in the shales of the Potoco Formation and the tuffs of the Quehua Formation. Intensity of alteration is variable, but locally a pure-white clay rock was observed (kaolinite?). The dacite porphyry intrusives are also locally altered to clay.

Silicification is common in the agglomerates of the Quehua Formation. In some localities, strongly silicified agglomerate overlies tuff which has been largely altered to clay. Silicification is also locally present in the conglomerates of the Quehua Formation and in the dacite porphyry intrusive rocks.

Chloritization was noted only in one area of dacite porphyry intrusive rocks, and sericitization was noted locally in the intrusive andesite porphyry.

In addition, most surface exposures of both the andesite porphyry and dacite porphyry stocks contain coatings of iron oxides, particularly along joint planes. Some manganese oxide may also be present.

MINERALIZATION

Sulfide or oxide minerals are present in all rock units in the district. Disseminated and vein mineralization was observed in the dacite porphyry stocks and in the adjoining sedimentary rocks of the Quehua Formation. Sulfide minerals are also present as disseminations and partial replacements in the intrusive breccia at the Animas mine. The sulfide minerals are galena, sphalerite, pyrite, and chalcopyrite. Silver is associated with these minerals as native silver or as argentiferous galena; barite is the principal gangue mineral.

The oxide deposits consist of hematite veins in the andesite porphyry intrusives and in adjoining sedimentary rocks of the Potoco Formation. The veins contain siderite, barite, and quartz gangue, plus silver in its native form and in tetrahedrite and stromeyerite (Ahlfeld, 1944, p. 13).

VEIN DEPOSITS

Most of the deposits are veins that follow the principal structural trends; the veins strike approximately N. 35° E. and N. 60° W., and have steep dips. They are probably epithermal and are exposed in many small pits and adits, and in some of the principal mines (Colon, Tesorera, Toldos) of the district. Most of the veins contain sulfide minerals and barite gangue.

A second vein type occurs both in an intrusive andesite porphyry (Toldos mine) and in adjacent sedimentary rocks (Inca mine). The mineralization consists primarily of hematite and barite and siderite gangue. The veins contain relatively small amounts of native silver and copper-silver sulfide minerals but no pyrite, galena, or sphalerite.

DISSEMINATED AND REPLACEMENT DEPOSITS

Disseminated native silver, galena, sphalerite, and pyrite are present in hydrothermally altered parts of intrusive dacite porphyry and in adjacent altered sedimentary rocks (Hedionda mine). The minerals are extremely fine grained and often invisible to the naked eye.

A unique mineral deposit in the district is at the Animas mine, where a breccia pipe contains disseminated sulfide mineralization as well as local sulfide replacements of the breccia matrix. The sulfide minerals are argentiferous galena, sphalerite, and pyrite.

PRINCIPAL MINES

Animas mine

Geology.—The Animas mine is presently (1966) the only producing mine in the district. The mine workings, in the southwest corner of the district (pl. 1 and fig. 2), are in a mineralized breccia pipe, about 40 meters wide and 300 meters long. The long axis of the pipe trends approximately N. 30° W. In the mine, the breccia is cut off by a fault on the west and is in contact with fractured and altered siltstone and shale of the Potoco Formation (fig. 3) on the east. Surface exposures indicate that additional breccia should be present a short distance west of the fault in the mine.

The breccia consists of angular to subrounded fragments of igneous and sedimentary rocks in a fine-grained matrix. The fragments are commonly 3–10 centimeters in diameter, but some are much larger. The percentage of sedimentary rock fragments within the breccia increases toward its eastern contact. The breccia is hydrothermally altered, but the alteration products have not been identified.

Mineralization at the surface consists of iron oxides. In the mine, sulfides are present mainly in the breccia matrix. Sulfide minerals are disseminated, but locally they entirely replace the matrix in "pockets" commonly 1–2 meters in diameter. These pockets constitute the ore currently being mined and consist primarily of argentiferous galena with associated sphalerite and pyrite. The principal disseminated mineral observed is pyrite.

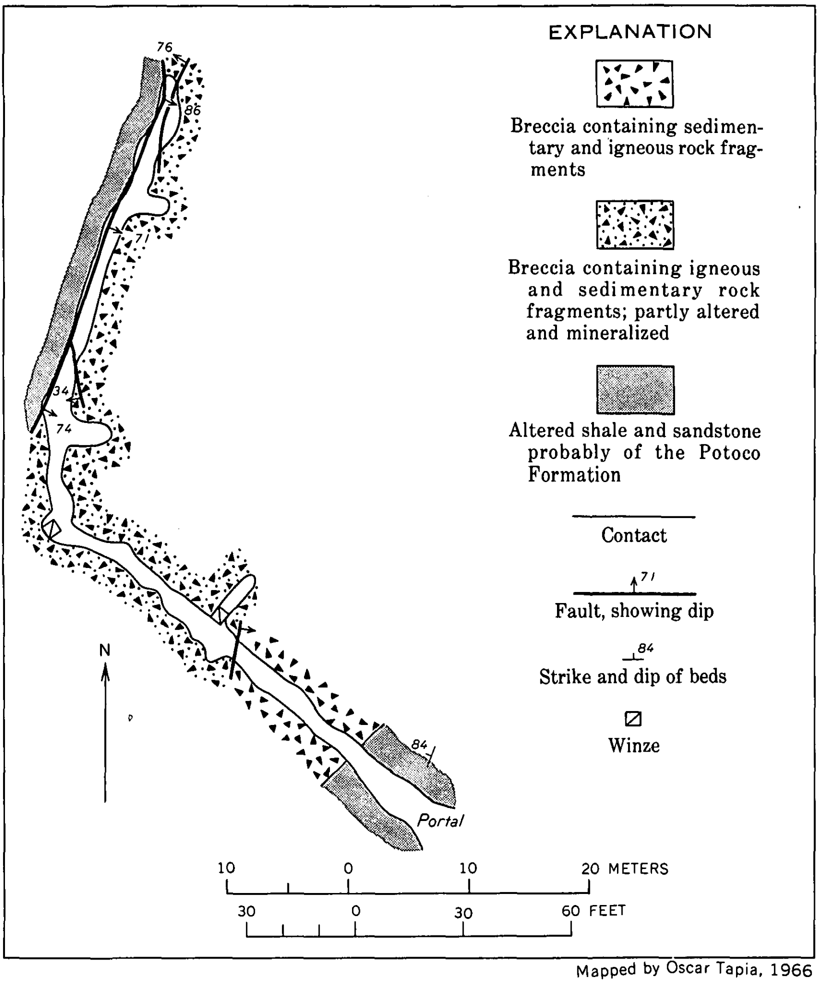


FIGURE 3.—Main adit of the Animas mine, Bolivia.

Geochemistry.—The widely spaced geochemical soil-sampling grid of the district (fig. 7) shows no anomaly over the Animas mine area.

Geophysics.—A Turam electromagnetic survey was made over an area 400 meters by 300 meters in the mine vicinity, along traverse lines spaced 20 meters apart, to detect strongly mineralized zones within the breccia. The electromagnetic survey indicated the presence of several weak electromagnetic anomalies (conductors). Conductors *A*, *B*, and *C* (fig. 4) represent a series of en echelon conductive zones parallel to the most prominent faults visible in the mine (fig. 3), and possibly reflect other mineralized faults. The cause of the other conductors (fig. 4) is indeterminate.

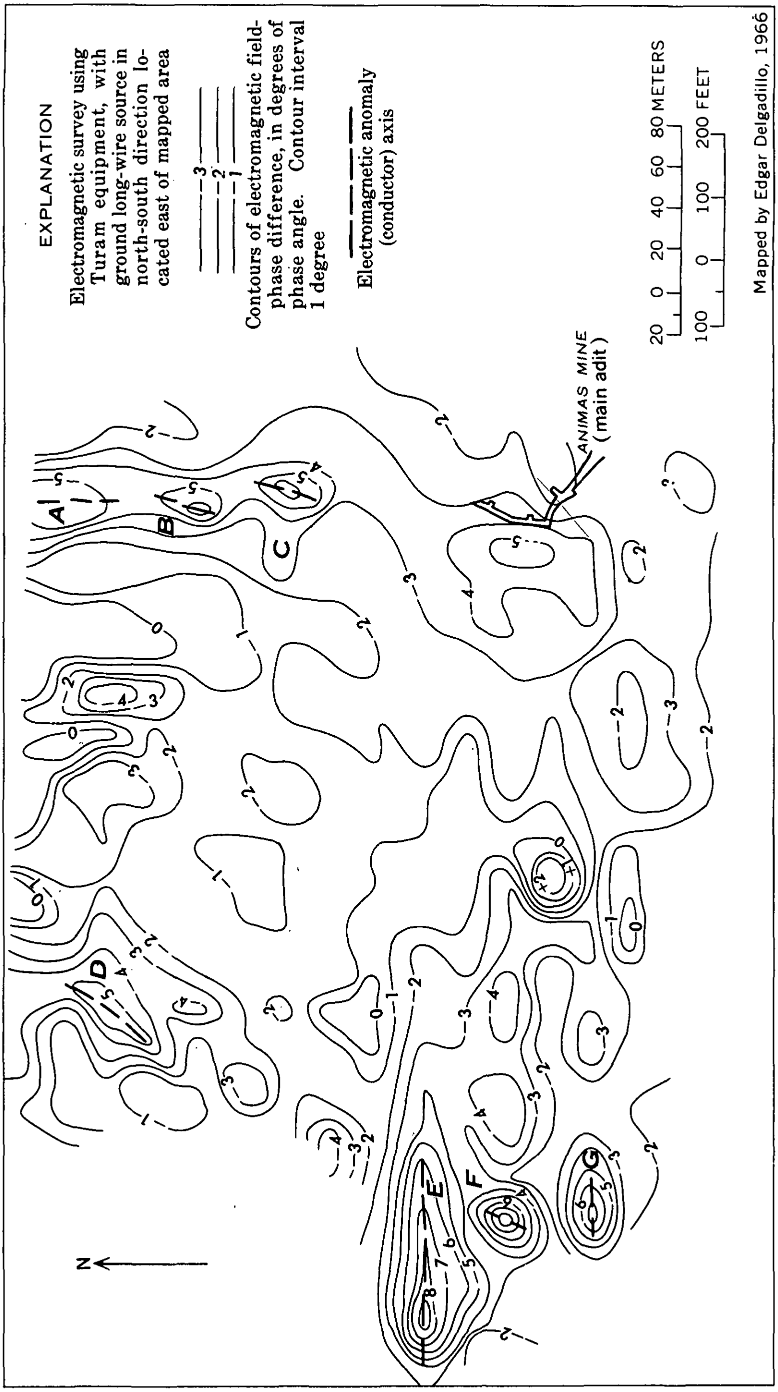


FIGURE 4.—Electromagnetic map of the Animas mine area.

Conclusion.—The Animas mine area exposes a mineralized breccia containing disseminated sulfide minerals as well as the local pockets of high-grade material now being mined. The amount of mineralized breccia above the level of present mine workings probably exceeds 1 million tons. Estimated possible reserves are several million tons. These reserves possibly could support an open-pit mine, if thorough testing of the deposit reveals a commercial grade of mineralization.

Bertha mine

The Bertha mine, half a kilometer south of the village of San Cristóbal (pl. 1 and fig. 2), consists of a tunnel 195 meters long (fig. 5) entirely within a horizontal bed of conglomerate of the Quehua Formation. In the last 35 meters, the tunnel follows a mineralized fault zone striking approximately N. 70° W. and dipping 34°–64° N. The fault zone ranges from 1–80 centimeters in width and contains lenses of sulfide minerals as much as 30 centimeters thick. Mineralization consists of pyrite, sphalerite, galena, and an unidentified soft glassy yellow mineral. The conglomerate wallrock near the fault zone is partly silicified and contains disseminated pyrite. Inasmuch as the fault is well exposed in the face (fig. 5), and contacts with the intrusive dacite prophyry are nearby (pl. 1), the grade of mineralization may increase further west.

Colon mine

The Colon mine, on the ridge 1.2 kilometers southwest of San Cristóbal (pl. 1) is small; accessible mine workings total 25 meters in length. The mine has exposed two irregular lenticular veins. One vein strikes north-northwest, dips northeast at a low angle, and has a thickness of 10–50 centimeters. The other vein strikes northeast, dips 40° N.W., and has a thickness of 15–20 centimeters. Both veins consist of massive barite with traces of galena. The wallrock consists of altered Quehua Formation.

Hedionda mine

The Hedionda mine, the oldest known in the district (Barba, 1637), is nearly 1 kilometer north of San Cristóbal (pl. 1). The main presently accessible mine openings are three adits, named Alkamari, Cuaresma, and DeWett. The largest adit, the Cuaresma (fig. 6), exposes a series of east-striking south-dipping sedimentary rocks in contact with intrusive dacite porphyry. The dip of the sedimentary rocks increases as the contact is approached, and a 6- to 10-meter-wide zone at the contact is brecciated. The sedimentary rocks consist of tuff(?), and agglomerate (Quehua Formation). Both the sedimentary rocks and the intrusive dacite are strongly hydrothermally altered and contain large amounts of white clay (kaolin?). All these rocks also contain disseminated sulfide minerals and native silver, some of which is so finely disseminated that it is invisible to the naked eye. Several mineralized faults also are present in the mine (fig. 6). Mineralization consists of pyrite, galena, sphalerite, and native silver. The mine workings have recently been channel sampled in detail by the Lipez Mining Co., and preliminary results indicate the presence of disseminated silver, lead, and zinc. According to Mr. O. B. Stoughton, manager (oral commun., 1966), if results continue similar to those obtained to date, an ore body amenable to open-pit or related mining methods may be developed.

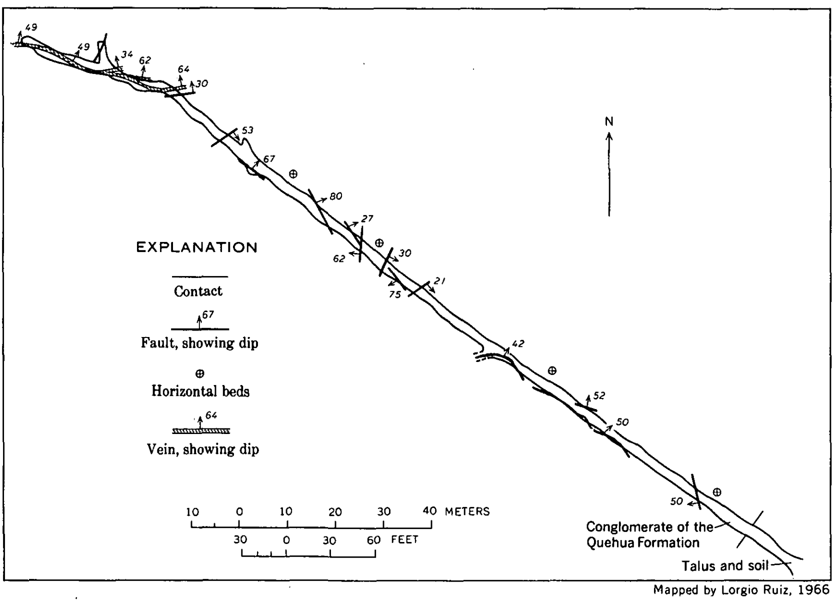


FIGURE 5.—The Bertha mine, Bolivia.

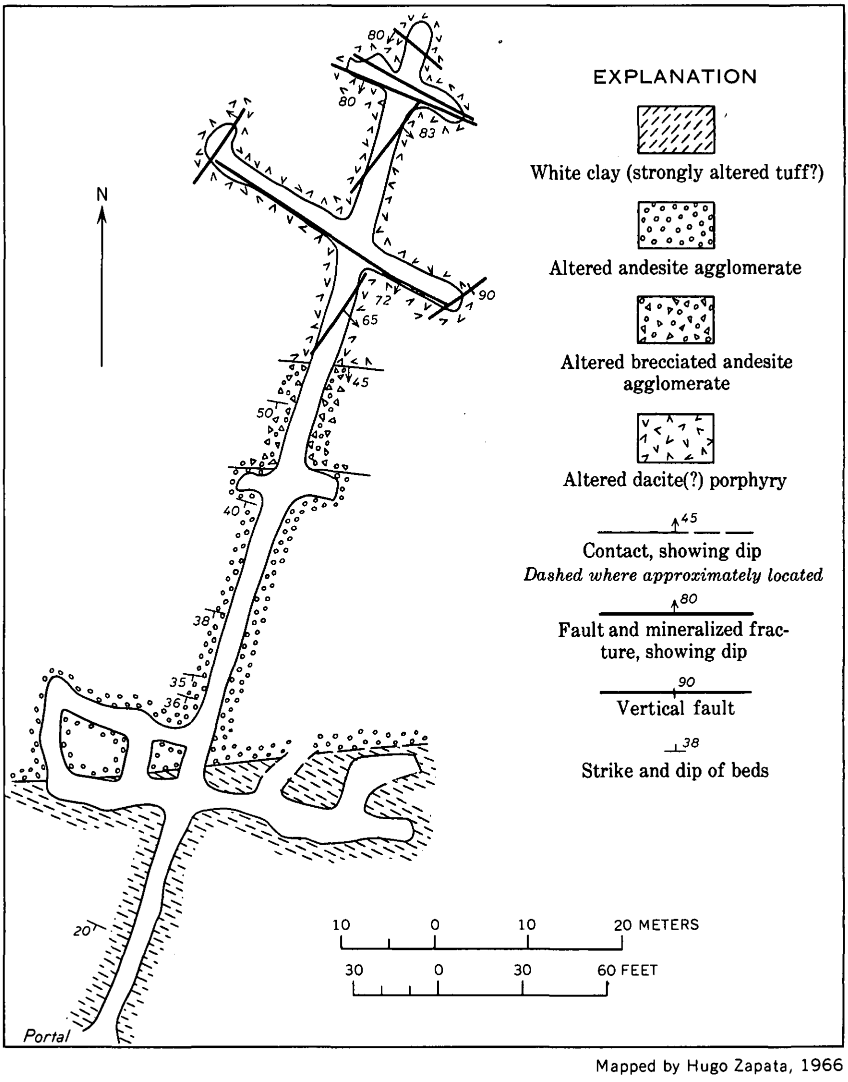


FIGURE 6.—The Cuaresma adit, Hedionda mine, Bolivia.

Inca mine

The Inca mine, 1.5 kilometers southeast of San Cristóbal (pl. 1 and fig. 2), may be regarded as an extension of the Toldos mine. The mine is not readily accessible and was not mapped, but surface pits (pl. 1) show that the mine exploited several veins striking N. 0°–30° W., dipping steeply northeast, and having an average thickness of 10–40 centimeters. The principal vein minerals are hematite and barite. Traces of other minerals have not yet been identified, but silver is reportedly present. The wallrock is a sequence of hydrothermally altered sedimentary rocks (Potoco Formation).

Tesorera mine

The Tesorera mine, 700 meters southwest of San Cristóbal, exploited a mineralized fault zone which strikes N. 55° E. and dips 85° SE. in the mine. At the surface, wallrock on both sides of the fault is hydrothermally altered agglomerate; whereas, in the mine, the agglomerate forms the north wall of the fault and an intrusive dacite porphyry forms the south wall. Both the agglomerate and the dacite are hydrothermally altered. Most of the alteration products are clay (kaolin?), but silicification was also observed. The mineralized fault zone contains fault breccia about half a meter wide, and contains pyrite and galena. The dacite contains disseminated pyrite.

Toldos mine

The Toldos mine, in the southeast corner of the district (pl. 1 and fig. 2), is the most extensively developed mine in the area. Most of the development is on the main level (pl. 2), but there are several levels above the main level and one below. The mine is now flooded below the main level.

Geology.—The mine entrance (pl. 2) exposes a series of altered shales and sandstones containing local conglomerate (Potoco Formation). Similar rocks crop out on the surface above the mine (pl. 1), but most of the mine workings (pl. 2) are in a green intrusive andesite porphyry. The intrusive rock is cut by a series of mineralized fault zones and veins striking N. 30°–40° E. and dipping steeply northwest. The andesite porphyry wallrock is locally altered adjacent to the faults and veins. The wider veins and faults, 0.5–1.0 meter wide, were exploited for their silver content, and many veinlets and veins, 1–30 centimeters wide, remain in the mine. The mineralization consists primarily of hematite, barite, and siderite, but quartz and magnetite occur locally. The principal ore minerals reportedly are native silver and stromeyerite (Ahlfeld and Schneider-Sherbina, 1964, p. 304).

Geophysics.—A magnetometer survey was conducted on the surface over the mine area, along northwest-trending traverse lines 50 meters apart, perpendicular to the general strike of the veins and faults. A magnetometer traverse also was made within one section of the mine. The underground traverse detected magnetic anomalies of 300–800 gammas corresponding to some of the veins; other veins had no associated magnetic anomaly. On the surface the magnetometer results outlined some weak linear northeast-trending magnetic anomalies with a magnetic relief of about 100 gammas. These anomalies are obscured by a magnetic gradient of 400 gammas over a distance of about 400 meters parallel to the strike of the anomalies. This gradient is probably related to the northwest-trending contact between the Potoco Formation and the intrusive andesite porphyry (pl. 2).

The two crosscutting magnetic trends hamper magnetic interpretation and correlation with geology.

Conclusions.—The mineralized faults and veins in the mine are extensive but have been largely mined out above the main level. They no doubt continue below this level, where only a small amount of mining was done in the past because of difficulties with water and carbon dioxide gas. Modern mining technology can overcome these difficulties if the silver content of the veins is sufficient to support mining. The Lipez Mining Co. is now (1966) sampling the veins and planning to unwater the flooded part of the mine.

Trapiche mine

The Trapiche mine, at the south end of San Cristóbal (pl. 1 and fig. 2), consists of 305 meters of drifts and crosscuts. It explored the area beneath some previously worked veins west of the mine entrance. No veins are cut by the mine workings, but several fault structures, which are the probable roots of the veins above, are exposed in the mine. This feature indicates that the mineralization in the San Cristóbal district is epithermal.

GEOCHEMICAL SURVEYS

SAMPLING AND ANALYSIS

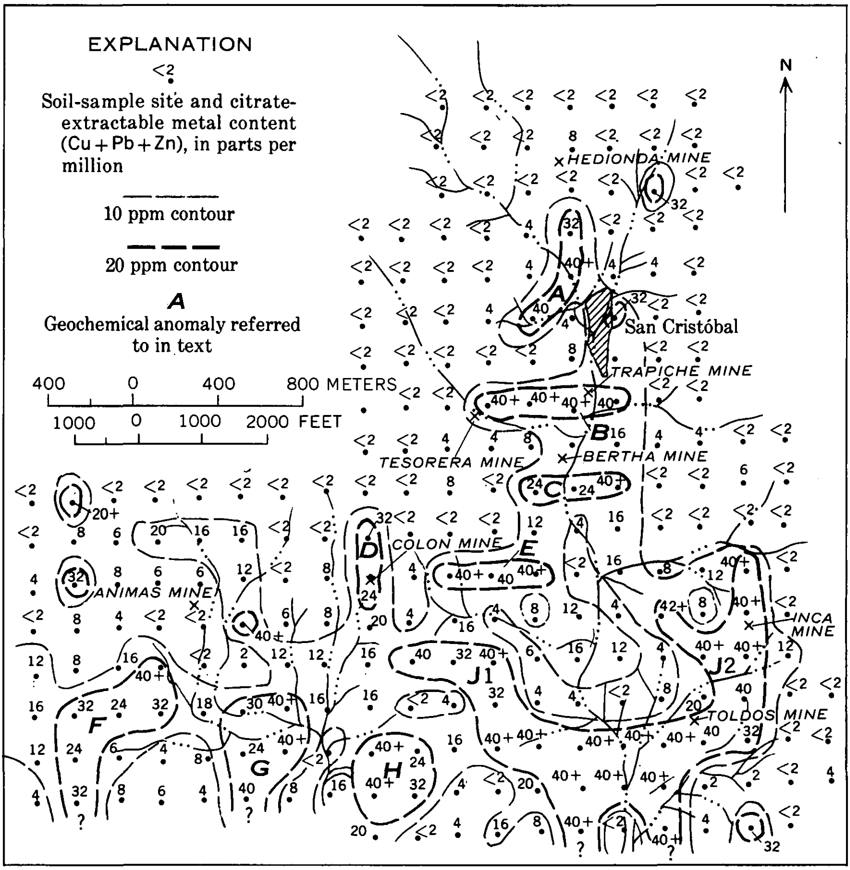
Two geochemical surveys were completed. The first was a reconnaissance soil-sampling survey along the creeks; the second involved soil sampling on a 200-meter-square grid over an area exceeding 6 square kilometers. All samples were taken at a depth of 5–10 centimeters and were screened in the field to approximately —80 mesh, with a nylon cloth screen.

The samples were all analyzed in a field laboratory for their citrate-extractable heavy metal (copper, lead, and zinc) content by standard techniques, dithizone being the test reagent (Ward and others, 1963, pp. 27–29).

RESULTS AND INTERPRETATION

The reconnaissance survey indicated the limits of the mineralized district, and the grid sampling subsequently outlined the mineralized area in greater detail (fig. 7). The geochemical anomalies shown in figure 7 extend about 1.5 kilometers south of the southern edge of the map. This extension anomaly is interpreted as representing drainage from the mineralized district and was therefore not outlined in detail.

The grid sampling indicated that the geochemical background in the district is less than 2 ppm (parts per million) combined citrate-extractable copper, lead, and zinc. The geochemical anomalies containing more than 20 ppm metal, or more than 10 times



Compiled by H. S. Jacobson, 1966

FIGURE 7.—Cooper-lead-zinc geochemical soil survey map of the San Cristóbal district. Reconnaissance survey indicates that anomalous values continue to about 1.5 kilometers south of south edge of this map. (These anomalies are probably due to drainage.)

the geochemical background, are therefore strong anomalies. Correlation of the anomalies (fig. 7) with the geology (pl. 1 and fig. 2) shows two significant features:

1. Anomalies *B*, *C*, and *E* have an easterly trend which may be correlated with sulfide veins having a similar strike.
2. Anomalies *F*, *G*, *H*, and *J*1 are apparently related to the intrusive andesite porphyries.

The relationship of most of the other anomalies to the geology is not clear because of the wide sample spacing. Anomaly *J*2 is primarily due to contamination from mine dumps of the Toldos mine.

ECONOMIC POTENTIAL

The San Cristóbal district is mainly a silver district, the principal future economic potential of which lies in its possible resources of disseminated silver minerals, particularly in view of the current favorable silver market and of the possible utilization of low-cost open-pit mining methods. Disseminated native silver probably is present in several localities within the district, in addition to the known deposit at the Hedionda mine. The detection of such mineralization will require careful sampling and analysis of altered rocks throughout the district.

Underground mining of the veins has a relatively unfavorable economic potential because: (1) Most of the veins near the surface have already been mined, (2) the veins are epithermal and therefore are unlikely to have significant extensions in depth, and (3) underground mining in the district is hampered by the presence of water and carbon dioxide gas.

RECOMMENDATIONS

We recommend that mineral exploration of the district be continued in two stages:

1. A study of rock alteration combined with a geochemical survey of all rock outcrops of the district except those of the dacite porphyry lavas (fig. 2). The survey would consist of sampling, at 25- to 50-meter intervals, all the outcrops within the area indicated, followed by a petrographic study of selected samples to identify the altered minerals and by geochemical analysis of all the samples. Geochemical analysis for silver, lead, and zinc is suggested; analysis for silver can be made by the method described by Nakagawa and Lakin (1965), and analysis for lead and zinc, by standard methods (Ward and others, 1963).

2. Diamond drilling of favorable areas determined by the above investigation and the geological data described in this report.

In addition we recommend that the following work be done at the principal mines (this does not include work presently being conducted by the Lipez Mining Co. at the Hedionda and Toldos mines):

Bertha mine

1. Detailed channel sampling of the mine workings and analysis for silver, lead, and zinc.
2. Diamond drilling of two vertical holes, 100 meters deeps, to test the grade and continuity of mineralization of the mineralized breccia. The holes should be collared in the breccia outcrops above the mine (pl. 1).
3. Pitting or mining to explore electromagnetic anomalies (conductors) *A*, *B*, and *C* (fig. 4).

Animas mine

Drifting ahead, from the present face along the mineralized fault exposed in the face, to explore for ore lenses in the fault zone.

Tesorera mine

Detailed underground channel sampling to determine the grade of disseminated mineralization, because the geology of the mine is similar to that of the Hedionda mine.

REFERENCES CITED

Ahlfeld, Federico, 1944, La geología del mineral de San Cristóbal de Lípez (Bolivia): Minería Boliviana: v. 1, no. 8, p. 9-15.

Ahlfeld, Federico and Schneider-Sherbina, Alejandro, 1964, Los yacimientos minerales y de hidrocarburos de Bolivia: Bolivia, Dept. Nac. de Geología, Bol. 5, 388 p.

Barba, A. A., 1637, Arte de los metales: Madrid.

Nakagawa, H. J., and Lakin, H. W., 1965, A Field method for the determination of silver in soils and rocks *in* Geological Survey research 1965: U.S. Geol. Survey Prof. Paper 525–C, p. C172–C175.

Torrico, H., 1966. Estudio Geologico de La region de San Cristóbal: Facultad de Ciencias Geologicas, U. S. M. A. thesis, La Paz, Bolivia.

Ward, F. N., Lakin, H. W., Canney, F. C. and others, 1963, Analytical methods used in geochemical explorations by the U.S. Geological Survey: U.S. Geol. Survey Bull. 1152, 100 p.

U. S. GOVERNMENT PRINTING OFFICE : 1968 O - 324-333